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This study analysed peer-reviewed literature comparing conventional and organic livestock production systems on sustainability indicators within the topics of economy, productivity, environment, animal welfare and public health. For many indicators, insufficient data were found to draw any conclusions on a difference. The strong points of both conventional and organic livestock production systems were used to formulate lessons learned for sustainable livestock production systems. As sustainability indicators often interact with other sustainability indicators in opposing directions, sustainable livestock production should be approached as a multi-criteria problem optimising a balanced combination of sustainability indicators in all topics.

Deze studie heeft wetenschappelijke literatuur geanalyseerd, die conventionele en biologische dierlijke productiesystemen kwantitatief vergelijkt op duurzaamheidsindicatoren binnen de onderwerpen economie, productiviteit, milieu, dierenwelzijn en volksgezondheid. Voor veel indicatoren zijn onvoldoende gegevens gevonden om conclusies te trekken over een verschil. Gevonden sterke punten van zowel conventionele als biologische systemen zijn gebruikt om lessen te trekken voor duurzame veehouderij. Aangezien duurzaamheidsindicatoren vaak onderling samenhangen in tegenstrijdige richting moet een duurzame veehouderij gezien worden als een multicriteria beslissingsprobleem, waarin een gebalanceerde combinatie van indicatoren uit alle duurzaamheidsonderwerpen moet worden geoptimaliseerd.

Key words: Livestock production; conventional; organic; Europe; literature search

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Preface

Sustainable livestock production systems are needed to feed the larger, more urban, richer and older world population. Quantitative information about the sustainability performance of existing livestock production systems, to aid the debate on what actions could be developed and implemented, is fragmented. Wageningen University & Research performed an analysis of peer-reviewed literature that quantitatively compared performance of conventional and organic livestock production systems to identify strong points of both systems. Strong points of a system are those sustainability indicators on which the system outperforms the other system. Except for productivity, results varied per indicator: sometimes conventional and sometimes organic systems performed better. In case of productivity, conventional systems outperformed organic systems on all indicators. For many sustainability indicators, the number of studies was limited, and solid conclusions could not be drawn. Based on the strong points from both systems that could be identified, lessons learned for sustainable livestock production systems were formulated. It showed that sustainability indicators often interact with other sustainability indicators in opposing directions. Hence, sustainable livestock production should be approached as a multi-criteria decision problem optimising a balanced combination of indicators on all sustainability topics.

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Summary

S.1 Key findings

Sustainable livestock production systems are needed to feed the larger, more urban, richer and older world population in 2050. Quantitative information about the sustainability performance of existing livestock production systems can aid the debate of which actions could be developed and implemented. Strong points of conventional and organic dairy cattle, beef cattle, pig, laying hen, and broiler production systems were identified in peer-reviewed literature for a limited number of sustainability indicators within the subjects of economy, productivity, environment, animal welfare, and public health (Table S.1). Strong points of a system are the sustainability indicators on which a system outperformed the other system. Except for productivity, results varied per indicator: sometimes conventional and sometimes organic systems performed better. In case of productivity, conventional systems outperformed organic systems on all indicators. For many sustainability indicators, the number of studies was too limited to draw solid conclusions on a quantitative difference between conventional and organic livestock production systems.

Table S.1
Identified strong points of both conventional and organic animal production systems

	Organic animal production systems	Conventional animal production systems
economy	• lower building costs per animal; • in most sectors, a higher income per animal or per full time employee, largely because of the farm gate price premium from the market.	• a lower labour need to produce an animal; • a lower level of income risk per animal.
productivity		• a higher output (in kg product) per animal per time unit; • higher reproduction numbers; • a more efficient feed conversion ratio, because of balanced diets, the use of higher performing breeds, and lower activity levels.
environment	• a lower eutrophication and acidification potential per unit of land; • a lower impact on local biodiversity, and fossil phosphorus depletion per unit of product.	• a lower land use and a generally lower acidification and eutrophication potential per unit of product, mainly related to a higher crop yield and higher animal performance.
animal welfare	• higher activity levels and better leg health.	• a lower risk of parasitic infections.
public health	• a similar or lower likelihood of antibiotic resistance in bacteria isolated from the farm environment, animals or animal products,[1] where the lower likelihood is attributed to a lower use of antimicrobials to treat and prevent disease in the animals; • a higher beneficial fatty acid level in cow milk, due to a higher amount of fresh forage in the ration.	• a similar or lower microbiological contamination in animal products[1].

1) Presence of microbiological hazards or antibiotic resistant bacteria on a farm does not imply that these bacteria or hazards will pass into humans through the food chain. Hygienic circumstances and control measures in the food chain between farm and consumer also determine this. However, a lower prevalence of microbiological hazards or antibiotic resistant bacteria at farm level will, at worst, have no influence on and, at best, decrease the risk of human infection.

The identified strong points of both conventional and organic animal production systems in Table S.1 were used to identify some lessons learned for sustainable livestock production systems[1]:

- Best practices and technologies that enhance animal production efficiency can help achieve food security, reduce environmental impact per unit of product, and improve the economic position of farmers. However, potential effects of such practices and technologies on other areas of sustainability, such as animal welfare and local environment, should not be ignored.
- Selection of feed products could be based on a balance between a low environmental impact of feed production, and high quality of the feed ration that ensures a high animal productivity and feed efficiency. To enhance future food security, food-feed competition is an important aspect to consider.
- Livestock grazing on land, which is less suitable to produce human edible protein through e.g. crop production, instead of on land, which is more suitable, could play an important role in achieving food security.
- Reducing environmental impact of feed production can be accomplished by balancing in- and outputs of nutrients per area of land while maintaining or increasing crop yield, and by animal production consuming by-products and residues from human food production and bio-energy industries.
- Benefits of increasing productivity per area of land such as lower land use should be balanced against increased local environmental impact.
- Antibiotics should be used prudently, based on a balance between the risk of development of antimicrobial resistance and animal welfare related to treatment of diseases in animals.
- Strong points of a livestock production system with a value for certain consumers could be used to allow for a farm gate price premium, which requires balancing against affordability for consumers.
- The use of high yielding breeds adapted to their environment should be balanced with animal welfare and environmental performance.
- The size of animal living space and size and amount of outdoor access could be set based on a balance between animal welfare revenues, human pleasure (e.g. of seeing animals outside), lower productivity levels, and higher risk of microbiological infections. Other improvements in housing design could also offer opportunities to improve animal welfare.
- Technological applications to reduce nutrient losses from manure management or application of manure processing techniques could contribute to reducing waste and improving nutrient and organic matter cycling and environmental performance of livestock systems.

The lessons learned show that improving one aspect of sustainability can have a negative impact on other sustainability aspects. Hence, sustainable livestock production should be approached as a multi-criteria problem optimising a balanced combination of indicators in all topics reviewed in this study, i.e. economy, productivity, environment, animal welfare and public health.

S.2 Complementary findings

In total, 183 unique studies were analysed in this review. Despite this relatively large number of studies, most of the reviewed sustainability indicators and animal species were only analysed in a limited number of studies. No studies were found that comprehensively addressed indicators for all topics. Most studies addressed indicators related to only one or two topics. In many studies, the number of farms from which reviewed samples originated was ten or less for each system. Most reviewed studies compared the systems using a sample without an outlook to sector level or society at large.

Care should be taken to extrapolate the identified differences found for individual indicators to sector or country level. This is due to the limited number of available studies for most indicators, potential

[1] The lessons learned are considerations for sustainable livestock production systems, which could be derived from the comparison between conventional and organic livestock production systems. These lessons learned are not intended to provide a complete picture of sustainable livestock production systems. More research is needed to develop such a picture.

publication bias in the literature, potential differences in farm practices between the reviewed studies, and the use of samples in the reviewed studies. For a sound extrapolation of the findings for an individual indicator to sector or country level, the effect of this indicator on other indicators must be considered. This applies to the effect on indicators within the same topic or from other topics. Sustainable livestock production is a multi-criteria optimisation problem in which a weighted combination of indicators should be optimised. Care should be taken when extrapolating the results of studies from North America and New Zealand to Europe and when extrapolating the results of this review to other regions than Europe, North America and New Zealand, because of differences in farming practices, climate and legislation, among others.

S.3 Method

This study aims to identify lessons learned for sustainable livestock production. For this, insights were retrieved from peer-reviewed literature that quantitatively compared the performance of conventional and organic livestock production systems. Sustainability indicators related to the topics economy, productivity, environment, animal welfare, and public health were reviewed. The project team, in close consultation with the project steering committee, selected these topics and indicators, because they were judged to be the most important for sustainable livestock production systems at the time of research. The review was limited to peer-reviewed studies on dairy cattle, beef cattle, pigs, broilers, and laying hens, the most common farm animal species in Europe, and to the regions of research Europe, North America, and New Zealand. The databases included were Biological abstracts, CAB abstracts, EconLit, Medline, Scopus, and Web of Science. For economy only, the AgEcon database was searched additionally. Articles with publication year 1995 until March 2015 in the English language were selected. Review articles were not included, because we focused on original sources of data. The literature search strategy consisted of the search term (‘conventional AND organic’) in combination with the relevant animal species and topic-specific search terms. Indicators were reviewed as presented in the studies without performing own calculations.

Samenvatting

S.1 Belangrijkste uitkomsten

Duurzame dierlijke productiesystemen zijn nodig om de grotere, meer urbane, rijkere en oudere wereldbevolking te voeden in 2050. Kwantitatieve informatie over de duurzaamheidsprestatie van bestaande dierlijke productiesystemen kan helpen in de discussie over welke acties moeten worden ontwikkeld en geïmplementeerd. In de peer-reviewed literatuur zijn de sterke punten van conventionele en biologische productiesystemen voor melkvee, vleesvee, varkens, vleeskuikens en leghennen geïdentificeerd voor een beperkt aantal indicatoren voor de duurzaamheidsonderwerpen economie, productiviteit, milieu, dierenwelzijn en volksgezondheid (tabel S.2). Sterke punten van een systeem zijn de duurzaamheidsindicatoren waarop het system beter scoort dan het andere systeem. De resultaten verschilden per indicator, behalve voor productiviteit: soms presteerden biologische en soms conventionele productiesystemen beter. Voor productiviteit presteerden conventionele systemen beter dan biologische systemen op alle indicatoren. Voor veel duurzaamheidsindicatoren waren er te weinig studies beschikbaar om een goede conclusie te kunnen trekken over een kwantitatief verschil tussen conventionele en biologische dierlijke productiesystemen.

Tabel S.2
Gevonden sterke punten van conventionele en biologische dierlijke productiesystemen

	Biologische dierlijke productie	Conventionele dierlijke productie
economie	• Lagere gebouwkosten per dier; • In de meeste sectoren een hoger inkomen per dier of per werknemer (fte), grotendeels door de biologische prijspremie.	• Een lagere arbeidsbehoefte per dier; • Een lager inkomensrisico per dier.
productiviteit		• Een hogere productie in kg product per dier per tijdseenheid; • Hogere reproductiecijfers; • Een lagere voederconversie door gebalanceerde rantsoenen, hoog productieve rassen en lager activiteitsniveaus.
milieu	• Een lager eutrofiërings- en verzuringspotentieel per eenheid land; • Een lagere impact op lokale biodiversiteit en op fossiele fosforuitputting per eenheid product.	• Een lager landgebruik en een lager eutrofiërings- en verzuringspotentieel per eenheid product, grotendeels door de hogere gewasopbrengsten en hogere dierlijke productiviteit.
dierenwelzijn	• Een hoger activiteitsniveau en betere beengezondheid.	• Een lager risico op parasitaire infecties.
volksgezondheid	• Een gelijk of lager risico op antibioticaresistentie in bacteriën in de omgeving van een veehouderijbedrijf, dieren of dierlijke producten,[2] waarbij dit is toe te schrijven aan het mindere gebruik van antibiotica om ziekte in dieren te behandelen of te voorkomen; • Een hoger niveau van gunstige vetzuren in koeienmelk, vanwege het hogere aandeel van vers ruwvoer in het rantsoen.	• Een gelijk of lager niveau van microbiologische besmetting in dierlijke producten.[2]

2) De aanwezigheid van antibioticaresistente bacteriën of microbiologische gevaren op een boerderij impliceert niet dat deze bacteriën of gevaren in mensen terechtkomen via de voedselketen. Hygiëneomstandigheden en beheersmaatregelen in de keten tussen boerderij en consument zijn hiervoor ook bepalend. Een lagere prevalentie van antibioticaresistente bacteriën of microbiologische gevaren op een boerderij zal op zijn minst geen effect hebben, of anders het risico op gevolgen voor de humane gezondheid verlagen.

De gevonden sterke punten van zowel de conventionele als de biologische dierlijke productiesystemen (Tabel S.2) zijn gebruikt om lessen te trekken voor duurzame dierlijke productiesystemen:[2]

- Praktijken en technologieën die productiviteit verhogen kunnen helpen om de voedselzekerheid te verbeteren, de milieu-impact per eenheid product van dierlijke productiesystemen te reduceren en de economische positie van veehouders te verbeteren. Echter, de effecten van dergelijke praktijken en technologieën in andere duurzaamheidsonderwerpen, zoals dierenwelzijn en lokaal milieu, moeten niet worden genegeerd.
- De selectie van grondstoffen voor diervoeder zou gebaseerd kunnen worden op een balans tussen een lage milieu-impact en een hoge kwaliteit van het rantsoen dat een hoge productiviteit van het dier en hoge voederefficiency garandeert. Voor verbetering van de voedselzekerheid is de competitie tussen 'feed' en 'food' ook belangrijk.
- Dieren laten grazen op gronden die minder geschikt zijn om voor mensen eetbare eiwitten te produceren, in plaats van op gronden die meer geschikt zijn, kan een belangrijke rol spelen in het verbeteren van de voedselzekerheid.
- Reduceren van de milieu-impact van de teelt van veevoer kan bereikt worden door de in- en uitstroom van nutriënten per eenheid land te balanceren bij gelijkblijvende of grotere oogstopbrengst, en door gebruik van bijproducten en reststromen uit de levensmiddelen- en bio-energie-industrie als diervoeder.
- Baten van een hogere productie per hectare zoals een lager landgebruik zouden afgewogen kunnen worden met een verhoogde lokale milieu-impact.
- Antibiotica zouden spaarzaam kunnen worden gebruikt, gebaseerd op een afweging tussen het risico op ontwikkeling van antibioticaresistentie en dierenwelzijn gerelateerd aan het behandelen van ziekten.
- Sterke punten van dierlijke productiesystemen met een waarde voor sommige consumenten kunnen gebruikt worden voor een premie op de boerenprijs, maar dierlijke producten moeten wel betaalbaar blijven voor consumenten.
- Het gebruik van hoogproductieve en robuuste rassen aangepast aan de lokale omgeving kan gebalanceerd worden met dierenwelzijn en milieu.
- De oppervlakte per dier binnen en buiten, en hoelang dieren naar buiten mogen, kan gebaseerd zijn op een balans tussen een verbetering van dierenwelzijn, menselijk plezier (bijvoorbeeld door dieren buiten te zien), verlaging van de productiviteit en verhoging van het risico op microbiologische infecties. Andere verbeteringen in huisvestingssystemen bieden ook mogelijkheden om problemen met dierenwelzijn te verminderen.
- Technologische maatregelen om het verlies van nutriënten uit mest te beperken, en mestbewerking kunnen bijdragen aan het verminderen van mestoverschotten, het sluiten van nutriënten- en organische stofkringlopen, en het verbeteren van milieuprestaties van dierlijke productiesystemen.

Omdat duurzaamheidsindicatoren vaak samenhangen met andere indicatoren in tegenstrijdige richting, moeten de prestaties op deze indicatoren zijn afgewogen in duurzame dierlijke productiesystemen. Een duurzame veehouderij is een multicriteria beslissingsproces, waarin een gebalanceerde combinatie van indicatoren voor duurzaamheidsonderwerpen zoals economie, productiviteit, milieu, dierenwelzijn en volksgezondheid wordt geoptimaliseerd.

S.2 Aanvullende resultaten

In de literatuurreview zijn 183 unieke studies geanalyseerd. Voor de meeste van de geselecteerde duurzaamheidsindicatoren was het aantal studies dat die indicator bij een specifieke diersoort analyseerde echter beperkt. Geen enkele studie analyseerde indicatoren uit alle van de geselecteerde duurzaamheidsonderwerpen. De meeste studies analyseerden indicatoren uit slechts 1 of 2 van de onderwerpen. In veel studies kwam de genomen steekproef van 10 of minder bedrijven in elk

[2] De getrokken lessen zijn een aantal beschouwingen voor duurzame dierlijke productiesystemen, gebaseerd op de vergelijking tussen conventionele en biologische dierlijke productiesystemen. Deze studie pretendeert niet om met deze lijst een volledig beeld te schetsen van duurzame veehouderijsystemen. Verder onderzoek is nodig om dit beeld te ontwikkelen.

productiesysteem. De meeste studies vergeleken de productiesystemen op steekproefniveau, zonder extrapolatie naar sectorniveau of de maatschappij als geheel.

De gevonden verschillen voor indicatoren zijn niet zomaar te extrapoleren naar sector of landenniveau, omdat er een beperkt aantal studies gevonden zijn, er in de literatuur een mogelijke publicatiebias bestaat, landbouwpraktijken tussen de gevonden studies kunnen verschillen, en de studies gebaseerd zijn op steekproeven. Voor een correcte extrapolatie van de gevonden verschillen voor een duurzaamheidsindicator, moeten de effecten van deze indicator op andere indicatoren worden meegenomen. Dit heeft betrekking op indicatoren binnen hetzelfde duurzaamheidsonderwerp en in andere duurzaamheidsonderwerpen. Een duurzame veehouderij is een multicriteria beslissingsproces waarin een gewogen combinatie van duurzaamheidsindicatoren wordt geoptimaliseerd. De resultaten van de studies over Noord-Amerika en Nieuw Zeeland zijn niet zomaar te extrapoleren naar Europa, en de resultaten van deze literatuurstudie zijn niet zomaar te extrapoleren naar andere regio's dan Europa, Noord-Amerika en Nieuw-Zeeland, vanwege verschillen in onder andere landbouwpraktijken, klimaat en wetgeving.

S.3 Methode

Deze studie heeft als doel om lessen te trekken voor duurzame dierlijke productiesystemen. Hiervoor zijn peer-reviewed studies geanalyseerd die de duurzaamheidsprestatie van conventionele en biologische dierlijke productiesystemen kwantitatief vergelijken. Indicatoren zijn bestudeerd in de duurzaamheidsonderwerpen economie, productiviteit, milieu, dierenwelzijn en volksgezondheid. Het projectteam heeft deze onderwerpen en indicatoren in overleg met de stuurgroep gekozen, omdat deze het meest belangrijk zijn voor duurzame dierlijke productie systemen ten tijde van het onderzoek. Studies zijn geanalyseerd over melkkoeien, vleeskoeien, varkens, vleeskuikens en leghennen, de in de Europese Unie meest voorkomende landbouwhuisdieren, en met als onderzoeksregio Europa, Noord-Amerika en Nieuw-Zeeland. Literatuur is gezocht in de databases Biological abstracts, CAB abstracts, EconLit, Medline, Scopus en Web of Science. Specifiek voor economie is ook gezocht in de AgEcon database. Studies met publicatiejaar 1995 tot maart 2015 in het Engels zijn geselecteerd. Review studies zijn niet meegenomen, omdat we ons richtten op de originele databronnen. De zoektermen waren ('conventional AND organic') in combinatie met de geselecteerde diersoorten en onderwerp-specifieke zoektermen. Indicatoren zijn geanalyseerd zoals ze zijn gepresenteerd in de studies zonder zelf berekeningen erop uit te voeren.

1 Introduction

By 2050 the world's population is expected to reach 9.6 billion, with nearly all of the population increase in developing countries (United Nations, 2013). Urbanisation will continue at an accelerated pace and income levels will about double compared to today (Alexandratos and Bruinsma, 2012). Alexandratos and Bruinsma (2012) estimated that global food demand will increase by 1.1% per year from 2005/07 to 2050. They also expect that in this period, global demand for meat will grow by 1.3% per year and for milk and dairy products by 1.1% per year. So, compared to 2005/07, demand in 2050 is expected to be approximately 75% higher for meat and 60% for milk and dairy products. Searchinger et al. (2013) indicated three categories of solutions to sustainably feed this larger, more urban and richer world population in 2050: 1) solutions that reduce the growth in food consumption, by reducing amongst others waste, obesity and excessive consumption; 2) solutions that increase food production on existing agricultural land, by e.g. increasing yield; and 3) solutions that reduce the environmental impact of food production, by e.g. efficient use of inputs. This study focuses on identifying solutions in the last two categories. The actions that need to be developed and implemented within each category are subject to debate. Quantitative information for this debate is fragmented. A consistent overview of advantages and disadvantages of existing livestock production systems could provide valuable insights for further development of livestock production systems, but is missing. A wide variety of livestock production systems exists. One common and more studied classification is that between organic and conventional systems. Studies have compared conventional and organic livestock production systems on sustainability topics, such as on the environment (Thomassen et al., 2008), on animal welfare (Hovi et al., 2003), on economics (McBride and Greene, 2009; O'Hara and Parsons, 2013) or on human safety and health (Smith-Spangler et al., 2012). Both systems potentially have advantages and disadvantages as demonstrated by literature. But most studies, however, focused on individual topics, without considering the other interrelated topics This study aims to provide a consistent overview of the quantitative advantages and disadvantages of both systems. Peer-reviewed studies that quantitatively compared conventional and organic livestock production systems were reviewed. Explanations for the observed differences provided in the studies were used to identify lessons learned for sustainable development of livestock production. This study focused on sustainability indicators related to economy, productivity, environment, animal welfare and public health for the most common farm animal species in the European Union (EU): dairy cattle, beef cattle, pigs, broilers and laying hens.

2 Material and methods

2.1 Defining conventional and organic production systems

This study focused on livestock husbandry in the EU and in countries that have husbandry systems that could be applied in the EU. Therefore, we included studies performed in Europe, North America or New Zealand. An analysis of livestock production systems in other parts of the world was outside the scope of this study. Care should be taken when extending the results of this study to those other regions, because livestock production systems in those other regions can be substantially different.

In this study, conventional production systems were typified by the production systems used by the majority of farms, which use technologies for increased productivity, such as high-yielding breeds, modern breeding and feeding techniques, modern medication and other veterinary health products, machines and equipment, and (artificial) fertilisers and pesticides. Conventional livestock production systems have to comply with local legal requirements in force for all livestock producers irrespective of their production system, but no additional legal requirements or standards are required. Therefore, it should be noted that farming practices can differ substantially among conventional livestock producers, even though they are categorised in the same production system group.

Organic agriculture was typified as a holistic production management system that promotes and enhances agroecosystems health including biodiversity, biological cycles, and soil biological activity (Codex Alimentarius Commision, 2007). It emphasises the use of management practices that prefer the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, cultural, biological and mechanical methods to fulfil any specific function within the system, as opposed to using synthetic materials. In addition to the legal requirements for conventional livestock production systems, the organic production system has to comply with legal requirements and clearly defined standards on organic livestock production. Such requirements in the EU are provided in Council Regulation (EC) No. 834/2007 and Commission Regulation (EC) No. 889/2008, in the United States of America (USA) in the Code of Federal Regulations chapter 7, section 205, and in Canada in the Organic Products Regulations, 2009. In New Zealand, for domestically sold products, producers have to comply with the Fair Trading Act 1986 and for export products with the Official Organic Assurance Programme, as well as the requirements of the importing country. Basic characteristics include animal access to open-air areas, a close relationship between production and land to avoid environmental pollution, minimisation of mutualisation of animals, only tethering or isolating of individual animals for a limited period of time for safety, welfare or veterinary reasons, restricted use of veterinary medicinal products, and use of organically produced feed.

2.2 Demarcation of sustainability

There are multiple definitions for sustainability, for example:

- According to the general 'Brundtlund' definition, sustainable development is development that ensures that it meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987).
- White (2013) argued that an overall accepted definition of sustainability is not available, but that the three most common terms associated with sustainability were 'environment', 'social' and 'economic'.
- Lebacq et al. (2013) stated that sustainable livestock systems should be economically viable for farmers, environmentally friendly, and socially acceptable, and distinguished three sustainability pillars: economic sustainability, environmental sustainability and social sustainability.

In this study, we used the three sustainability pillars distinguished in Lebacq et al. (2013) as a basis. Furthermore, Lebacq et al. (2013) identified many different topics and indicators within the economic, environmental and social sustainability pillar. In this study, we used the topics and indicators as described below. These topics and indicators were selected by the project team in close consultation with the steering committee of the project, because they were assumed to be the most important for sustainable development of livestock production systems at the time of research.

Economic sustainability pillar

In the economic sustainability pillar we used indicators farm income, risk and employability to quantify the economic performance of the system. We also used indicators for productivity, because literature suggests that productivity is key for agricultural production to be able to feed the world in 2050 (e.g. Connor, 2008). Productivity is linked to all sustainability pillars; to the environmental and economic sustainability pillars, for example, through dilution of maintenance (i.e. at higher productivity, the amount of feed needed for an animal's survival is a lower proportion in total feed use resulting in lower feed intake and feed costs per kg product), and to the social sustainability pillar, for example, when an animal's productivity reaches its biological limits. In this study, we followed the classification of Lebacq et al. (2013) and included productivity in the economic sustainability pillar.

Economy

Selected indicators for economy were farm income, risk and employability. These were regarded as important signals for economic sustainability of a business, farmers' willingness to adopt a production system, and local economic development, respectively. With regard to farm income we also reviewed two specific underlying components, i.e. costs incurred (variable, fixed, total) and farm gate price premium achieved in the market. Moreover, we distinguished between different definitions of farm income, as some studies used the concept of gross margin (revenues minus variable costs), while others measured whole-farm income (revenues minus all costs excluding farm labour). Attention was also given to the unit of measurement, e.g. farm, animal or full time equivalent (FTE). With regard to risk, the coefficient of variation was used, which is a unit-free measure of variation defined as the standard deviation divided by the mean. Besides, qualitative inferences such as 'higher' or 'lower' risk were included in the review as well. In relation to employability, both direct hours spent on the farm and number of indirectly induced jobs were considered, if available. Also qualitative assessments such as 'more work' were included.

In addition to economic viability of producers, affordability of consumers to buy animal products can be part of the economic sustainability pillar. Since the focus of this study was on the primary sector, an analysis of the affordability of consumers was outside the scope.

Productivity

Indicators related to productivity were not selected prior to the literature search. Instead, we reviewed quantitative data about productivity reported in the studies that were retrieved in the other topics. All mentioned productivity indicators in the current review were taken from the original studies. This study did not recalculate or integrate the different assessed sustainability indicators to an overall one. In the original studies, productivity was defined as the amount of product produced per animal, e.g. milk and egg yield, body weight gain, protein and fat content, numbers of offspring, or the amount of product produced by an animal related to the amount of input in that animal, i.e. feed conversion ratio. All indicators were considered independently, although some could be correlated. An increased milk yield, for instance, could be related to reduced milk fat contents. Although it might be possible to correct for this correlation, by for example using the fat corrected milk equation, in this study no such additional indicators were calculated.

Recently, some studies (Wilkinson, 2011; Dijkstra et al., 2013; Van Zanten et al., 2015) argued that the productivity as described above overlooks the fact that human-edible plant products, such as cereal grains, are fed to livestock. Direct human consumption of these grains is more efficient in terms of global land use. This becomes of importance when land availability is not abundant anymore. The studies developed new metrics of agricultural efficiency based on the human-edible protein and energy conversion ratios. Wilkinson (2011) and Dijkstra et al. (2013) developed ratios of the amount of energy or protein in the feed of an animal potentially edible for humans over the amount of energy or protein in the products produced by this animal that is edible for humans. Van Zanten et al. (2015) developed the Land Use Ratio (LUR), to account for the competition for land between food and feed production. The LUR includes all the land that is used in a product system, and divides the maximum amount of human digestible protein that could have been produced on that land by food crops, over the amount of human digestible protein that is produced by livestock. Livestock systems that value land with low opportunity costs for arable production (e.g. due to slope or soil quality) and/or by-products from the food and energy industry (e.g. beet pulp) are identified as land-efficient systems. None of the aforementioned methods, however, account for differences in essential amino acid content between plants and animals. Since indicators such as LUR have only recently been developed, they have not been adopted in the literature, and we did not find a study quantitatively comparing conventional and organic livestock farming systems based upon these indicators.

Environmental sustainability pillar

For environment, we used indicators that quantify the impact of livestock production on global warming (greenhouse gases), eutrophication, acidification, energy use, and land use. A limited number of studies assessed the impact of livestock systems on other environmental impact categories, such as biodiversity loss, eco-toxicity, or soil fertility. These results are also included in this review. The antimicrobial resistance of bacteria found in the environment of farms due to use of antimicrobials on the farm is presented under public health.

Social sustainability pillar

In the social sustainability pillar, we used indicators for animal welfare and public health.

Animal welfare

For animal welfare, we used indicators that quantify the impact of livestock production system on behavioural problems (aggression, damaging behaviour), stress sensitivity, robustness, lameness and leg health, helminth infections, diseases, other health problems, and mortality. The occurrence of antimicrobial resistance in an animal and its environment can negatively affect the effectiveness of therapeutic use of antibiotics in these animals and thus impact animal welfare. Indicators for antimicrobial resistance are reviewed under public health.

Public health

For public health, we used indicators that quantify zoonotic microbiological hazards, antimicrobial resistance, chemical hazards, fine dust and selected potential beneficial aspects of food. Zoonotic microbiological hazards and toxic compounds can result in human health problems through consumption of contaminated products and direct contact with the animals. Because mastitis-causing bacteria such as Staphylococcus aureus (S. aureus) (Oliver et al., 2005) and Streptococcus spp. (Food and Drug Administration, 2012) can occasionally cause food poisoning in humans, we also included the mastitis-causing bacteria in the review for microbiological hazards in dairy cattle.

The use of antimicrobials in food animals can result in antimicrobial resistance in bacteria present on the farm, which may spread to humans through contact with these animals or their surroundings and through consumption of products from these animals (Van den Bogaard and Stobberingh, 2000; Marshall and Levy, 2011).

Concerning chemical hazards, we selected studies on organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs), ochratoxin A and heavy metals. Organochlorine pesticides include a large number of different chemical substances, and some of these compounds have been linked to diseases, such as breast cancer (Høyer et al., 1998). The use of most of these substances has been banned in the EU and USA since the 1980s. However, they are extremely persistent in the environment and the human body. The specific organochlorine pesticide Dichlorodiphenyltrichloroethane (DDT), may be associated with adverse health outcomes such as breast cancer, diabetes, decreased semen quality, spontaneous abortion, and impaired neurodevelopment in children (Beard, 2006; Eskenazi et al., 2009). Due to these effects DDT has been banned in the USA since 1972 and in the EU since 1986 (earlier in some Member States) . PAHs include over 100 different chemical substances, of which a number are carcinogenic and mutagenic (Phillips, 1999). Falcó et al. (2003) associated human intake of PAHs through consumption of meat and meat products with increased risk of developing cancer. PAHs are widely distributed in the environment and food of animal origin can be contaminated through ingestion by animals of contaminated plants, insects, or soil. The fungal toxin Ochratoxin A is a regular contaminant of cereals and grains and can be found in many common foods, including pork, poultry and dairy products. Human exposure to ochratoxin A has been associated with the kidney disease Balkan endemic nephropathy, symptoms of which include tumours of the kidney and urinary tract (Clark and Snedeker, 2006). Heavy metals are widespread in the environment because of industrial, domestic, agricultural, medical and technological applications (Tchounwou et al., 2012) and can lead to kidney damage, bone effects and fractures (cadmium), neurological damage (mercury), neurotoxic effects (lead), cancer and various types of cancer (arsenic and chromium) (Järup, 2003; Tchounwou et al., 2012). Food of animal origin can be contaminated with heavy metals, through agricultural use or ingestion by animals of contaminated plants, insects or soil.

Fine dust was included for its possible effect on the health of animal handlers. Because no studies were found dealing with fine dust, this indicator was not further elaborated on. Finally, for potential beneficial aspects, studies about essential elements, fatty acid composition, vitamins and cholesterol were selected.

2.3 Identification of the strong points of each system and lessons learned

To identify the strong points of the organic and conventional system, we performed a search of the peer-reviewed literature on each topic. Strong points of a system were those where a system outperformed the other one, based on a selected indicator. The indicators as presented and defined in the reviewed articles were compared without additional calculations. A system was defined to outperform the other one when several studies indicated that the performance, as measured by the selected indicator, of one system compared to the other one was significantly better and the direction was consistent across many of these studies. Hereby, the provided statistical significance level of the reviewed study was used, which was mostly the 5% level. Studies were qualitatively weighed in the analysis based on the sample size, the method of analysis and the extent to which results were corrected for confounding variables. Furthermore, studies were screened for the explanations of the differences mentioned.

The lessons learned were identified in project group sessions with the researchers involved in the project, while discussing the strong points of each system and the explanations for the identified differences presented in the reviewed studies.

2.4 Literature search strategy

The literature search strategy consisted of the general search terms (cattle OR cow OR calf OR calves OR veal OR chicken* OR broiler* OR laying hen* OR pig* OR hog* OR sow OR swine*) in combination with (conventional AND organic) and topic-specific search terms. For economy the topic-specific search term was (economic performance OR people-planet-profit OR 3-P OR economic and social impacts OR integrated sustainability assessment OR economic feasibility OR economic evaluation OR economic assessment OR risk assessment OR multi-criteria assessment OR employability OR cost price OR profitability), for environment (LCA OR life cycle assessment OR life cycle analysis), for animal welfare (welfare) and (health OR disease* OR mastitis OR lameness OR ketosis OR metabolic disorder* OR reproduction OR fertility), and for public health (zoono* OR food safety OR resistance OR human health OR public health OR toxic* OR contamination* OR residue* OR fine dust OR finedust OR hazard*). Including other relevant terms related to the environmental impact of livestock production such as acidification, eutrophication, climate change, energy use, ammonia, nitrate, methane, sulphur dioxide, deforestation or land-use change did not influence the search yield. Only studies that used a life-cycle approach were included in the environmental assessment, to ensure inclusion of the environmental effects of processes in non-farmer links in the supply chain that are inextricably bound up with the production system. For productivity no specific search strategy was used. Articles found with the search strategy for the other topics that also reported about productivity were included for productivity. Articles with publication year 1995 until March 2015 in the English language were selected. We selected peer reviewed articles only; books, book sections, and conference proceedings were not considered. Review articles were not considered in the comparison, because we focused on original sources of data. However, these articles were studied for their content. The databases included in the study were Biological abstracts, CAB abstracts, EconLit, Medline, Scopus and Web of Science.

3 Results and discussion

3.1 Selected papers

Of the 4,171 initial results that were retrieved, 183 studies were finally used in the study to compare organic with conventional animal production (Table 1). Studies were excluded because they appeared in two or more databases, had a different subject (e.g. bio-energy production, crop production, other animal species, waste and water treatment), covered another other area of research than Europe, North America or New Zealand, were not peer-reviewed (book, book section, conference proceeding), did not include quantitative data comparing conventional with organic, or were a review.

Table 1
Hits and selected studies for further analysis in the study

	Topic					
	Economy a)	Environment b)	Animal welfare c)		Public health d)	Total
			Health	Welfare		
Number of studies after initial search						
Web of Science	285	29	459	96	162	1,031
CAB abstracts	175	31	533	151	199	1,089
Biological abstracts	246	18	13	65	176	518
Medline	71	4	210	33	40	358
Scopus	164	1	381	159	764	1,469
EconLit	44	1	5	1	0	51
Extra e)	2	0	0	0	0	2
Total	987	84	1,258	505	1,337	4,171
Number of studies after screening title and abstract excluding doubles	n.r. f)	53 g)	176	90	136	455
Number of studies after screening full text excluding doubles used in analysis	20	30	42	10	89	183 h)

a) Additionally the AgEcon database was searched. Of the 60 initial results, none were peer-reviewed articles and thus not selected for analysis in this study (most were conference proceedings); b) Articles were excluded based on the following criteria: different subject (e.g. bio-energy production; crop production; processing), no hard data available, no peer-reviewed article, review article. The search yield contained three review articles, which were studied for their content but not included in the analysis; c) One literature search was performed with the search term 'Welfare' and one with the other search terms '(health OR disease* OR mastitis OR lameness OR ketosis OR metabolic disorder* OR reproduction OR fertility)'. The number of studies in the initial search and the number of studies after screening the title and abstract could both include the same papers. The number of studies after screening the full text only includes unique studies; d) Articles were excluded based on the following criteria: No peer-reviewed article (book, book section, conference proceeding), different subject (e.g. plant production, other animal species, waste and water treatment), Other regions than Europe, North America or New Zealand, no comparison organic and conventional livestock production system, review article. The review articles were studied for their content but not included in the analysis;
e) Retrieved from literature search of other topics; f) n.r. = not recorded; g) Including doubles; h) Sum of the number of papers for each topic is 191, but 8 papers were analysed in more than one topic.

3.2 Comparison of conventional and organic animal production from literature

In this section, the results described are those of the analysis of the identified articles that compared indicators within the topics economy, productivity, environment, animal welfare and public health between organic and conventional livestock production for dairy cattle, beef cattle, pigs, broilers, and laying hens.

3.2.1 Economy

The reviewed studies that compared the economic performance between organic and conventional livestock production are presented in Appendix 1. The total number of selected papers on economic performance was fairly limited (20) and unevenly distributed across sectors. It ranged from nine studies for dairy cattle, six for beef cattle, to three, two and one for broilers, laying hens and fattening pigs respectively. The latter was a study for various type of meat farms including beef and pig farms. For sows, no paper was available. From the various indicators, farm income and price premium were covered most frequently (in 90% and 75% of the studies, respectively), followed by (part of) costs, employability and level of risk. Farm income was mostly expressed as whole-farm income (four studies were on gross margin). Employability mostly referred to hours worked on the farm. O'Hara and Parsons (2013) also included indirectly induced jobs. Risk was discussed by two papers, both addressing dairy farming. Berentsen et al. (2012) measured risk as coefficient of variation. Del Prado et al. (2011) made only qualitative inferences about risk. Units applied per indicator differed greatly across papers. For instance, Pazek and Rozman (2008), Berentsen et al. (2012), Cobanoglu et al. (2014) and Kiefer et al. (2014) expressed farm income at farm level with varying farm scales, while Bokkers and De Boer (2009) and Dekker et al. (2011b) used FTE as unit. Fernández and Woodward (1999), Salevid and Kumm (2011), Gillespie and Nehring (2012) and Bjorklund et al. (2014) expressed variable costs in beef cattle per head, whereas Greer et al. (2008) and Kumm (2002) used hectare and kg of meat respectively. The majority of papers provided quantitative assessments, albeit not with regard to all indicators; Del Prado et al. (2011), Gillespie and Nehring (2012) and Kumm (2002) made purely qualitative assessments. From the quantitative studies, eight were modelling studies, six used panel data, three were case studies and another three were based on experiments. Some papers were very detailed on all indicators, such as O'Hara and Parsons (2013) for dairy cattle, and Bokkers and De Boer (2009) and Cobanoglu et al. (2014) for broilers, while others only provided an aggregate figure for farm income, such as Greer et al. (2008), Kiefer et al. (2014) and Leenstra et al. (2014). In total, 13 papers were in a European context, while six were from the USA and Canada, and one from New Zealand.

Dairy cattle

Comparing organic versus conventional dairy farms, most studies reported a price premium for organic milk above the conventional farm gate price. The reported premium varied from 15% in the Netherlands (Berentsen et al., 2012) to 84% in Canada (O'Hara and Parsons, 2013). In 2001, Stonehouse et al. (2001) reported for Canada no price premium for organic, but at the time of the research the organic market was not yet well established. Papers also agreed on the higher rate of employability in the organic sector (McBride and Greene, 2009; Del Prado et al., 2011; O'Hara and Parsons, 2013), but most papers did not provide exact numbers and did not specify own versus hired labour. Less agreement existed with regard to costs. Although most studies found lower costs per cow for organic farms compared to conventional farms (Stonehouse et al., 2001; Berentsen et al., 2012; O'Hara and Parsons, 2013), they mostly dealt only with variable costs, such as concentrates, fertilisers or veterinary costs, and did not mention fixed costs, such as investments in land or farm labour spent on producing feed, nor considered to express costs per kg of milk produced. McBride and Greene (2009) found higher costs for organic farms and attributed this to the relatively small scale of the farms. With regard to the level of risk, Berentsen et al. (2012) found that conventional dairy farms had lower income risk due to more stable milk and feed prices and more stable milk yields. Also Del Prado et al. (2011) suggested that conventional farms face less risk as they rely less on farm-level feed. However, they also inferred that in the longer term the conventional sector is more vulnerable, due to its larger dependency on energy inputs and energy prices for herbicides and fertilisers.

Beef cattle

Literature on the economic performance of organic versus conventional beef cattle was fairly consistent: veterinary costs per animal head (the papers did mostly not clarify if this included only the costs of medication products and veterinarians or also included e.g. farmer's labour for treatment of sick animals), costs of fertiliser per hectare and building costs were lower on organic farms, and feed prices, labour and fixed costs were lower on conventional farms. Farm-gate price premiums of organic beef varied between 12% and 25% of the farm-gate price of conventional beef. With regard to farm income, papers were less conclusive. Gillespie and Nehring (2012) found lower whole farm income per head and Bjorklund et al. (2014) lower gross margin per pen of 8 steers for organic farms, while Salevid and Kumm (2011) in their modelling study found a higher whole-farm income per 100 head for organic beef farms. Greer et al. (2008) could not conclude on a difference but stressed that organic farms had more potential to substantially improve performance, e.g. with regard to feed and pasture management, through advancing knowledge and skills.

Pigs

The one selected qualitative study on organic versus conventional pig production (Kumm, 2002) did not conclude on farm income, but suggested that a substantial price premium for organic pork would be needed to compensate for the system's lower number of piglets per sow per year, lower growth rates, lower feed efficiency and higher labour intensity. The study assumed that conventional pig farms were more mechanised, using e.g. precision feeding and accurate climate regulation, and used more advanced breeding programmes.

Broilers

The three studies comparing organic with conventional broiler farms were congruous. Variable and fixed cost per bird (Bokkers and De Boer, 2009) and per kg (Castellini et al., 2012; Cobanoglu et al., 2014) were found to be higher on organic farms. Examples were found in feed costs, among others due to lower feed efficiency and a ban on the use of antimicrobial growth promotors in feed, whose use is also restricted in conventional feed in the future. Also costs of labour were higher on organic farms, as a result of less mechanisation, higher slaughter age and lower stocking density. Despite the higher costs, all studies concluded there were much higher incomes for organic farms both per FTE (Bokkers and De Boer, 2009), per kg (Castellini et al., 2012) and per farm (Cobanoglu et al., 2014), as a result of large farm-gate price premiums of around 100%.

Laying hens

The two modelling papers on laying hens agreed that the very high price premium for organic eggs, i.e. 139% in Dekker et al. (2011b), outweighed the higher feed prices. Therefore, both papers found higher income levels for organic laying hen farms, expressed per FTE (Dekker et al., 2011b) and per kg (Leenstra et al., 2014).

Conclusions

The number of papers comprehensively addressing economic indicators was relatively small and widely varied with regard to context, research design, definitions used, units applied and implicit amount of farm labour used. Consistent findings across the studies reflected that organic animal production compared to conventional production used more labour per animal, had lower building costs per animal, higher levels of price risk, yield risk and income risk, and substantial farm-gate price premiums. Studies also showed ambiguity on a number of other indicators. For instance, whole-farm income per animal, per hectare or per FTE of organic farms was generally found to be higher, especially for broiler farms and farms with laying hens, whereas opposite results were found for beef cattle and (in some cases) dairy. Similarly, the reviewed papers were inconclusive about veterinary costs per animal, which were found to be lower for organic dairy and beef cattle compared to conventional cattle but higher for organic broilers compared to broilers in conventional systems. Also on feed costs there was ambiguity, both per animal and per kg of product.

3.2.2 Productivity

In this section, studies are described that made a comparison of productivity parameters on animal level between organic and conventional dairy cattle, beef cattle, pigs, broilers, and laying hens (Appendix 2). Productivity parameters of the organic system are expressed relative to the conventional system.

Dairy cattle
Results were based on twelve different studies, of which nine were performed in Europe (mainly North-West Europe) and three in the USA. Eleven studies used data collected on a range of farms (5 to 292 farms per group), whereas van Calker et al. (2007) made use of modelled data.

Milk yield of organic dairy cows was generally lower compared to conventional dairy cows (Figure 3.1). In this figure, the milk yield level of the conventional dairy cows was set at 100%. In all twelve available studies, milk yield of the organic cows was lower compared to the conventional ones, ranging from 95.3% to 68.0% of the milk yield of conventional cows. The differences between organic and conventional herds were consistent over time (2003-2013). Milk fat and protein contents in organic milk were provided in four out of these twelve studies. In three studies, no significant difference was reported, whereas Butler et al. (2009) reported increased milk fat and protein content in organic milk compared to the contents in conventional milk (Figure 3.2).

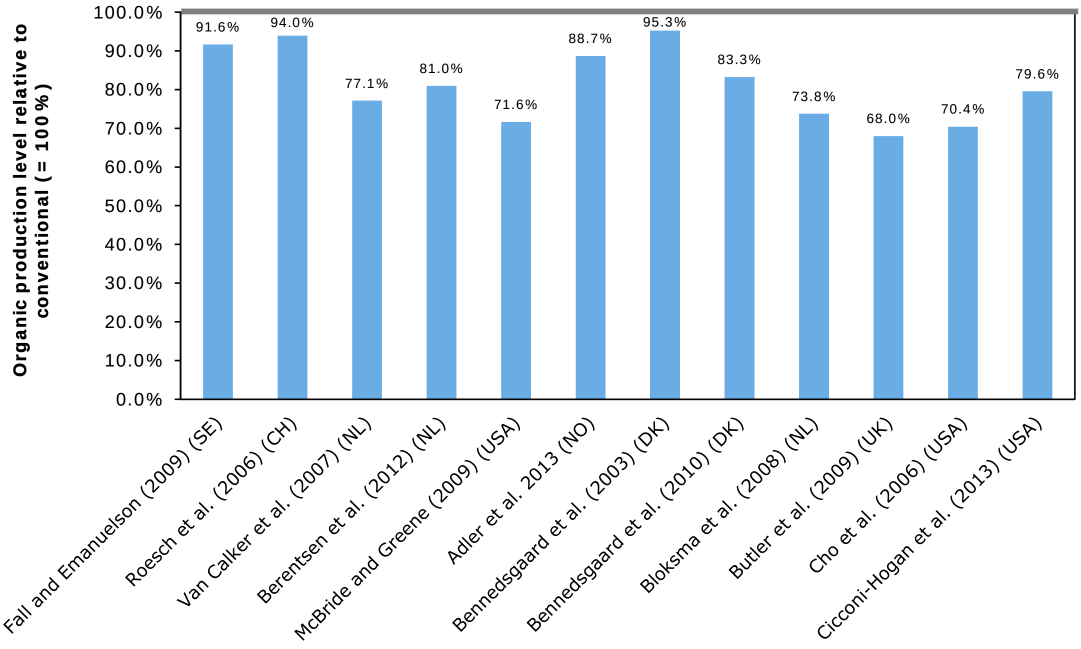

Figure 3.1 *Milk yield of organic dairy cows, expressed relative to milk yield of conventional dairy cows (= 100%)*

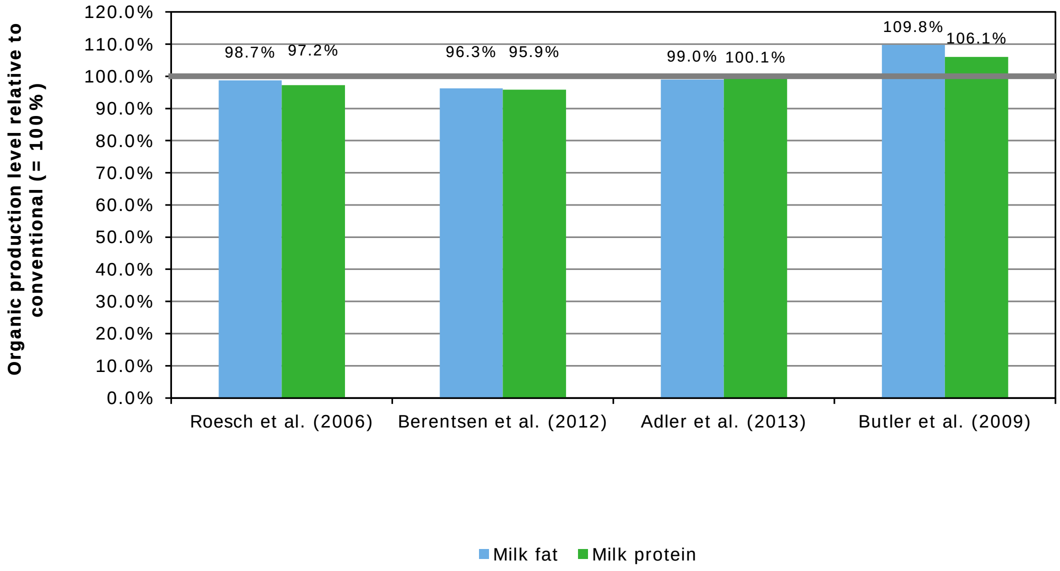

Figure 3.2 *Milk fat and milk protein content in milk of organic dairy cows, expressed relative to in milk of conventional dairy cows (= 100%)*

Several reasons were provided to explain the reduced milk yield of organic dairy cows. Organic herds generally had a longer, and more regulated, pasture season (Alvasen et al., 2012). In Sweden, for instance, organically managed cows had to get more than six kg of the daily dry matter intake from the pasture and they had to spend at least 12.5 hours per day on pasture during the pasture season (Swedish Organic Certification Association, 2011). Moreover, some organic farms used no or very low levels of concentrate supplementation or conserved forage (less than 5% of dry matter intake) throughout the lactation period (Butler et al., 2009). The higher forage proportions, the lower forage crude protein concentrations, and the lower levels of concentrate in the rations of organic dairy cows went along with lower intakes of energy and crude protein, consequently decreasing milk yields and milk urea concentrations (Butler et al., 2009; Bennedsgaard et al., 2010; Adler et al., 2013).

In the study of Bloksma et al. (2008), organic farms were keeping a range of breeds (MRIJ, Montbeliarde, Brown Swiss, Jersey), with a limited percentage of high-yielding Holstein Frisian cows (20%), while the conventional farms had almost exclusively Holstein Frisian cows (95%). The Jersey breed was used by several organic dairy farmers, and milk production of this breed is significantly lower compared to the breeds used in conventional farms (Bennedsgaard et al., 2010), but milk components are higher.

Beef cattle

Data for beef cattle were based on two studies, of which one originated from Ireland (Casey and Holden, 2006) and one from the USA (Bjorklund et al., 2014). The Irish study included five organic and five conventional farms, whereas the American study compared the results of 16 organic and 16 conventional beef cattle from one experiment.

Relative body weight gain of organic beef steers in the two available studies was 87.8 and 77.6% of that of conventional steers (Figure 3.3). The reduced growth rates of the organic steers could be explained by a poorer forage quality and pasture drought conditions (Bjorklund et al., 2014). Moreover, organic beef cattle were more dependent on local feed (Blanco-Penedo et al., 2009b). Furthermore, in one study the organic steers had more sub-clinical parasitic infections, indicated by the high prevalence of liver parasites and inflammatory digestive lesions at slaughter, which according to the authors could also be a contributory cause to low carcass weights (Blanco-Penedo et al., 2009b). The authors suggested that this may be related to the grazing management on organic farms and the permanent indoor conditions (which the authors stated as the traditional Spanish beef cattle housing system) and standardised parasites-prophylaxis on conventional farms. One organic unit produced Angus beef, an early maturing breed that is usually produced for meat quality rather than weight gain (Casey and Holden, 2006).

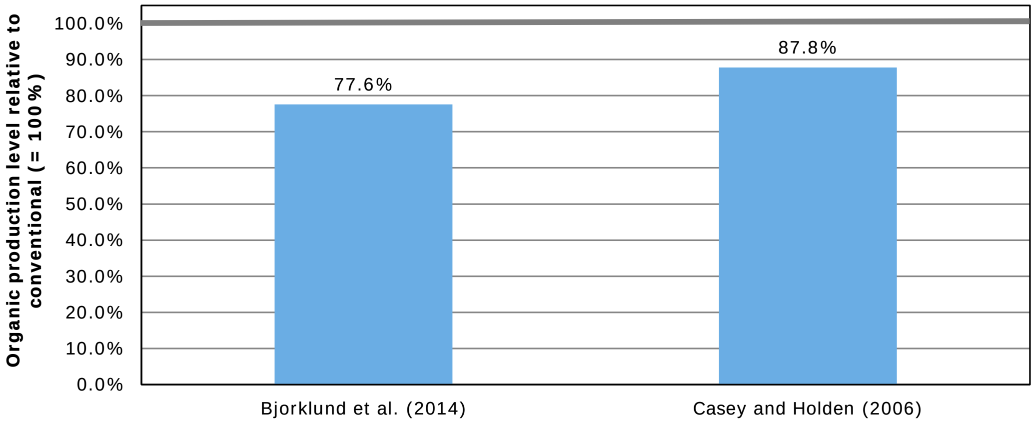

Figure 3.3 *Daily body weight gain of organic beef steers expressed relative to conventional beef steers (= 100%)*

Pigs

Pig data were based on five studies, all originating from Europe. One French study (Dourmad et al., 2014) collected in five different EU-countries data of one pig farm per system per country. A Swedish study (Lindgren et al., 2013) collected data of five conventional and five organic pig farms. In the study of Millet et al. (2004) data of 32 organic and conventional pigs were compared within one experiment. The two remaining studies made use of statistical data, supplemented with expert knowledge to describe both systems (Basset-Mens et al., 2006; van der Werf et al., 2007).
Feed intake level of organic sows was 20.2% or 29.1% higher compared to conventional sows (Figure 3.4), whereas the number of piglets weaned per sow was between 2.0% (near-significant difference) and 29.7% lower (Figure 3.4).

In the study of Lindgren et al. (2013) both the total number of piglets born per litter (including stillborn piglets) and the number of piglets stillborn per litter was higher in organic herds than in conventional herds, resulting in a similar number of piglets born alive in both systems. No significant difference was found in mortality of live-born piglets. Therefore, the number of weaned piglets per sow per litter was similar in both systems (9.8 vs. 10.0 for organic and conventional, respectively). Possibly, one contributing factor to the larger litters in the organic system would be the longer nursing period, which implies a longer recovery period for the sow before next mating which has been shown to be beneficial for the reproductive performance. In the organic herds farrowing interval was 20 days longer than in the conventional herds. Most of this difference can be explained by the longer nursing period in the organic herds, but later and more scattered oestrous behaviour among the organic sows is also an explanatory factor.

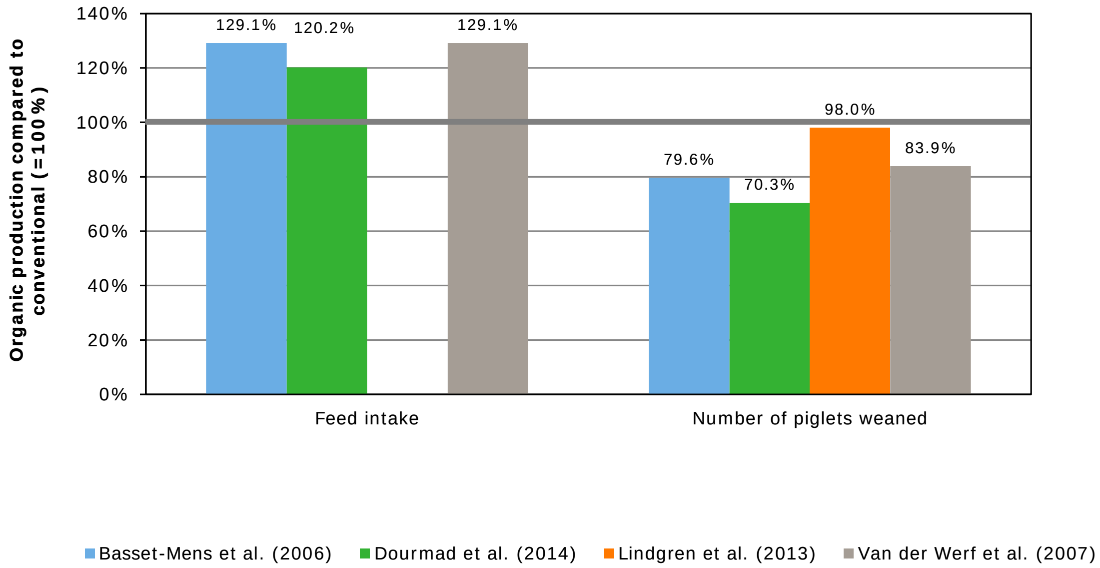

Figure 3.4 *Feed intake and number of piglets weaned per sow per year of organic reproductive sows, expressed relative to those of conventional sows (= 100%)*

In one study, the feed conversion ratio of organic fattening pigs was similar to conventional fattening pigs, whereas feed conversion ratio in two other studies was 7.4% and 10.6% higher as compared to the conventional fattening pigs, meaning that organic fattening pigs needed more feed to produce the same amount of meat than conventional fattening pigs (Figure 3.5). It should be noted that the studies only reviewed the feed intake on production animal level and not on system level. Therefore, the feed intake of, for example, breeding animals and replacements animals was not taken into account. For an analysis on system level, feed intake of such animals should be included in the feed conversion ratio.

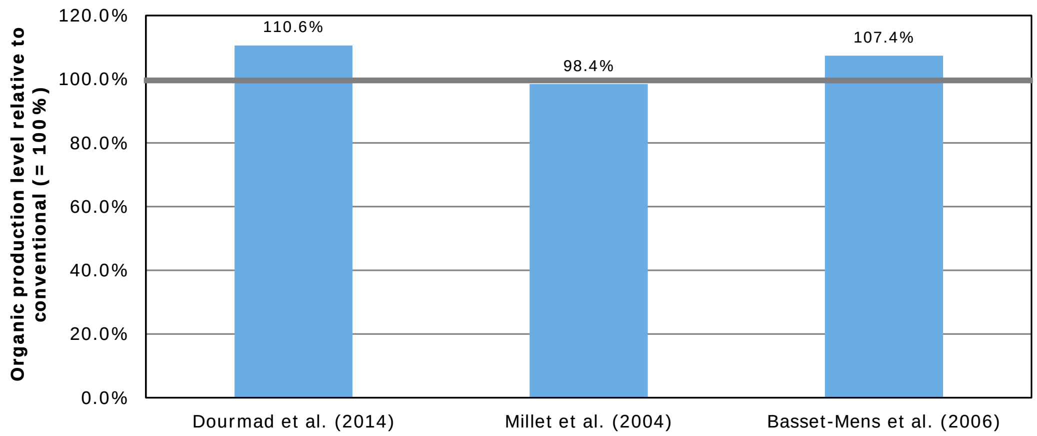

Figure 3.5 *Feed conversion ratio of organic fattening pigs, expressed relative to conventional fattening pigs (= 100%)*

Because of the limited availability of some nutrients, especially with regard to essential amino acids, there is concern that nutritional imbalances encountered in practice might lead to a drop in pig meat quality of organic pigs, although effects may differ between strains (Sundrum et al., 2011). Brandt et al. (2010) observed higher feed intake levels of pigs housed under organic compared to conventional conditions. This can be explained by the fact that feed intake of pigs is mostly determined by energy and protein content of the diet. Hence, under organic diets, which have lower-energy content and limiting amino acids (usually lysine), pigs will have a higher voluntary feed intake. In comparable studies (Millet et al., 2004; Millet et al., 2005b), there was not only an increase in feed intake but also in daily weight gain of the organic pigs, and no difference in feed conversion ratio when comparing organic versus conventional feeding and housing.

Broilers

Broiler data were based on three studies (Bokkers and De Boer, 2009; Boggia et al., 2010; Castellini et al., 2012), all originating from Europe. Comparison within three broiler studies showed that relative daily body weight gain of organic broilers ranged between 83.5 and 76.4%, whereas feed conversion ratio was 40.0 to 52.6% higher as compared to conventional broilers (Figure 3.6).

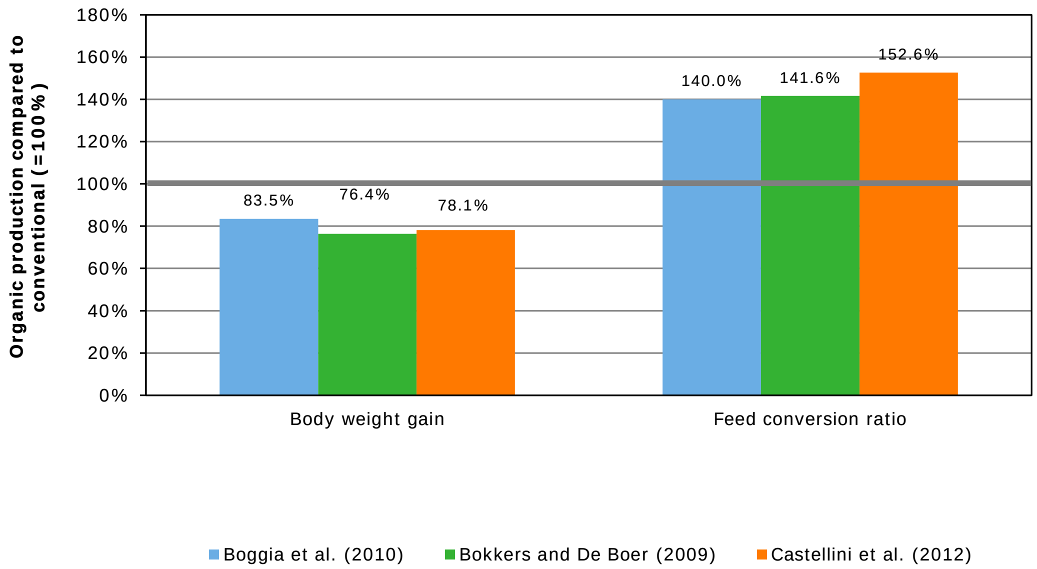

Figure 3.6 *Daily body weight gain and feed conversion ratio of organic broilers, expressed relative to those of conventional broilers (= 100%)*

The use of slow-growing broilers in organic systems versus the use of fast-growing broilers in conventional systems is the primary cause for the difference in productive performance (Castellini et al., 2012). The higher locomotive activity of slow-growing broilers reduces the body energy available for body growth. Nielsen et al. (2003) reported that slower-growing broilers used an outdoor area more often than faster-growing broilers. The slow-growing broilers were much more active and appeared to forage more, thereby consuming more nutrients from the outdoor area, as compared to the fast-growing broilers. The fast-growing broilers rarely went outside, and when they did, they grouped around the feeder or rested instead of foraging. Cold temperatures are also known to increase feed intake and worsen feed conversion ratio. Therefore, temperature could in part explain the effect of outdoor exposure on feed intake and feed conversion. Part of the lower feeding efficiency of organic systems is also due to the older slaughtering age of the organic broilers, thereby increasing maintenance requirement, and as a consequence feed conversion ratio. Moreover, synthetic amino acids, organic acids, and enzymes like phytase produced with genetically modified organisms are banned in organic systems, which makes it more difficult to meet the higher dietary requirements of such productive broilers (Castellini et al., 2012). Nielsen et al. (2003) reported that fast-growing broilers were able to increase consumption of a low-nutrient diet to the extent that weight gain was maintained, although feed conversion ratio increased. In contrast, slow-growing broilers that were fed a low-nutrient diet apparently lacked the ability to increase feed consumption, so that feed conversion ratio worsened, although not significantly. In contrast, Lewis et al. (1997) found that a low-nutrient diet resulted in slower growth for both fast-growing and slow-growing broilers. However, in that study, there was more protein relative to energy in the conventional diet than in the low-nutrient diet, and the feed intake did not increase. Therefore, it is possible that feed intake did not increase because the energy needs were being met. Slow-growing broilers were much less heavily muscled than the fast-growing broilers. The slow-growing broilers, however, appeared to have a greater proportion of feathers relative to their body weight, which could conceivably increase sulphur amino acid requirements (Fanatico et al., 2008). The studies only reviewed the feed intake on production- animal level and not on system level, and therefore did not take the feed intake of, for example, parent animals and grandparent animals into account. For an analysis on system level, feed intake of such animals should be included in the feed conversion ratio.

Laying hens

Four studies, all from Europe, were available to assess the productivity of organic versus conventional laying hen systems. Leinonen and Kyriazakis (2013) made use of normative sector data. Dekker et al. (2011a) used normative data for the conventional system, whereas data for the organic system were obtained from interviews with 20 randomly selected organic farmers. Englmaierová et al. (2014) compared 72 conventional laying hen farms with 72 organic farms. Leenstra et al. (2012) collected data on 257 farms in three countries (Switzerland, France and the Netherlands). All four studies showed that egg production of organic laying hens was lower compared to conventional hens, ranging from 1.5 to 12.6% (Figure 3.7). The average of 1.5% reduced egg production on organic farms in Leenstra et al. (2012) was the average of non-significant differences between the systems in Switzerland and France, and a significant 5.7% lower egg production on organic farms in the Netherlands. Three of the studies (Dekker et al., 2011a; Englmaierová et al., 2014; Leenstra et al., 2014) showed that feed conversion ratio was 5.5 to 28.1% higher in organic compared to conventional production (Figure 3.7). The higher feed conversion ratio of organic laying hens, as compared to laying hens kept in conventional cage housing, is partly inherent to the loose hen housing in the organic system, in which laying hens have a higher energy expenditure due to higher activity levels and outdoor access. Differences in feed conversion ratio among the 20 organic farms showed that there is potential for improvement in organic production. An improved feed conversion ratio in organic laying hen production may be realised by changes in e.g. feed composition, farm management, genetic merit of the hen, metabolic energy demand of the laying hen, occurrence of feather pecking or diseases, and in the percentage of damaged eggs (Van Knegsel and Van Krimpen, 2008). The studies only reviewed the feed intake on production-animal level and not on system level. Therefore, they did not take the feed intake of, for example, parent animals and great-parent animals into account. For an analysis on system level, feed intake of such animals should be included in the feed conversion ratio.

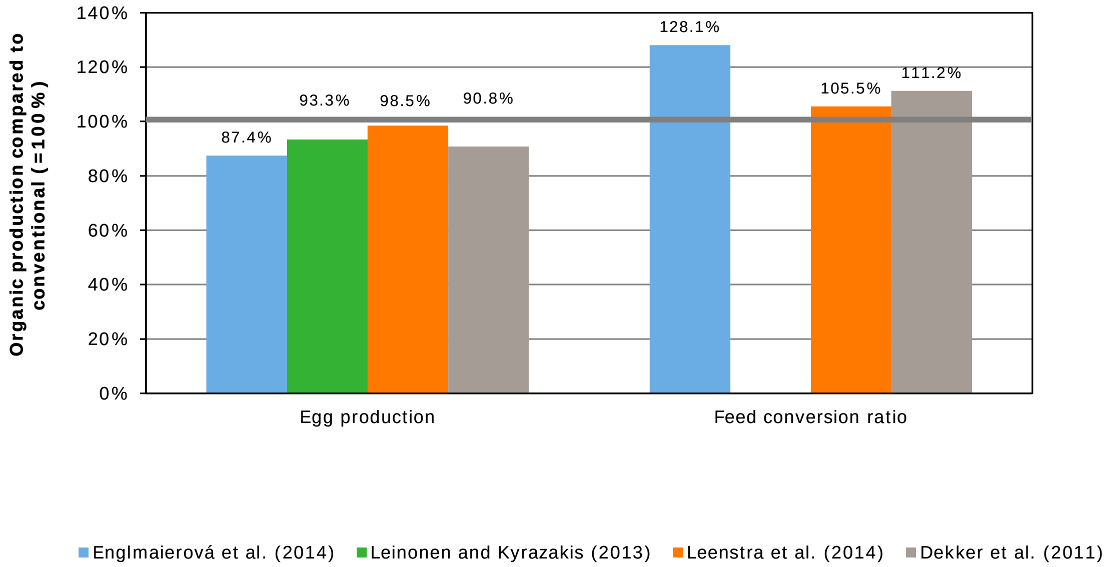

Figure 3.7 *Feed conversion ratio and egg production of organic laying hens, expressed relative to those of conventional laying hens (= 100%)*

Conclusions

Based on comparisons of both systems, it can be concluded that productivity of all studied organic livestock types, i.e. dairy cattle, beef cattle, pigs, broilers and laying hens, generally was lower compared to the conventional systems. More specifically, milk yield in organic systems was consistently lower compared to conventional systems in all studies. Milk fat and protein content, however, were similar or higher in organic milk compared to conventional milk. In all studies, daily weight gain of organic beef cattle was lower compared to conventional beef cattle. Organic sows consumed more feed and had lower numbers of weaned piglets than conventional sows. In two studies, feed conversion of organic fattening pigs was less efficient compared to conventional fattening pigs, whereas in one study the opposite was the case. All studies showed a lower rate of egg laying and feed efficiency in organic laying hens compared to conventional hens. For a correct comparison of feed efficiency on system level, the feed intake of breeding and replacement stock should also be included in the analysis in addition to the feed intake of the production animals.

Conventional livestock husbandry has higher productivity in terms of the amount of product output per animal than organic livestock husbandry, although the extent to which varied between animal species. Part of these differences is due to different breeds of animals used and part is due to differences in production practices (housing and feeding strategy). Within this context, however, it should be recognised that the focus on productivity and feed efficiency has led to increased amounts of human edible products, such as cereal grains, in rations of livestock (Davis et al., 2015). Nevertheless, the use in rations of residues from processing of crops, which are not edible by humans can have a great value for animals, especially for ruminants. To determine the contribution of livestock production to food security, focus should not only be on increasing animal productivity, but also on increasing the number of human beings nourished per hectare arable land. From this perspective, lower yielding animals, likely ruminants, but the concept is the same with monogastric animals, on marginal land (i.e. land with low opportunity costs for arable production) might be more important in terms of food security than higher yielding animals on arable land (Van Zanten et al., 2015).

3.2.3 Environment

The studies that compared environmental impacts between organic and conventional livestock production are presented in Appendix 3. In the following section, all environmental impacts are expressed per unit of product. The final paragraph of the results section on environment provides insight into the environmental impacts per ha of land. Environmental impacts per unit of product is a measure for the efficiency of production, whereas environmental impacts per ha of land is a measure for the potential local impact of a production systems.

Dairy cattle

Fifteen studies compared the environmental impact of conventional and organic dairy production systems. One study (Chen and Corson, 2014), however, was based on data from another included study (Van der Werf et al., 2009), and one study (Halberg et al., 2005) was based on multiple other included studies. These two studies were excluded, resulting in thirteen studies for the comparison. Of these, twelve studies assessed the impact on global warming (Figure 3.8) of dairy production, by calculating the global warming potential (GWP) per unit of milk. The GWP of a product (e.g. milk) measures its total contribution to global warming by summing up emissions of greenhouse gases (i.e. carbon dioxide, methane, and nitrous oxide) based on the radiative forcing of each gas relative to that of CO_2. On average, the GWP per unit product was the same (0% difference) for organic and conventional systems (range -17% to 20%). Five of the twelve studies tested for statistical differences (Appendix 3). One study reported a significant higher ($p<0.05$) GWP in case of organic dairy production (Kiefer et al., 2014), whereas the other studies did not find a significant difference in GWP between the systems (Thomassen et al., 2008; Van der Werf et al., 2009; Kristensen et al., 2011; Flysjö et al., 2012).

Generally, organic systems have a higher enteric methane emission per unit of product because of the, on average, lower milk yield per cow and due to an increased use of roughage. Emissions of carbon dioxide and nitrous oxide are generally lower in organic systems due to the absence of synthetic fertiliser, lower nitrogen application levels, and a relatively low use of concentrates in the dairy cow's diet (i.e. reducing energy use for feed production). Generally, the increase in enteric methane emission is levelled out by the decrease in nitrous oxide and carbon dioxide emissions. The largest differences were found by Del Prado et al. (2011) and Williams et al. (2006). In the first study, the GWP per unit product of organic systems was 17% lower compared with conventional systems. In contrast with most other studies that used empirical farm data, Del Prado et al. (2011) performed a simulation study based on dairy production data in the UK. The main assumption was that both systems had the same number of animals, milk yield per cow, and diet composition. The difference between the systems related to the use of mineral fertilisers and pesticides. As a result, enteric methane emission per unit product was the same, whereas nitrous oxide and carbon dioxide emissions related to on-farm feed production were lower in the organic system. These lower emissions were explained by the use of grass clover swards limiting the need for fertiliser application. Williams et al. (2006) found the GWP per unit of product in organic systems to be 20% higher compared with conventional systems, but the article lacks an explanation for this difference. After Williams et al. (2006), the largest difference was found by Capper et al. (2008). In this study, the GWP of organic systems was 13% higher compared with conventional systems. The authors explained the difference to be related to the lower milk yield per cow (-25%) in organic systems compared with conventional systems. Capper et al. (2008) emphasise the importance of dilution of maintenance in reducing the environmental impact of animal production. The concept postulates that maintenance nutrient requirement of cattle is spread over increased units of production, reducing natural resource use and GHG emissions per unit of product.

Six studies assessed the impact on acidification (Figure 3.8). On average, acidification potential (AP) was higher (9%) for organic than for conventional systems (range -13% to 60%). This average, however, was highly influenced by the result found by Williams et al. (2006), who reported 60% higher AP for organic systems compared with conventional systems (explanation lacking). Excluding this study, AP of organic and conventional systems is comparable (-1%). Two of the six studies tested for statistical differences. Both studies found no significant difference in AP between the systems (Thomassen et al., 2008; Van der Werf et al., 2009). Acidification was mainly related to the emission of ammonia from manure in stables, in storage, during grazing, and after fertiliser application. The higher AP per unit product in organic systems compared with conventional systems found by Thomassen et al. (2008) and Capper et al. (2008) was explained by the lower milk yield per cow, increasing the AP per unit of product. No clear explanation was given for the lower AP per unit product in organic systems found by the other studies.

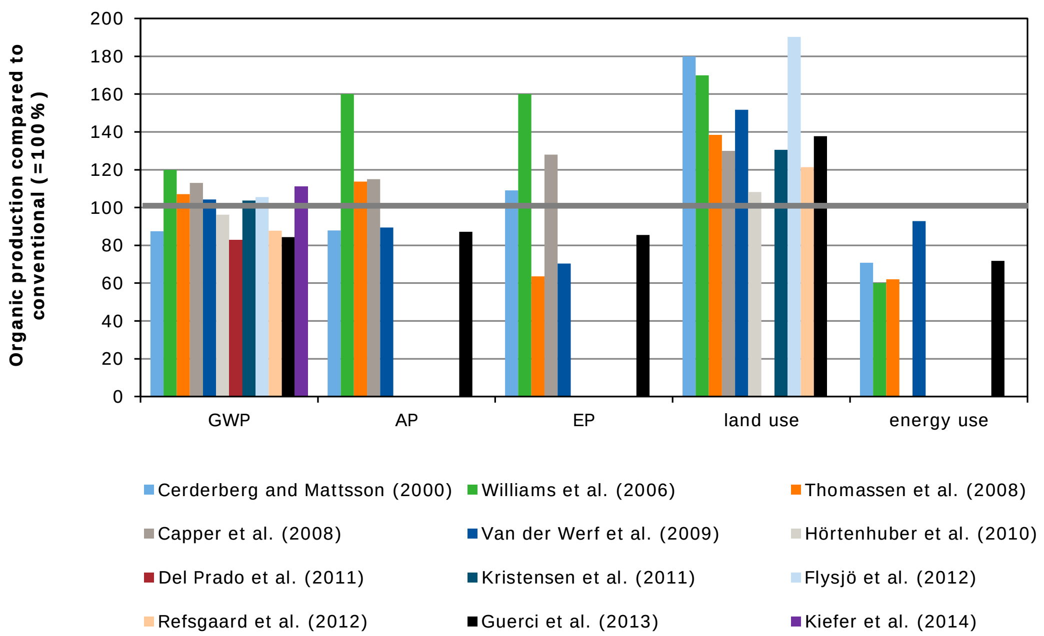

Figure 3.8 *Environmental impacts (%) per unit of product of organic relative to conventional dairy production systems (GWP=global warming potential; AP=acidification potential; EP=eutrophication potential)*

The same studies that assessed the impact on acidification also assessed the impact on eutrophication (Figure 3.8). Eutrophication potential (EP) per unit of product was on average 3% higher in organic systems compared with conventional systems (range -36% to 60%). Again, this result was highly influenced by the results found by Williams et al. (2006), who reported a 60% higher EP in case of organic dairy production. They provided no explanation. Excluding this study, EP of organic systems is 9% lower compared with conventional systems. Two of the six studies tested for statistical differences. Thomassen et al. (2008) reported a significant lower ($p<0.001$) EP in case of organic dairy production, whereas Van der Werf et al. (2009) did not find a significant difference. Eutrophication is mainly related to leaching of nitrate and phosphate and to emissions of ammonia from manure and synthetic fertilisers. Generally, organic systems result in a lower EP per unit of product due to the absence of synthetic fertiliser and a lower nitrogen and phosphate fertilisation level compared with conventional systems. Thomassen et al. (2008), for example, explained that the lower EP per unit product in organic systems compared with conventional systems relates to the lower nitrogen and phosphate surplus per ha, caused by the lower input of fertilisers and concentrates. Compared to other studies, however, the difference in EP between organic and conventional systems found by Thomassen et al. (2008) is relatively large (-36%), which is explained by a difference in location of the two systems (i.e. the conventional farms were located on sandy soils with a relatively high net nitrogen leaching factor, whereas the organic farms were located on clay and peat soils with a lower net nitrogen leaching factor). Cederberg and Mattsson (2000) found the EP per unit product in organic systems to be higher compared with conventional systems. This related to the assumption that part of the phosphate surplus is accumulated in the soil (Cederberg, 1998) limiting the possibility for organic systems to reduce leaching of phosphate, and to the use of feed products with a high EP (peas) in organic systems. Capper et al. (2008) attributed the higher EP per unit product in organic systems to the lower milk yield per cow.

Ten studies assessed the impact on land use, which includes the land for production of animal feed (Figure 3.8). Land use per unit of product was consistently higher in organic systems (on average 49%) compared with conventional systems (range 8% to 90%). Three (Thomassen et al., 2008; Van der Werf et al., 2009; Kristensen et al., 2011) of the ten studies tested for statistical differences and all three found a significant higher ($p<0.01$) land use in case of organic dairy production. This higher land use is explained by lower crop (grass) yields per ha and lower milk yield per cow resulting in a higher amount of maintenance feed per kg of product, i.e. the amount of feed required to keep the animal alive with no product, no gain, and no loss of body substance. Variation between studies is large, mainly due to differences in diet composition, and due to differences in crop (grass) yields and milk yields.

Five studies assessed the impact on energy use (Figure 3.8). Fossil energy use per unit of product was consistently lower in organic systems (on average 29%) compared with conventional systems (range -40% to -7%). Two of the five studies tested for statistical differences. Thomassen et al. (2008) reported a significant lower ($p<0.001$) energy use in case of organic dairy production, whereas Van der Werf et al. (2009) did not find a significant difference. The on average lower use of energy per unit of product in organic systems compared with conventional systems is explained by the absence of synthetic fertilisers and a relatively low use of concentrates (e.g. Cederberg and Mattsson, 2000). Both the production and transport of concentrates are important contributors to energy use. In the study of Thomassen et al. (2008), for example, production and transport of concentrates determined 83% of the total energy use in conventional systems and 67% in organic systems (i.e. from cradle-to-farm gate).

Three studies assessed the impact on biodiversity loss. All three studies found the impact per unit product to be lower in organic systems compared with conventional systems, despite the fact that organic systems require larger areas of land. Differences compared with conventional systems ranged from -76% (Guerci et al., 2013) to -57% (Mueller et al., 2014) and -5% (Del Prado et al., 2011). Only Mueller et al. (2014) tested for statistical differences; results were significant lower on case of organic dairy production ($p<0.05$). The lower impact per unit product of organic systems is explained by the absence of pesticides and synthetic fertiliser, a lower stocking rate per ha, and a better balance between cutting and grazing and the level of external inputs (Del Prado et al., 2011).

One study assessed the impact on terrestrial toxicity, referring to the impact of toxic substances such as copper and sink on terrestrial ecosystem, and one study considered soil quality. Van der Werf et al. (2009) found the impact per unit product on terrestrial toxicity to be 59% lower in organic system compared with conventional systems, but results were not significantly different. Del Prado et al. (2011) concluded that soil quality (referring to soil structure and chemical fertility) was higher in case of organic systems, related to, e.g. the use of clover. Del Prado et al. (2011) did not test for statistical differences.

Beef cattle

Three studies compared environmental impacts of conventional and organic beef production systems. Casey and Holden (2006) compared the systems based on GWP, Williams et al. (2006; update results) compared the systems based on GWP, energy use, EP, AP and pesticide use, and Refsgaard et al. (2012) compared the systems based on GWP and land use. Williams et al. (2006) distinguished between beef produced by calves from dairy systems and from suckler systems. Results are shown in Figure 3.9. GWP per unit product was lower (14% on average) in organic systems compared with conventional systems (range -32 to -3%). Only Casey and Holden (2006) tested for statistical differences. They found a significant lower GWP in case of organic beef production ($p<0.05$). The lower GWP can be explained by reduced carbon dioxide and nitrous oxide emissions in organic systems due to a lower use of (synthetic) fertilisers, which compensates the increased methane emissions caused by a higher amount of roughage in organic diets. Furthermore, differences in diet can contribute to differences between GWPs of organic and conventional systems. Casey and Holden (2006) found that lower GWP of organic systems was related to the use of less concentrates per kg live weight. In addition, the type of concentrate fed in organic systems (i.e. locally produced and unprocessed barley) had a lower GWP than concentrate fed in non-organic systems (i.e. composition of different processed and unprocessed ingredients). Compared to Casey and Holden (2006) and Williams et al. (2006), differences in GWP between conventional and organic systems found by Refsgaard et al. (2012) were relatively large. This is explained by the assumption that emissions related to enteric fermentation and manure did not differ between the two systems, whereas the absence of synthetic fertiliser and the use of locally produced grain instead of important soy contributed to a reduced GWP of organic systems.

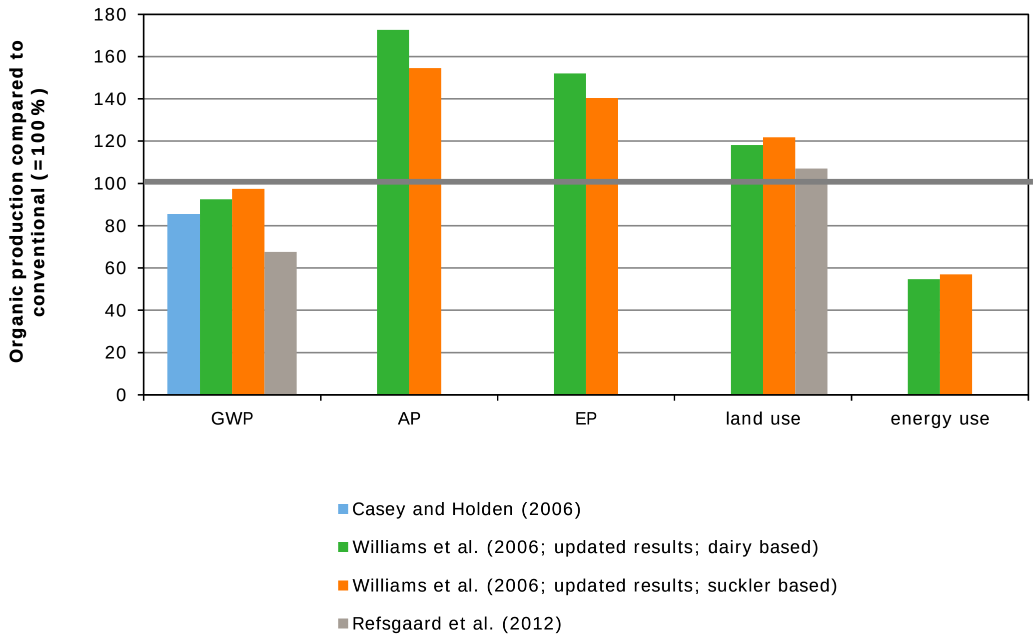

Figure 3.9 *Environmental impacts (%) per unit of product of organic relative to conventional beef production systems (GWP=global warming potential; AP=acidification potential; EP=eutrophication potential)*

For other impact categories, Williams et al. (2006; updated results) found a higher acidification potential, a higher eutrophication potential, and a higher land use in organic systems compared to conventional systems. This can be explained mainly by lower crop and grass yields and lower growth

rates of animals in these systems. Energy use was found to be lower in organic systems compared with conventional systems. This lower energy use in organic systems can be explained by the absence of pesticides and synthetic fertilisers (i.e. energy use during production is avoided), and by the use of more local and unprocessed feed products (e.g. roughage) compared to non-organic systems.
Results of the comparison on beef production are in line with results reported by De Vries et al. (2015), who compared environmental impacts of contrasting beef systems based on a literature review.

Pigs

Nine studies compared the environmental impact of conventional and organic pig production systems. Six of these studies, however, used the same data originating from the study of Basset-Mens and Van der Werf (2005). Therefore, only four studies are included in the comparison (Figure 3.10). Basset-Mens and Van der Werf (2005) and Van der Werf and Salou (2015) compared conventional with organic pig production in France, Williams et al. (2006) compared organic and conventional systems in England and Wales, and Dourmad et al. (2014) compared conventional and organic systems from Europe (i.e. five conventional systems from Denmark, the Netherlands, Spain, France and Germany, and two organic systems from Denmark and Germany). Comparison of systems among countries could potentially bias results, but because environmental impacts of the conventional and organic system reported by Dourmad et al. (2014) were in line with other studies, their results were also included.
On average, organic systems were found to have a higher GWP (29%) compared with conventional systems (range -10 to 72%), a higher land use (120%; range 70 to 211%), and a higher energy use (14%; range -10 to 40%). Two of the four studies tested for statistical differences (Basset-Mens and Van der Werf, 2005; Dourmad et al., 2014). Neither study found a significant difference in GWP between the two systems, whereas energy use was mentioned to be significantly higher (no p-value reported) in Basset-Mens and Van der Werf (2005), but no difference was found in Dourmad et al. (2014). Both studies reported a significant higher land use in case of organic pig production (no P-values reported). The on average higher impacts for GWP, energy use and land use of organic systems mainly relate to a lower performance (number of piglets per sow per year) and a higher feed use per kg of meat produced (exact feed composition not mentioned). Williams et al. (2006) found the GWP and energy use of organic systems to be lower compared with conventional systems, which was explained by a lower use of nitrogen as input during feed production, reducing the emission of nitrous oxide during crop cultivation and impacts related to production of synthetic fertilisers.

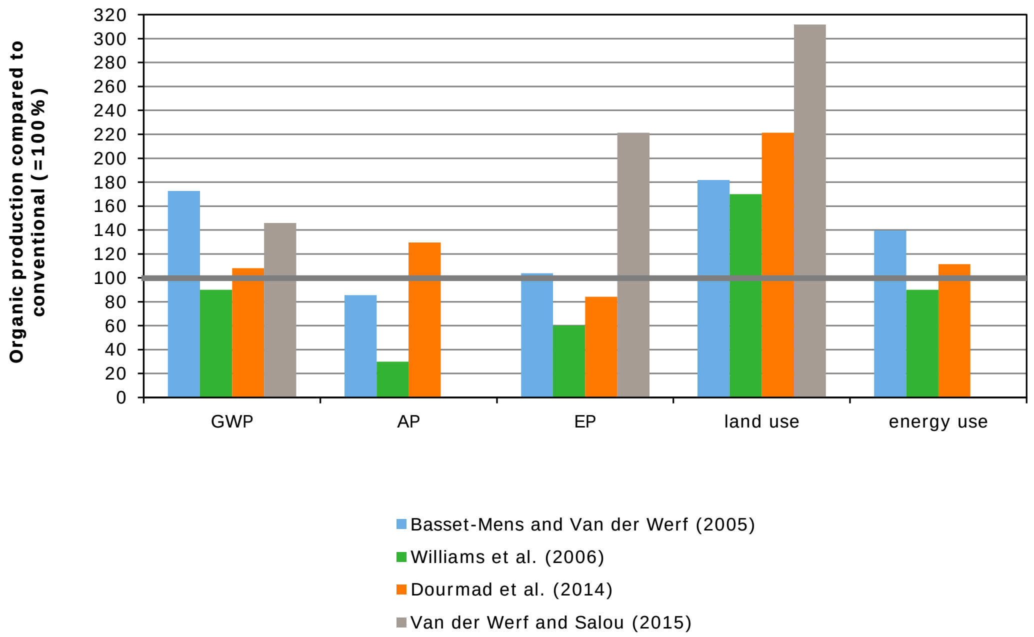

Figure 3.10 *Environmental impacts (%) per unit of product of organic relative to conventional pig production systems (GWP=global warming potential; AP=acidification potential; EP=eutrophication potential)*

For AP and EP per unit of product, results differed between studies. On average, AP was 18% lower in organic systems (range -70 to 30%), whereas EP was 17% higher in organic systems (range -40 to 121%). No significant difference in AP or EP between the systems was found (Basset-Mens and Van der Werf, 2005; Dourmad et al., 2014). The AP of pig production mainly relates to manure management. Basset-Mens and Van der Werf (2005) assumed the type of manure in organic systems to be solid manure, resulting in lower ammonia emissions and a lower AP compared with conventional systems, whereas Dourmad et al. (2014) assumed the main part of manure in organic systems to be liquid. The EP of pig production mainly relates to crop cultivation. The lower EP for organic systems in the study of Dourmad et al. (2014) was explained by the use of feed ingredients with a low environmental impact. Furthermore, they emphasise the difference in variability within systems. According to Dourmad et al. (2014), variation in environmental performance is lower in conventional than in alternative (e.g. organic) systems, which relates to the higher variation in animal performance and greater diversity in type of housing and manure management in alternative (organic) systems. Williams et al. (2006) did not provide an explanation for the lower AP and EP per unit of product of organic systems.

Broilers

Five studies compared environmental impacts of organic and conventional broiler production systems (Figure 3.11). Williams et al. (2006) compared organic and conventional systems in England and Wales; Van der Werf and Salou (2015) compared impacts of organic and conventional broiler production in France; Leinonen and Kyriazakis (2013) compared impacts among three systems in the UK (standard indoor, free-range and organic production); and Boggia et al. (2010) and Castellini et al. (2012) compared LCA impacts among three systems in Italy (conventional, organic and organic-plus). Organic-plus has more restrictive requirements than organic with regard to growth speed of animals and housing (m^2/animal) to improve animal welfare and meat quality. Boggia et al. (2010) and Castellini et al. (2012) were based on a comparison of single farms only, which do not necessarily represent corresponding production systems.

On average, organic systems resulted in a higher environmental impact per unit product than conventional systems in case of all impact categories. Compared to conventional systems, organic systems had a similar to higher GWP (4%; range -28 to 50%), a higher AP (66%, range 50 to 96%), a higher EP (105%; range 100 to 140%), a higher land use (130%; range 89 to 215%), and a higher energy use (18%; range -14 to 59%) per unit product. One of the four studies tested for statistical differences. Leinonen and Kyriazakis (2013) reported a higher GWP in case of organic when compared with conventional ($p<0.05$), but no significant difference in GWP between organic and free range. The same study reported a significant higher AP, EP and energy use in case of organic broiler production compared with either conventional or free range ($p<0.05$).

Information that explains differences between systems is limited in all studies except for Leinonen and Kyriazakis (2013), which were discussed into detail by Leinonen et al. (2012a). Leinonen et al. (2012a) concluded that differences in environmental performance among broiler production systems mainly resulted from differences in length of the production cycle and in feed conversion ratio. Although the finishing weight was lower in the standard indoor (2.0 kg) and the free range systems (2.06 kg) compared with the organic system (2.17 kg), the standard indoor system required 2.9 kg of feed per kg edible carcass weight (including broilers and breeders), the free range system 3.6 kg, and the organic system 4.5 kg. Differences in AP mainly resulted from differences in emissions of ammonia from manure in stable and storage (i.e. more feed per kg meat results in a larger amount of manure produced per kg meat). Furthermore, ammonia emission from manure increases with the length of the production cycle, which is higher for the free range (58 d) and the organic system (73 d) compared with the standard indoor system (39 d). In the case of similar diets, an increased feed conversion ratio will increase land use, primary energy use and GWP per kg edible carcass weight. In general, however, energy use per unit of product in organic production systems was found to be similar to that in conventional systems (Figure 3.11) because, even though organic systems used, absolutely, more feed, they also used feed products with a lower energy use (i.e. locally produced, absence of synthetic fertiliser). The higher energy use for organic systems compared to conventional systems in the study of Leinonen and Kyriazakis (2013) was explained by the fact that a relatively larger proportion of organic feed was cultivated overseas and imported to the UK compared with conventional feed.

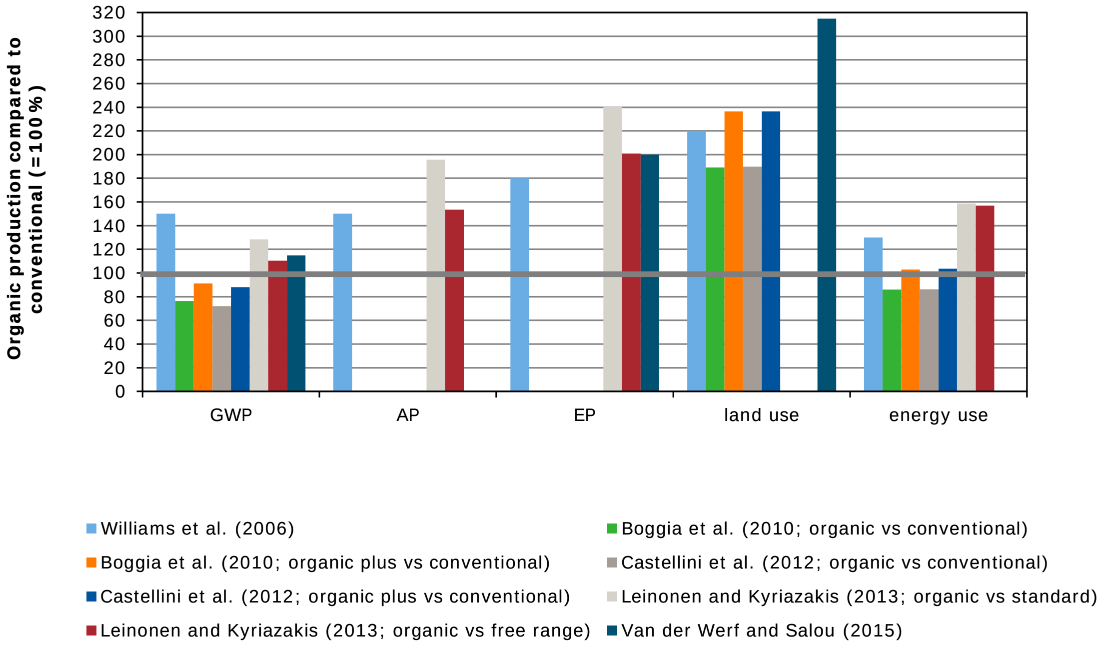

Figure 3.11 *Environmental impacts (%) per unit of product of organic relative to conventional broiler production systems (GWP=global warming potential; AP=acidification potential; EP=eutrophication potential)*

Laying hens

Four studies compared environmental impacts of organic and conventional egg production systems (Figure 3.12). Williams et al. (2006) compared organic and conventional systems in England and Wales, Dekker et al. (2011b) compared impacts among seven systems in the Netherlands (battery cage, single and multi-tiered barn, single and multi-tiered free range, and single and multi-tiered organic production), Leinonen and Kyriazakis (2013) compared impacts among four systems in the UK (battery cage, standard indoor, free-range and organic production), and Moudrý jr. et al. (2014) compared an organic and conventional system in Czech Republic. Results by Leinonen and Kyriazakis (2013) are explained in detail by Leinonen et al. (2012b). On average, organic systems resulted in a higher environmental impact per unit product than conventional systems in case of all impact categories, except for global warming. Compared to conventional systems, organic systems had a similar to lower GWP (-5%; range -44 to 30%), a higher AP (32%; range 10 to 54%), a higher EP (62%; range 30 to 85%), a higher land use (89%; range 66 to 120%), and a higher energy use (9%; range -13 to 40%) per unit product. Only Leinonen and Kyriazakis (2013) tested for statistical differences. They found no significant difference in GWP between the systems, but AP, EP and energy use were significantly higher ($p<0.05$) in organic systems compared to conventional systems. Organic egg production resulted in a lower or equal GWP when compared with conventional egg production, except for Williams et al. (2006). The lowest value was found by Moudrý jr. et al. (2014) reporting a 44% lower GWP for the organic system compared with the conventional system. They, however, assumed large differences in technological development between the two systems, with conventional systems using energy demanding technologies (e.g. air conditioning, egg management operations), and organic systems relying on human labour with no contribution to global warming. AP, EP and land use per unit of product were consistently higher for organic systems compared with conventional systems in all three studies. A higher feed consumption per kg of eggs and a lower crop yield per ha in organic systems explained the main part of the differences (Leinonen et al., 2012b). Results for energy use differed between studies. The lower energy use for organic systems found by Dekker et al. (2011b) was explained by a lower energy use during crop cultivation, related to fewer field operations and the absence of synthetic fertiliser. The higher energy use for organic systems found by Leinonen and Kyriazakis (2013) was explained by the higher feed consumption per kg of eggs and the lower crop yield per ha, together with the fact that a larger part of the feed used in organic systems was produced overseas.

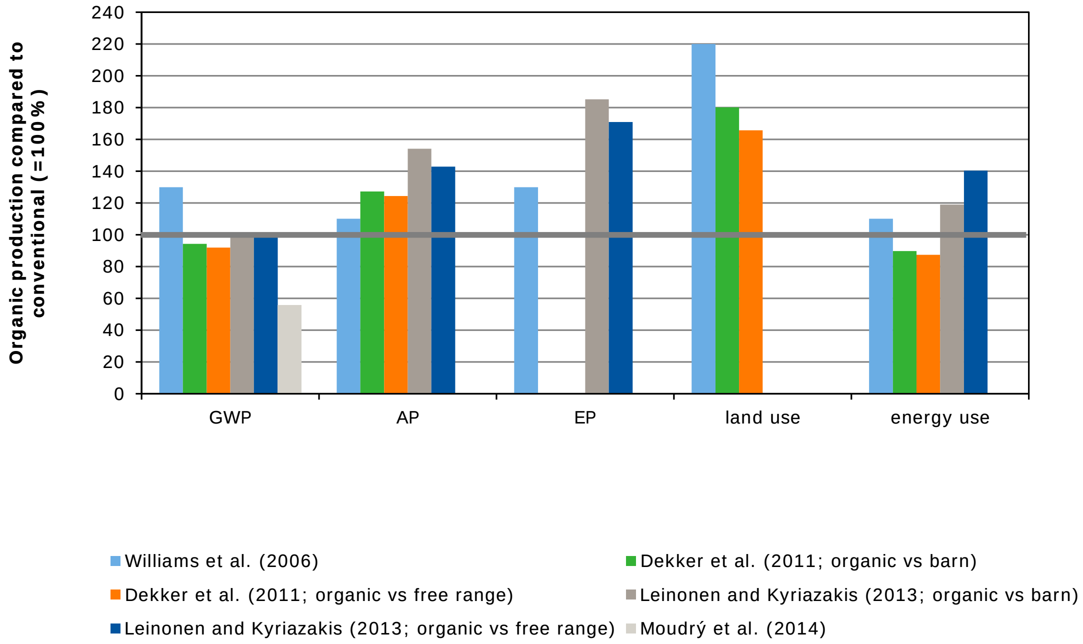

Figure 3.12 *Environmental impacts (%) per unit of product of organic relative to conventional egg production systems (GWP=global warming potential; AP=acidification potential; EP=eutrophication potential)*

Environmental impacts per ha of land

Five studies assessed the local impact of organic and conventional systems by analysing the nitrogen and phosphorus surplus per ha of land at the farm level, or by analysing AP, EP, and terrestrial toxicity per ha of land at the chain level (Figure 3.13). Four of the five studies tested for statistical differences, except for Cederberg and Mattsson (2000).

Expressing GWP and energy use per ha of land is not useful to gain insight into the environmental impact of organic and conventional systems because these impact categories do not contribute to a local environmental problem. In addition, it should be noted that calculating one average value for AP, EP and terrestrial toxicity per ha of land at the chain level can be misleading because it enables compensation of poor results for one of the chain processes by another. Furthermore, without site-specific knowledge on the local ecosystems that are exposed to the emission of pollutants, it is not possible to quantify the local impacts accurately (Potting and Hauschild, 2006).

Except for the results on terrestrial toxicity reported by Basset-Mens and Van der Werf (2005), impacts expressed per ha of land were found to be significantly lower in case of organic systems in all studies. Whereas AP and EP per unit of product were generally higher in organic systems compared with conventional systems, these impacts are often lower when expressed per ha of land. Results imply that the local impact of organic systems is lower compared with conventional systems.

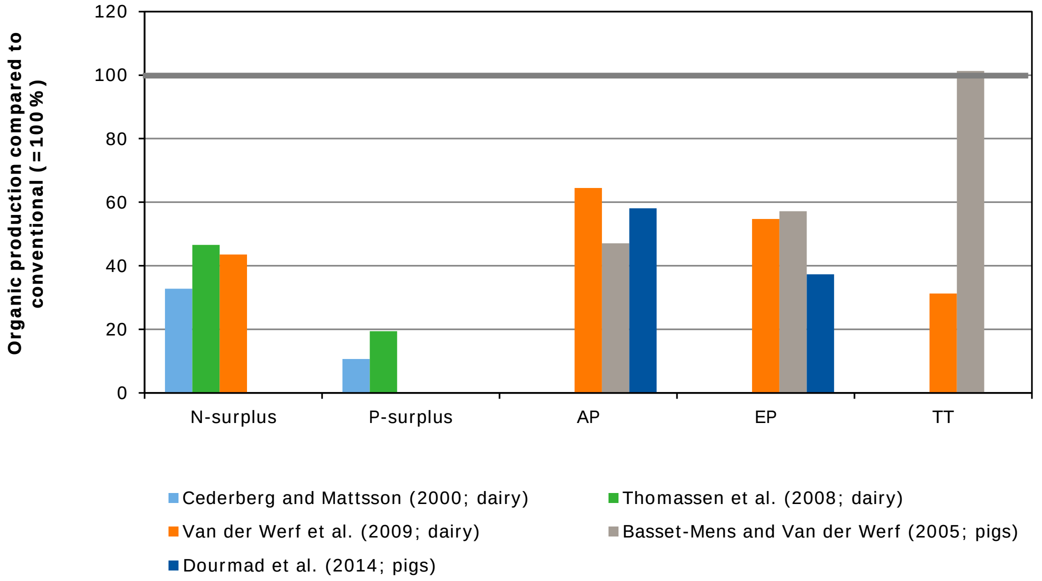

Figure 3.13 *Environmental impacts (%) per ha of land of organic relative to conventional production systems (AP=acidification potential; EP=eutrophication potential; TT=terrestrial toxicity; N-surplus and P-surplus are calculated at farm level; AP, EP and TT are calculated at chain level)*

Conclusions

Only a limited amount of studies were found for each indicator and animal species, complicating extrapolation to entire sectors. Given this observation, the reviewed studies showed in general that conventional systems resulted in a lower AP and EP per unit of product (except in a few studies on dairy and pig production), and in a lower land use (all studies) compared with organic systems. This lower impact was mainly related to a higher crop yield and a higher animal productivity in conventional systems.

In terms of land use, however, it should be noted that none of the studies distinguished between marginal land (i.e. land with low opportunity for arable production) and highly productive cropland. Accounting for the suitability of land to produce human edible protein more efficiently (e.g. through crop production) could alter conclusions about land use efficiency of livestock systems (Van Zanten et al., 2015).

Organic systems were found to have a lower AP and EP per unit of land, indicating a lower local environmental impact. This lower impact was related mainly to the absence of synthetic fertilisers and lower fertilisation levels. To better understand the results on local impacts, however, site-specific knowledge on local eco-systems is required.

Organic system were also found to have lower impact on biodiversity, eco-toxicity, and fossil phosphorus depletion per unit of product, but these impacts were examined in a limited number of studies only.

There was no clear difference between the two systems in case of global warming and energy use. On the one hand, organic systems showed a larger the impact relative to conventional due to higher enteric methane emissions (dairy and beef cattle) and lower productivity levels. On the other hand, organic systems showed a smaller impact due to lower emissions from crop cultivation and feed production related to the absence of synthetic fertiliser, lower fertilisation levels and the use of locally produced unprocessed products. It should be noted, however, that the use of local feed does not always reduce the environmental impact because other aspects such as agro-ecological circumstances are important too.

In case of energy use, there seems to be a distinction between ruminant and monogastric systems. In case of dairy and beef cattle, energy use per unit product was consistently lower in organic systems compared with conventional systems. In case of pigs, broilers and laying hens, there was no consistent difference in energy use between organic and conventional systems. Differences between types of livestock relate to differences in diet, and the ability of ruminants to use grass and other roughage products that can be produced with low energy costs.

3.2.4 Animal welfare

In this section, studies are described that made a direct comparison of welfare parameters on animal level between organic and conventional dairy cattle, beef cattle, pigs, broilers, and laying hens (Appendix 4).

Dairy cattle

Most studies comparing health and welfare on conventional and organic farms aimed at udder health, mostly evaluating somatic cell count, either at herd level (in the bulk milk) or at cow level. Nine studies found no statistically significant difference in somatic cell count between organic and conventional farms (Bennedsgaard et al., 2003; Sato et al., 2005a; Valle et al., 2007; Fall et al., 2008a; Fall and Emanuelson, 2009; Sundberg et al., 2009; Mueller and Sauerwein, 2010; Cicconi-Hogan et al., 2013a; Stiglbauer et al., 2013). One of these studies (Cicconi-Hogan et al., 2013a) also looked at specific types of pathogens found on the bulk milk tank and did not find a difference there either. One study (Garmo et al., 2010) found a significantly lower somatic cell count on organic farms as compared to conventional farms. On the other hand, five papers (Weller and Cooper, 1996; Vaarst and Bennedsgaard, 2001; Nauta et al., 2006; Roesch et al., 2007; Park et al., 2012) found a higher SCC on organic farms as compared to conventional farms. Two of these four studies (Weller and Cooper, 1996; Vaarst and Bennedsgaard, 2001), however, did not provide a level of significance. Thatcher et al. (2014) evaluated the somatic cell count in a study where the herd on a research farm was split in two groups, which were managed differently for a number of years. In the first years after conversion, the somatic cell count (both in terms of bulk milk somatic cell count and number of cows with an elevated somatic cell count) was higher on organic farms. In the last years of the 10-year study, there was no statistically significant difference anymore. The management on the organic herd was adjusted and that resulted in equal udder health. Four papers evaluated clinical mastitis, based on farmers' report and/or treatment records. One of these studies (Fall et al., 2008b) found no difference and three (Hardeng and Edge, 2001; Valle et al., 2007; Langford et al., 2009) found a lower level of clinical mastitis on organic farms compared to conventional farms.

Regarding hock lesions, only one paper was found (Brenninkmeyer et al., 2013) which compared the incidence of hock lesions between 38 organic and 33 conventional dairy herds in Germany. They found a significantly ($p<0.01$) higher prevalence of hock lesions in conventional farms than in organic farms (68 vs. 22%). They also found a correlation of 0.48 between hock lesions and lameness. The high incidence of hock lesions in conventional farms was mainly caused by poor cubicle design and the absence of bedding material, as indicated by regression analysis. Langford et al. (2009) found a yearly incidence of lameness of 37% on organic farms and of 32% on conventional farms, but differences were not tested statistically. Rutherford et al. (2009) found lower lameness prevalence on organic farms as compared to conventional farms during winter time (LSMeans 20% vs 14%), but found prevalence of sole disorders on organic farms not to differ statistically. Weller and Cooper (1996) observed a numerically lower incidence of lameness on organic farms (that they attributed to higher proportion of forage in the diet of organic cows), but this difference was not statistically significant. Langford et al. (2011) investigated behavioural differences in 20 organic and 20 conventional farms. They found that organic herds showed more aggression at the feeding gate. Aggression could become a welfare problem if levels are excessive and animals are prevented from feeding. The higher aggression levels in the organic herds could be caused by a higher proportion of cows feeding at peak feeding time compared with conventional herds (58 vs. 48%). In turn, this could be due a poorer average roughage quality on organic farms, as suggested by the authors. In the same study, a relationship between lying and lameness was found, with farms that had a percentage of cows lying also having a higher percentage of lame cows (correlation of 0.55). On conventional farms a higher percentage of cows lying down in the bedded areas was detected (43% vs. 38%). The relationship between lameness and farm type was not investigated in this study.

With regard to metabolic diseases, four studies looked at blood metabolites. Two of these studies (Roesch et al., 2005; Fall et al., 2008c) did not find any statistically significant differences between the two farm systems. One study (Blanco-Penedo et al., 2012b) described lower levels of the blood metabolite levels beta-hydroxybutyrate and non-esterified fatty acid (NEFA) in blood of cows on organic farms compared to cows on conventional farms, but these lower blood metabolite levels were not associated with lower clinical ketosis levels. One study (Abuelo et al., 2014) found higher levels of ketosis-related blood metabolites in blood of cows on organic farms. Three studies found a lower incidence of clinical ketosis (measured by the number of treatments) on organic farms compared to conventional dairy farms (Hardeng and Edge, 2001; Bennedsgaard et al., 2003; Valle et al., 2007), while three studies (Weller and Cooper, 1996; Langford et al., 2009; Blanco-Penedo et al., 2012a) did not find a statistically significant difference in incidence of clinical ketosis between conventional and organic farms. One study (Abuelo et al., 2014) studied 23 metabolic parameters around parturition in cows on 22 cows from a conventional herd and 40 cows from two organic herds. The prevalence of subclinical ketosis (based on NEFA) was higher on organic farms compared to conventional farms. On the other hand the organic farms showed higher insulin sensitivity than conventional farms, which is an indication that there is a lower risk of metabolic disturbances on organic farms. Conventional farms showed higher levels of inflammatory activity, especially through higher levels of serum amyloid A. This made the authors conclude that subclinical ketosis levels were higher on organic farms as compared to conventional farms and that organic farms had a smoother transition of cows from gestation to lactation. The same data were used in a study towards oxidative stress (Abuelo et al., 2015), which is higher if an animal is less able to repair the damage resulting from the systemic manifestation of reactive oxygen species. They concluded that cows on two organic farms had a higher risk of oxidative stress than cows on one comparable conventional farm. One study on essential elements in blood (Blanco-Penedo et al., 2014) did not find any difference between conventional and organic farms. Four studies reported milk fever (reported by farmers and/or represented by treatments). Two of these (Weller and Cooper, 1996; Valle et al., 2007) did not find a difference, while the other two (Hardeng and Edge, 2001; Langford et al., 2009) reported a lower incidence of milk fever on organic farms compared to conventional farms.

Except for two studies on claw health (Rutherford et al., 2009; Brenninkmeyer et al., 2013), the reviewed studies reporting clinical disease levels were based upon farmers’ reported disease incidences or treatments (either reported by the farmer upon request of the researcher or reported routinely by a veterinarian). The results of these studies should be handled with care, since farmers might use different definitions for these diseases or might have different treatment protocols. One study corrected the results for the difference in disease definition between farmers (Richert et al., 2013). After that correction differences between farm systems disappeared, indicating the importance of the farmers’ definition in studies that evaluate farmers’ reported clinical disease data.

Two studies on parasites (Sato et al., 2005a; Hoglund et al., 2010) concluded both that the prevalence of parasites was higher on organic farms than on conventional farms.

Although they did not measure clinical disease as such, a number of studies were published on the prevalence of microbiological pathogens in animals. Bidokhti et al. (2009) found a lower risk on conventional farms on bovine coronavirus and bovine respiratory syncytial virus. Kuhnert et al. (2005) found more shiga toxin *Escherichia coli* on organic farms than on conventional farms. For other microbial animal health hazards, such as *Mycobacterium avium* subsp. *paratuberculosis* (Cazer et al., 2013), *Salmonella* spp. (Fossler et al., 2004; Fossler et al., 2005a; Fossler et al., 2005b), and *Cryptosporidium* in calves (Silverlas and Blanco-Penedo, 2013), no differences were found.

Five studies were carried out on reproductive performance of organic and conventional dairy farms. Two studies did not see a difference in reproductive performance between conventional and organic farms (Fall et al., 2008b; Fall and Emanuelson, 2009). Loef et al. (2007) reported statistically significant 3-4 days longer calving to calving interval, calving to first insemination interval, and calving to last insemination interval on organic farms as compared to conventional farms. Sundberg et al.

(2009) reported a 5-7 days longer calving to calving interval on organic farms compared to conventional farms. That was in concordance with Reksen et al. (1999) who found a 9 day longer calving to calving interval on organic farms compared to conventional farms. However, in the study of Reksen et al. (1999) no statistical significant difference in open days was found.
Differences in diseases and reproductive performance may impact the longevity of cattle. Ahlman et al. (2011) did not find a statistically significant difference in the productive life of cows on organic farms as compared to conventional farms. At herd level, Thomsen et al. (2006) found that close to 0% of the organic farms had one or more dead cows (involuntary mortality and/or euthanasia) on the farm, while this percentage was almost 16% on conventional farms. Alvasen et al. (2012) did not find a statistical significant difference between the two farm systems. Finally, Thomsen et al. (2007) did find a statistically significant higher percentage of loser cows on organic farms as compared to conventional farms.

Beef cattle

One study was found that compared the health of cattle on organic beef farms to conventional beef farms (Blanco-Penedo et al., 2012c). Based upon farmer reported data, the prevalence of mastitis, reproductive disorders, abortion, podal disorders, milk fever and ketosis were studied. Of these diseases, the only indicator that differed significantly was reproductive disorders with an incidence of 3.8% on organic farms and 0.4% on conventional farms.

Pigs

Eijck and Borgsteede (2005) investigated intestinal parasitic infections in 36 Dutch conventional, free range and organic pig farms. All observed cases were subclinical, as no clinical cases were recorded. They found that coccidial infections occurred more on organic farms (91% fecal sample prevalence) than on free range farms (44%), with conventional farms in between (67%), but differences were not significant. Ascarid infections occurred significantly more ($p<0.05$) on free range (50% fecal sample prevalence) and organic farms (73%) than on conventional farms (11%). This study indicates that intestinal parasitic infections are more common on organic than on conventional farms. As Eijck and Borgsteede (2005) did not record other traits related to health or productivity, no meaningful conclusions can be drawn on the effects of these subclinical worm infections on health and performance.

Knage-Rasmussen et al. (2014) compared incidences of lameness between 44 conventional and nine organic sow herds and found a much higher lameness prevalence in conventional sow herds (24% vs. 5%). Lameness was more prevalent in the summer and was linked to a higher incidence of bursitis. The outdoor access in the organic sows increases their opportunities for locomotion, probably leading to reduced lameness levels.

Millet et al. (2005a) performed an experimental study, focusing on the effects of organic housing and organic diet on stress sensitivity in slaughter pigs. They found that organic housing led to reduced stress sensitivity, measured by the significantly lower haptoglobin and lactate levels in the organically housed pigs compared to conventionally housed pigs at slaughter. These differences could be caused by the larger space allowance and outdoor access in organic housed pigs. No effects of organic diet were found on these parameters. To assess the biological relevance of these lower haptoglobin and lactate levels, further on-farm research is needed that evaluates effects on health and performance.

Broilers

For broilers, three studies were found that compared welfare of organic and conventional broilers. Van Overbeke et al. (2006) compared titres against Newcastle disease, infectious bursitis and infectious bronchitis at day one and at slaughter between conventional and organic broilers (eleven conventional and nine organic flocks). They found that at slaughter age, conventional broilers had higher infectious bronchitis titres than organic broilers, whereas organic flocks had higher infectious bursitis titres. They concluded that these higher infectious bursitis titres in organic flocks could be related to the timing of vaccination (day one and 18), which could not provide the organic birds with sufficient protection up to their slaughter age of twelve weeks. Van Overbeke et al. (2006) further concluded that the higher bronchitis titres in conventional broilers are a sign of poorer respiratory health status in conventional flocks compared to organic flocks, although clinical signs of bronchitis were not observed. Tuyttens et al. (2008) compared health and welfare at seven conventional and seven organic broiler farms. They compared broilers at slaughter age and found that organic broilers had higher acute phase protein levels in their blood, indicating according to the authors a better ability to cope with stress (Figure 3.14). Further, conventional broilers had a much shorter latency to lie (256±39 vs. 546±39 seconds), when placed in a bucket with a shallow layer of water, which is indicative of poorer leg health. Also hock lesions were more frequently found on conventional broilers than on organic broilers. This last finding was also reported by Williams et al. (2013) in an experimental study, where they compared fast and slow growing broilers (used in conventional and organic broiler farms, respectively) and challenged them with a *Campylobacter* infection. More cases of hock lesions were found in fast than in slow growing broilers (30-40 vs. 10-20 cases), irrespective of infection. Furthermore, the incidence of footpad lesions increased after infection in the fast, but not in the slow growing broilers (34 vs. 4 cases).

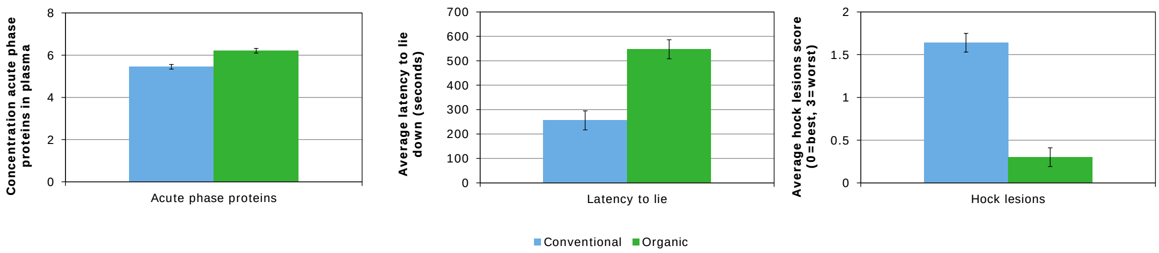

Figure 3.14 *Comparison of incidence of hock lesions, acute phase proteins and latencies to lie between conventional and organic broilers (after Tuyttens* et al.*, 2008)*

Laying hens
For laying hens, Jansson et al. (2010) compared intestinal parasitic infections between conventional and organic farms in 169 Swedish flocks. They distinguished between conventional cages, floor housing, aviary systems and free range and organic systems. Conventional cage systems are prohibited in the EU since 2012, as they provide limited space to the birds and no access to perches, nests and litter. Since 2012, only furnished cages and non-cage systems are allowed.

Jansson et al. (2010) found that intestinal parasitic infections were much less common in conventional cage systems than in any of the other systems (Figure 3.15). This is probably due to the fact that hens have no contact with litter or manure in the conventional cage system, which they do have in the other systems. No significant differences were found between indoor systems (floor housing and aviary) and free range and organic systems, which provide outdoor access. Important risk factors for worm infections were the absence of a hygiene barrier on the farm and the age of the house.

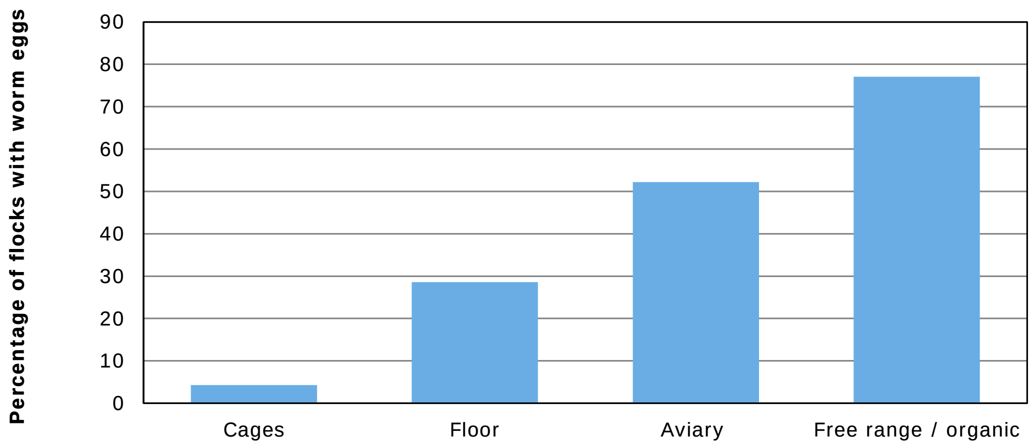

Figure 3.15 *Average prevalence of worm eggs in cage, floor, aviary and free range and organic systems (after Jansson* et al.*, 2010)*

Conclusions
Both the conventional and organic production system seem to have strengths and weaknesses regarding welfare. However, as indicated in the introduction of this paragraph, caution is warranted when interpreting the results for pigs, broilers, laying hens and beef cattle, because only a limited number of studies was found that matched our search criteria.

Not many differences between conventional and organic dairy farms could be found with regard to animal health. Especially in the studies that used routinely collected data such as calving intervals or somatic cell counts, there were approximately equal numbers of studies that found better performance of organic farming compared to conventional farming as vice versa. Studies on clinical disease showed either no difference or lower levels of clinical disease on organic farms as compared to conventional farms. However, caution must be used, since many of the studies on clinical disease were based on treatment records and/or farmers' reported data. Overall, disease and health problem incidences seem to be comparable between organic and conventional dairy farms. There were differences in behaviour and welfare between conventional and organic farms, but in most cases these differences were not related to the systems studied, but to the housing and management of the individual farmer. Dairy cows on organic farms had fewer hock lesions than conventional dairy cows, which was related to cubicle design and lying comfort. Cows on organic farms were also more active (low activity levels are correlated to increased problems with lameness). Also, more aggression around feeding was seen in cows on organic farms. Intestinal parasitic infections were higher in pigs on organic farms and in laying hens housed in non-cage systems (either conventional or organic), indicating that the increased contact with manure and free-range access is a clear risk factor for intestinal parasitic infections. Possibilities to use anthelminthic treatments may also be more limited for organic farms, due to restrictions on preventive use.

In both sows and broilers, a higher incidence of leg problems was found in conventional compared with organic farms. In broilers, this was indicated by the shorter latency to lie, when placed in a shallow layer of water. This was accompanied by a higher level of hock lesions in birds on conventional farms compared with birds on organic farms. This difference in leg health in broilers seems mainly related to the genotype that is used, as the slow growing genotype used in organic production is known to have fewer problems with leg health (SCAHAW, 2000). In sows, the lower incidence of lameness in organic sows seems mainly related to increased activity through the outdoor access, as this is the major difference between organic and conventional sow housing. Finally, some evidence was found for an improved stress resistance or robustness in organic broilers and pigs, caused by the use of different genetics and by the differences in housing system (more space and outdoor access in organic systems).
Especially for broilers, laying hens and pigs, more studied are needed focusing on systematic comparisons of organic and conventional farms. This would allow for drawing firmer conclusions for these species.

3.2.5 Public health

In this section, studies that made a comparison of public health indicators between organic and conventional dairy cattle, beef cattle, pigs, broilers, and laying hens are described. Indicators related to microbiological hazards, antimicrobial resistance, chemical hazards and product quality aspects (essential elements, fatty acids, vitamins, cholesterol) (Appendix 5).

3.2.5.1 Microbiological hazards
For zoonotic and potentially zoonotic microbiological hazards 48 papers were reviewed. Many different hazards were compared between organic and conventional production (Table 5.1, Appendix 5). The results are provided per animal species, dairy cattle, beef cattle, pigs, broilers, and layers.

Dairy cattle
For zoonotic and potentially zoonotic microbiological hazards related to dairy cattle, 15 studies were reviewed. One study (Miranda et al., 2009b) addressed hazards in cheese at retail level in Spain, seven addressed hazards in milk on farm level in Europe, and seven in milk on farm level in the USA. The studies addressed 17 different microbiological hazards at farm level and four at retail level. S.

aureus and Escherichia coli (E. coli), including (ST)EC (O157), were both addressed in six papers, the other hazards in a maximum of two papers. Ten studies did not find significant differences in prevalence or count of a microbiological hazard between organic and conventional, and one study (Sato et al., 2004b) did not provide significance levels. Only three studies reported significant ($p<0.05$) differences between conventional and organic. On conventional dairy farms compared to organic dairy farms, Kouřimská et al. (2014) reported significantly lower ($p<0.001$) total mesophilic bacteria count in bulk milk and Čuboň et al. (2008) mentioned significantly lower total bacteria count (p='++') and coliform organisms (p='+') in bulk milk, without giving a p-value. Kouřimská et al. (2014) explained differences by hygiene conditions at the farm, specifically disinfection of milking equipment, which is not related to the farming system. Čuboň et al. (2008) did not provide an explanation for the differences. In contrast, Coorevits et al. (2008) found significantly less ($p<0.01$) isolates of spore forming bacteria (*Bacillus*) in organic bulk milk compared to conventional. However, results differed between specific bacteria. For example, they found a significantly higher ($p<0.05$) number of Bacillus licheniformis isolates in conventional milk, whereas the number of *Bacillus cereus* isolates was significantly higher ($p<0.05$) in organic milk. The higher occurrence of thermotolerant bacteria, such as *Bacillus licheniformis*, in conventional milk, they stated, could be possibly explained by the larger amount of concentrated feed (which is heat-treated) and/or tropical waste ingredients used in conventional dairy compared to organic dairy. The higher number of *Bacillus cereus* isolates in organic milk was explained by Coorevits et al. (2008) by the less indoor housing of cows on organic farms compared to conventional farms, and thus a higher amount of soil ingestion by organic cows. They also found a significantly higher ($p<0.05$) number of spore forming bacteria isolates in late summer/autumn compared to other seasons. This indicates studies comparing spore forming bacteria between production systems should use samples taken in similar seasons or should correct for a difference in sample taking season.

The study of Čuboň et al. (2008) involved only one organic and one conventional farm, the study of Coorevits et al. (2008) only five farms each, and no number of farms was mentioned in Kouřimská et al. (2014). These numbers in combination with the different hazards reviewed complicate extrapolation of the results to all dairy farms in the organic or conventional sector. The other studies, which did not find a difference, also provided reasons why they expected a difference. The most common reasons for an expected lower microbiological bacteria count in conventional farming were the use of dry cow therapy in conventional farming and the lack of this in organic farming and a higher amount of pasture feeding in organic farming. Hygiene during manufacturing and processing in the supply chain after the farm was mentioned to be very important for the presence of *E. coli*, *S. aureus*, *Salmonella* spp. and *Listeria monocytogenes* (*L. monocytogenes*) in cheese on retail-level (Miranda et al., 2009b). Thus, without data about the hygiene status of the companies from farm to retail outlet, the results of analysis of cheese from a retail outlet might not be usable to identify differences in the same hazards at farm level.

Beef cattle

Three studies were reviewed with respect to microbiological hazards in beef production. Blanco-Penedo et al. (2009b) found significantly fewer condemnations of liver ($p=0.000$) and kidney ($p=0.000$) during the meat inspection in organic beef calves compared to conventional beef calves in Spain, whereas organic beef calves had more condemnations of lungs ($p=0.000$), digestive tract ($p=0.000$) and legs ($p=0.039$). Pathological condemnations could be an indication for the presence of microbiological hazards.

The two other studies reviewed the microbiological prevalence on supermarket level in Spain. Miranda et al. (2009a) did not find a significant difference in the prevalence of *E. coli*, *S. aureus*, *Salmonella* spp. and *L. monocytogenes* between organic and conventional beef. They argued that this lack of a difference could be due to contamination during slaughter and processing and via food handlers, making this just as important as the initial off-farm prevalence for the contamination of consumer products. Guarddon et al. (2014) found a significant lower ($p<0.05$) prevalence of mesophilic aerobic bacteria in conventional beef compared to organic beef, but no significant difference in Enterobacteriaceae.

Without data about the hygiene status of the slaughter industry, meat processing industry and other activities between farm and consumer product outlet, the results of analysis of beef products might not be usable to identify differences in the same hazards at farm level.

Pigs

For microbiological hazards related to pigs, nine papers were reviewed. All studies focused on pig production in Europe. Nine different hazards were addressed. Each hazard was addressed in maximum two papers. Three studies related to farm level, four to both farm and slaughterhouse level, and two to retail level. On farm and processing level, two studies did not provide significance levels for comparing organic and conventional (Hoogenboom et al., 2008; Ranta et al., 2010). In six of the studies, samples originated from ten or less farms, supermarkets or brands (be it conventional, organic or both). Bonde and Sørensen (2012) collected samples at 11 conventional and 11 organic farms, and Rutjes et al. (2014) at 24 conventional and 42 organic farms. Hoogenboom et al. (2008) compared the average result of 30 organic farms to the national average. Generalising the results from these papers to the entire organic and conventional sectors is therefore complicated.
Laukkanen et al. (2008) found the *Yersinia pseudotuberculosis* prevalence in pigs to be significantly higher ($p<0.05$) in organic farming, but did not mentioned the significance levels of the differences in sample, intestinal tract, tonsil, pluck set and carcass prevalence. Hellstrom et al. (2010) found the pig, intestinal tract, tonsil, pluck set (heart, lungs, oesophagus, trachea, diaphragm, liver, kidneys, and tongue with tonsils) and carcass prevalence of *L. monocytogenes* to be significantly higher ($p<0.05$) in organic pigs. Rutjes et al. (2014) found that the pig seroprevalence of Hepatitis E virus to be significantly higher ($p<0.05$) in organic pigs. They provided no significance level for their observed difference in farm prevalence and in percentage of farms with a pig seroprevalence of more than 95%. In one study on farm and processing level (Nowak et al., 2006), in three out of four sample types for *Yersinia enterocolitica* prevalence was significantly lower ($p<0.049$) in organic than conventional.
The reasons for the identified differences stated in the papers were the outdoor access of organic pigs resulting in more contact with other animals, the environment and manure, higher between pig contact in organic farming due to larger group sizes, higher contamination levels in the organic compound feed, more contaminated piglets in organic farming and the lower use of antibiotics in organic farming.

On retail level, Miranda et al. (2008b) found significantly higher ($p=0.0231$) *E. coli* in organic pork loin compared to conventional. In contrast, Guarddon et al. (2014) did not find a significant difference ($p>0.05$) in mesophilic aerobic bacteria and in enterobacteriaceae between organic and conventional pork steaks. Overall, more studies found higher microbiological contamination on organic pig farms and in organic pig meat than on conventional pig farms or in conventional pig meat than the other way around, and only few studies did find no significant difference.

Broilers

For microbiological hazards related to broilers, 19 studies were reviewed, which were about equally distributed between Europe and the USA. Five of these related to farm level, one to farm and processing level, two to processing level, and ten to retail level. Different indicators for microbiological contamination were used in and between the studies, such as farm prevalence, flock prevalence, sample prevalence, broiler and carcass prevalence, or number of bacteria detected on positive samples. Studies at farm and processing level were based on samples from between 3 and 18 farms per system. Some studies only mentioned the number of flocks, but did not mention from how many farms these flocks originated from. These small numbers complicate generalisation to entire sectors.

Salmonella was investigated in nine studies, of which three were at farm level, one at farm and processing level and five at retail level. Three of the Salmonella studies did not provide significance levels, two did not provide a significance level but said in words that no significant difference existed, two showed no significant difference ($p>0.05$), and three showed a significant difference between organic and conventional. Sapkota et al. (2014) found a significantly higher ($p=0.03$) poultry house prevalence on organic farms than on conventional farms and Mazengia et al. (2014) a significantly higher ($p=0.0394$) sample prevalence in organic than in conventional raw chicken in supermarkets. In contrast, Alali et al. (2010) found significantly higher fecal ($p<0.0001$) and feed ($p=0.007$) sample prevalence on conventional broiler farms compared to organic farms.

Campylobacter was investigated in nine of the studies, of which two were at farm level, one at farm and processing level, two at processing level and four at retail level. Hoogenboom et al. (2008) mentioned that Campylobacter farm and sample prevalence was much lower on conventional than on organic broiler farms, but did not provide a significance level. Rosenquist et al. (2013) mentioned that carcass prevalence at slaughter was significantly higher in organic compared to conventional broilers without providing a significance level, and found no difference ($p=0.428$) in the mean concentration. Three studies provided a quantitative significance level. Two studies found a significantly higher prevalence in organic compared to conventional broilers on farm and processing level, whereas one study (Luangtongkum et al., 2006) did not find a significant difference ($p>0.05$). Heuer et al. (2001) found a significantly higher ($p<0.001$) flock prevalence in organic compared to conventional broilers, although they did not detect a difference in broiler prevalence. Van Overbeke et al. (2006) found significantly higher prevalence in cecum ($p=0.024$) and duodenum ($p=0.036$) samples from organic compared to conventional broilers, but no difference in gastrointestinal tract prevalence. On retail level, two studies (Han et al., 2009; Mollenkopf et al., 2014) did not find a significant difference ($p>0.05$) and two studies (Cui et al., 2005; Hardy et al., 2013) did not mention significance levels.

Ten other potential microbiological hazards than Salmonella and Campylobacter were addressed in five studies, with maximal two studies per potential hazard. Four papers concerned Spain, one the USA. Of the six significant differences reported for these hazards, for two hazards organic had significantly lower ($p<0.05$) counts or prevalence than conventional and for four hazards organic had higher ($p<0.05$) counts or prevalence than conventional.

To ensure a sound comparison between organic and conventional, studies should correct for confounding variables. Van Overbeke et al. (2006) used farms from the same integration in their comparison, to control for differences in farm management. None of reviewed studies did control for potential confounding variables.

Most papers provided explanations for the observed differences or the lack of it. Explanations for higher microbiological prevalence at farm and processing level in the organic system included the older slaughter age of organic broilers, due to the use of a slow growing breed, outdoor access in organic farming, farm management, and differences in contamination levels of the feed, the contamination level of parent flocks or hatcheries, and the susceptibility of the breed. Explanations for the differences at retail level included next to explanations related to farm level, the size of the slaughterhouse, test methodology and nature of the sample (Lestari et al., 2009), the production region (Han et al., 2009) and handling of carcasses and meat during slaughter and processing (Miranda et al., 2008c; Mazengia et al., 2014). Given these last concerns, it is difficult to use the conclusions from studies focusing only at retail level to deduce conclusions about microbiological contamination levels at farm level.

Laying hens

Six studies were reviewed concerning laying hens. Three studies reviewed microbiological hazards in eggs on farm level (De Reu et al., 2006; Messens et al., 2007; Schwaiger et al., 2010), two hazards in eggs on retail level (Galis et al., 2011; Álvarez-Fernández et al., 2012) and two (Schwaiger et al., 2008; Schwaiger et al., 2010) hazards in laying hens. Although most studies had relatively large sample sizes, samples were only taken from a low number of farms. Two studies on farm level had a sample size of 10 conventional and 10 organic farms (Schwaiger et al., 2008; Schwaiger et al., 2010), one study 2 conventional and 1 organic farm (De Reu et al., 2006) and in one the sample size was not mentioned (Messens et al., 2007). The two studies concerning eggs on retail level analysed 64 eggs of each system (Galis et al., 2011) and 40 eggs of each system (Álvarez-Fernández et al., 2012). These rather small sample sizes indicate that the results of these studies can mostly be seen as indicative. Three studies (Messens et al., 2007; Schwaiger et al., 2010; Galis et al., 2011) did not report significance levels and Schwaiger et al. (2008) only provided statements in wording without providing quantitative levels. The two studies, that provided significance levels, reported about four hazards. De Reu et al. (2006) found that total aerobic bacteria was significantly higher ($p<0.001$) in organic and gram-negative bacteria were significantly lower in organic. Álvarez-Fernández et al. (2012) found no statistical difference ($p>0.05$) in aerobic bacteria and psychotrophs between organic and conventional eggs. The studies provided different explanations for the detected differences at farm level or for the lack of it. These include the contact of the eggs with soil, dust or faeces and the outdoor access of hens in organic farming (where they could eat contaminated worms, insects and vegetation), breed and the lower stocking density in organic farming (which could slow the spread from bird to bird). Hygiene levels and cross-contamination during packaging and handling of eggs in the supply chain were mentioned as causes for the lack of differences in the microbiological contamination of eggs on retail level (Schwaiger et al., 2010; Álvarez-Fernández et al., 2012). Given this last concern, it is difficult to use the conclusions from studies focusing only at retail level to deduce conclusions about microbiological contamination levels at farm level.

Conclusions

Many microbiological hazards were addressed in the reviewed studies. However, individual hazards were only addressed by a few studies, and these studies addressed different stages in the supply chain, different geographical locations, different indicators to measure microbiological contamination, different study designs, and different laboratory methods. Although sample sizes were in most cases sufficient for statistical analysis, the number of farms these samples originated from was often very limited. Most studies compared prevalence and/or loads between organic and conventional farms without correcting for potential confounding variables. This complicates whether observed differences can be assigned to the systems. This can also explain the lack of consistency in the results of the studies. A view shared by Wilhelm et al. (2009), who concluded that contradictory findings were reported in bacterial outcomes between organic and conventional dairy production. For beef cattle and laying hens, too few studies were found to draw conclusions about the microbiological contamination levels of conventional and organic production systems.

Given the above considerations, organic products of dairy cattle, pigs and broilers were more often contaminated similarly as conventional products or had a higher contamination level. This is in line with Van Loo et al. (2012), who concluded that meat produced under organic conditions is more often contaminated with foodborne pathogens. Results of studies addressing contamination levels at retail level were found not to be very useful to draw conclusions about farm level contamination, because the results could not be corrected for the management and hygiene circumstances during slaughter and processing. This might be a reason that Smith-Spangler et al. (2012) concluded that bacterial contamination in retail chicken and pork was unrelated to the farming method.

3.2.5.2 Antimicrobial resistance

The studies reviewed for antimicrobial resistance are presented in Table 5.2 in Appendix 5. In total 46 studies were reviewed, of which three concerned more than one animal species.

Dairy cattle

For dairy cattle, 20 studies were available on antimicrobial resistance. Of these, 19 concerned farm level analysis and one was on retail level. Six studies concerned Europe and 15 studies the USA (one study included both the USA and Denmark). Seven studies did not find a difference in single drug resistance between organic and conventional farms. Eleven studies found significantly higher ($p<0.05$) single antimicrobial resistance rates in conventional dairy farms compared to organic farms. The antimicrobials, to which resistance was higher in conventional farming, differed between the studies. For multidrug resistance, five studies did not show a difference in multidrug resistance between organic and conventional dairy farms, whereas three studies showed a higher level of multidrug resistance on conventional dairy farms. The main explanation for the higher levels of antimicrobial resistance in conventional dairy farms is the higher use of antimicrobials. Other explanations mentioned in the studies were the cross resistance due to biocide use and contamination from the environment (nature, humans, wild life, vehicles). On retail level, Miranda et al. (2009b) found significantly higher ($p<0.05$) antimicrobial resistance for some single antimicrobials in *E. coli* (ampicillin, streptomycin) and *S. aureus* (cephalotin, fosfomycin, gentamicin, streptomycin) on conventional cheese, whereas higher antimicrobial resistance for other antimicrobials (*E. coli*: doxycycline; *S. aureus*: ampicillin, doxycycline, sulfisoxazole) was shown in organic cheese. They found no difference in multidrug resistance between organic and conventional cheese. It was unclear if the contamination with antimicrobial resistant bacteria originated from the farm or from the environment or handlers during processing and transport in the supply chain.

Beef cattle

For beef cattle, two studies were available, both on the European and on the retail level (Miranda et al., 2009a; Guarddon et al., 2014). Miranda et al. (2009a) found significantly ($p<0.05$) higher single drug antimicrobial resistance rates in *E. coli* and *S. aureus* in conventional beef compared to organic beef, but no difference in *L. monocytogenes*. The explanation for the higher level in conventional products is the higher use of antimicrobials in conventional farming. A reason mentioned for not observing differences was cross-contamination during rearing or slaughter. Guarddon et al. (2014) did neither find a difference in resistance to tetracycline in mesophilic aerobic bacteria nor in enterobacteriaceae. They argued that this was caused by a higher than expected use of antimicrobials on the organic farms.

Pigs

For pigs, five papers were available. Of these, three concerned the farm level (Garcia-Migura et al., 2005; Hoogenboom et al., 2008; Nulsen et al., 2008), and two the retail level (Miranda et al., 2008b; Guarddon et al., 2014). Four studies concerned Europe and one New Zealand. The study of Nulsen et al. (2008) suggests higher single drug antimicrobial resistance rates on conventional farms compared to organic farms, although they did not provide significance levels. Hoogenboom et al. (2008) stated that conventional pig farming had much higher incidence of antibiotic resistant bacteria, but did not provide further quantitative data. Garcia-Migura et al. (2005) did not find a difference in multidrug resistance between conventional and organic pig farming. The explanation for the higher level in conventional products is the higher use of antimicrobials in conventional farming. Reasons provided for not observing differences were the use of conventional breeding stock with antimicrobial use history in organic farming, insufficient cleaning and disinfection in organic farms that allowed for persistence of antimicrobial resistant bacteria and the environment (feed, wild animals, litter, water). Miranda et al. (2008b) found higher single drug and multidrug antimicrobial resistance rates in conventional pork compared to organic pork. The explanation for the higher level in conventional products is the higher use of antimicrobials in conventional farming. Guarddon et al. (2014) did neither find a difference in resistance to tetracycline in mesophilic aerobic bacteria nor in enterobacteriaceae. They argued that this was caused by a higher than expected use of antimicrobials on the organic farms.

Broilers

For broilers, 20 papers were available. Of these, five concerned the farm level, three the processing level, and twelve the retail level. Eleven studies concerned Europe and nine the USA. The farm-level studies suggest significantly higher single and multidrug antimicrobial resistance rates on conventional farms compared to organic farms. The antimicrobials, to which resistance was higher in conventional farming, differed between the studies. The retail-level studies suggest higher antimicrobial resistance rates in conventional chicken meat compared to organic chicken meat. The explanation for the higher level in conventional products is the higher use of antimicrobials in conventional farming (e.g. Han et al., 2009; Álvarez-Fernández et al., 2013). In the studies that did not find a difference, the authors mentioned several reasons for not observing differences, such as the use of conventional hatcheries/parent stock with antimicrobial use history in organic farming, cross-contamination during rearing or slaughter, and insufficient cleaning and disinfection in organic farms that allowed for persistence of antimicrobial resistant bacteria and the environment (feed, wild animals, litter, water).

Laying hens

For laying hens, three studies were available and concerned Europe and farm level (Schwaiger et al., 2008; Schwaiger et al., 2010; Álvarez-Fernández et al., 2012). The studies suggest significant higher single and multidrug antimicrobial resistance rates on conventional farms compared to organic farms. The explanation for the higher level in conventional products is the higher use of antimicrobials and higher level of animal crowding in conventional farming. Reasons for not observing differences were cross-contamination from other animals and humans, other selectors as heavy metals, and poor sanitation.

Conclusions

Bacteria isolated from animals on conventional farms or its environment, and from conventionally produced products have a higher likelihood of antimicrobial resistance and of multidrug resistance against antimicrobials commonly used to treat animals. This is in line with previous studies. In a review, Van Loo et al. (2012) concluded that the bacteria isolated from conventionally produced livestock or meats may have a higher likelihood of antimicrobial resistance. Smith-Spangler et al. (2012) concluded in their review that the risk of isolating bacteria resistant to 3 or more drugs was higher in conventional products. Wilhelm et al. (2009) in their review concluded that antimicrobial resistance prevalence was lower in organic dairy production.

Multiple papers were available for dairy cows and broilers, whereas few papers were available for pigs, laying hens and beef cattle. For dairy cows and broilers studies were available concerning the USA and Europe. For antimicrobial resistance in pigs, laying hens and beef cattle, only studies concerning Europe and New Zealand (one study) were found, indicating a lack of studies for the USA. Conclusions on pigs, laying hens and beef cattle are only indicative.

3.2.5.3 Chemical hazards

Table 5.3 in Appendix 5 provides an overview of the studies reviewed for the selected chemical hazards. For each hazard a maximum residue level (MRL) has been set in legislation, which is the maximum amount of a residue of a substance legally permitted in or on food. MRLs are set to ensure the lowest possible consumer exposure. In the studies described below, all detected levels of the chemical hazards were below the corresponding MRL. So, even when significant differences were detected between conventional and organic products, even the highest level was below the MRL and products were safe for human consumption.

Dairy cattle

For dairy cattle, nine studies were available, all concerning Europe. Of these, three concerned the farm level, one the processing level and five the retail level. These studies concerned different chemical hazards, three about organochlorine pesticides, two about the mycotoxin ochratoxin A and four about heavy metals. For organochlorine pesticides, Luzardo et al. (2012) found a significantly lower ($p=0.003$) contamination level in organic, and Almeida-González et al. (2012) stated that the contamination level in organic was lower, without providing a quantitative significance level. The provided reason was the previous use of pesticides on conventional farms and not on organic farms. For DDT no difference was detected (Tsakiris et al., 2015). For ochratoxin A, Pattono et al. (2011) found the contamination level in conventional milk to be lower (no p value provided), because the contamination level in the feed of the cows was lower. In organic dairy farms, cows must use organic feed, which is produced without fungicides that control toxin-producing fungi. Skaug (1999) did not find a difference in ochratoxin A levels in milk. The level of heavy metals in organic dairy cattle was significantly lower ($p<0.05$) in organic production in two studies (Olsson et al., 2001; Tomza-Marciniak et al., 2011), and no differences were found in the other two (Gabryszuk et al., 2008; Rey-Crespo et al., 2013). This difference could be due to the amount of grazing, the amount of phosphate (which contains cadmium) fertiliser used, the age of the cows, because heavy metals accumulate in the body, or due to the month in milk production, because a higher milk production is linked to a higher metabolic rate. The available evidence is not very clear which system has a higher risk of chemical hazard contamination, although some evidence was found that organic dairy production resulted in a lower levels of organochlorine pesticides and higher ochratoxin A contamination in milk than conventional dairy production.

Beef cattle

For beef cattle only one study was available concerning slaughter plant level in Europe (Blanco-Penedo et al., 2009a). They did not find consistent differences in heavy metal concentration in liver and kidney between conventional and organic beef cattle.

Pigs

For pigs, two studies were available, both about Europe (Linden et al., 2001; Pozzo et al., 2010). Both concerned farm level and one of them processing level as well. Pozzo et al. (2010) found that the concentration of ochratoxin A was significantly higher ($p<0.05$) in organic pigs due to the higher concentration in the feed. Linden et al. (2001) found that the cadmium concentration in the kidney and manure was higher in organic pigs due to the higher concentration in feed and possibly intake of contaminated soil.

Broilers

For broilers, two papers were available; one concerned the farm level in Europe (Schiavone et al., 2008), and one the retail level in the USA (Nachman et al., 2013). Schiavone et al. (2008) did not find a difference in ochratoxin A concentration in broiler blood and feed. The USA study showed that the level of inorganic arsenic in conventional chicken breasts was significantly higher ($p<0.05$) than in organic, due to the use of the drug arsenic containing roxarsone, that is licenced for use in the USA but not in the EU, and possibly due to arsenic concentration in drinking water (Nachman et al., 2013).

Laying hens

For laying hens, two studies were available. Of these, one concerned farm level in Europe (Schiavone et al., 2008) and one concerned retail level in Europe (Luzardo et al., 2013). The level of ochratoxin A in eggs and in feed did not differ between conventional and organic systems (Schiavone et al., 2008). Luzardo et al. (2013) found significantly lower ($p=0.0007$) levels of PAHs in organic eggs. The last was explained by the lower concentration in the feed. Luzardo et al. (2013) did not find a difference in organochlorine pesticide concentration between conventional and organic eggs. In their review, Pussemier et al. (2006) indicated that both production systems are vulnerable to dioxins or PAH, where animal husbandry located in urbanised and industrialised regions such as Belgium has higher risk. For dioxins in organic eggs they concluded that these might contain more due to the outdoor access resulting in more intense contact with soil.

Conclusions

Only few papers about chemical hazards were available for each animal species. Therefore it was not possible to draw hard conclusions about which system has a higher risk of chemical hazard contamination. For dairy cattle some evidence was found that organic dairy production could result in a lower contamination level of organochlorine pesticides compared to conventional dairy production.

3.2.5.4 Product quality aspects related to public health (essential elements, fatty acids, vitamins, cholesterol)

Table 5.4 in Appendix 5 provides an overview of the studies reviewed for product quality aspects that can influence public health. Only studies for dairy cattle and laying hens were available.

Dairy cattle

For dairy cattle, nine studies were available of which some addressed multiple quality aspects. Seven of these concerned farm-level in Europe, one slaughter plant level in Europe and one retail level in the USA.

Four studies analysed essential elements, such as zinc, copper and selenium (Olsson et al., 2001; Gabryszuk et al., 2008; Adler et al., 2013; Rey-Crespo et al., 2013). Based on 10 conventional and 22 organic farms, Rey-Crespo et al. (2013) found significantly less (no p value mentioned) copper, zinc, and selenium in organic milk compared to conventional milk, because these elements were supplemented to conventional feed and not to organic feed. Olsson et al. (2001) found significantly higher ($p<0.05$) concentration of zinc in kidneys, a significantly lower ($p<0.05$) in their muscle and no difference in the liver and in mammary tissue of 29 organic cows on a research station compared to the 38 conventional cows also present on that research station. Gabryszuk et al. (2008) found that concentration of many essential elements in milk and cow hair did not structurally differ between organic and conventional cows. Based on 14 conventional and 14 organic dairy farms, Adler et al. (2013) found significantly more selenium in organically produced milk, because fish meal was included in the organic concentrates. The data is insufficient to conclude on a difference in essential elements between conventional and organic dairy farming. This is in line with Lairon (2010), who concluded that no difference between the husbandry systems in essential elements could be identified due to the low amount of available data.

Two studies (Popović-Vranješ et al., 2011; Adler et al., 2013) were available on vitamins, and both found no difference between the two systems.

For fatty acids, six studies were available (Bloksma et al., 2008; Butler et al., 2009; O'Donnell et al., 2010; Butler et al., 2011; Popović-Vranješ et al., 2011; Adler et al., 2013). Two studies found higher concentrations of conjugated linoleic acid (CLA) in organic milk compared to conventional milk (Butler et al., 2009; Butler et al., 2011), whereas Bloksma et al. (2008) did not find a difference. The higher concentration in organic milk was explained by a higher amount of grazing and fresh forage in organic farming. However, these results were based on samples from maximal five conventional and maximal five organic farms. Two studies found significantly higher ($p<0.001$) omega-3 fatty acids in organic milk (Bloksma et al., 2008; Adler et al., 2013). This was explained by a higher amount of grazing and fresh forage in organic farming and a higher intake of fish meal. Popović-Vranješ et al. (2011) found more ($p<0.01$) polyunsaturated fatty acids and less ($p<0.05$) monounsaturated fatty acids in organic milk, but no difference in saturated fatty acids and omega-6 fatty acids. They assigned the differences to the differences in amount of grazing and fresh forage. O'Donnell et al. (2010) found more ($p<0.001$) saturated fatty acids, less ($p<0.001$) mono- and polyunsaturated fatty acids, and less ($p<0.001$) trans 18:1 fatty acids in organic milk. They concluded that dietary components and formulations are more important for the fatty acid composition of milk than the management system. The amount of grazing and fresh forage is usually higher in organic than in conventional farming. This seems to result in equal or higher beneficial fatty acid concentrations in organic milk than in conventional milk. The review of Rembiałkowska and Średnicka (2009) also indicated that organic milk has higher content of CLA, n-3 fatty acids and a better n-6/n-3 fatty acids ratio than conventional milk. They indicated outdoor grazing, high biodiversity in pastures, low levels of concentrates, and no silage feeding as factors for the better beneficial fatty acids composition in organic milk compared to conventional milk.

Laying hens
For laying hens, one study (Matt et al., 2009) was available on farm level in Europe. This study analysed vitamins, fatty acids, and cholesterol (not further specified) in eggs. Negligible differences were found between the systems for vitamins and no difference in fatty acids. Cholesterol was lower (p value not provided) in conventional eggs. Provided possible reasons for the observed differences were breed, age of the hens, nutrition and management.

Conclusions
For beef cattle, pigs and broilers no studies and for laying hens one study were found concerning product quality aspects, such as essential elements, fatty acids, vitamins, and cholesterol. For dairy cattle, the studies indicate a better beneficial fatty acid composition in organic milk than in conventional milk, because of a higher amount of grazing and fresh forage in organic compared to conventional dairy farming. For other potentially beneficial compounds in dairy products, too few studies were found to draw conclusions.

3.3 Strong points of each system

The strong points of conventional livestock production systems are provided in Table 2 and of organic livestock production systems in Table 3. Although the strong points are animal species-specific, some general strong points can be identified.

Strong points of conventional livestock systems compared to organic systems are higher animal productivity, more efficient feed conversion ratio, lower feed prices, lower land use and generally lower AP and lower EP per unit of product, lower risk of parasitic infections and a lower or equal level of microbial contamination.
Strong points of organic livestock systems compared to conventional systems are the higher farm gate price and lower building costs per animal, lower AP and EP per unit of land, better leg health, and lower levels of antimicrobial resistance.

Table 2

Strong points of conventional compared to organic livestock production systems.

Strong points conventional livestock systems	Explanation for strong points provided in the reviewed studies
Dairy cattle	
Higher milk yield per cow	Higher energy and protein intake because of shorter pasture season; higher energy and protein intake because of bigger portion of concentrate in ration; more use of animals with bloodlines with a relative high share of high-yielding Holstein Frisian
Lower income risk per cow	More stable milk prices; more stable feed prices; lower production risk (more stable milk yields per cow)
Better availability of animal feed	Globally sourced feed, less own produced feed
More competitive	Larger scale of production
Lower AP and EP per unit of product (50% of the studies)	Higher productivity per animal and per unit of land
Lower enteric methane emissions per unit of product (total GWP similar to organic)	Higher concentrate levels, higher animal productivity
Lower land use per unit product	Higher intensity; higher animal productivity; higher crop yields
Less aggression around feeding	Better roughage quality
Higher or equal udder health	Higher use of antibiotics and thus more treatments and less subclinical mastitis
Lower or equal microbiological contamination	Less outdoor grazing; dry cow therapy; lower contamination level in feed
Beef cattle	
Higher growth rates	Higher forage quality and better pasture conditions; less dependent on local feeds; lower levels of sub-clinical parasitic infections; animals are selected for weight
Lower feed prices per kg feed	-
Lower fixed costs per head	Lower capital expense and insurance costs (lower valued stock, machinery and equipment, less improved pasture)
Lower labour costs per head	-
Lower AP and EP per unit of product	Higher productivity per animal and per unit of land
Lower land use per unit of product	Higher intensity; higher animal productivity; higher crop yields
Pig	
More efficient feed conversion ratio	Diets have more energy content and amino acid profile is better balanced, resulting in lower feed intake levels; no outdoor access, which means pigs are less exposed to low ambient temperatures
Lower costs of production per kg meat	More precision feeding; more accurate climate regulation of stable environment; more advanced breeding
Lower feed costs per kg feed	Better feed efficiency; lower feed prices, due to higher crop yields
Less work per animal	More mechanised and automated systems
Lower GWP, AP and EP and energy use per unit product in some studies	Higher animal productivity (number of piglets per sow); lower feed conversion ratio
Lower land use per unit product	Higher animal productivity; higher crop yields
Less worm infections	No outdoor access
Lower or equal microbiological contamination	No outdoor access; use of antimicrobials; lower contamination level in feed; less pig-pig contact, due to smaller group sizes; less contaminated young and breeding stock
Lower risk of ochratoxin A contamination in feed	Use of fungicides in feed production
Broiler	
More efficient feed conversion ratio	Fast-growing broilers; lower slaughter age results in less nutrients for maintenance; no outdoor access, which could expose broilers to low ambient temperatures; use of synthetic amino acids and additives (enzymes) in feed
Lower feed prices per kg feed	-
Lower feed costs per kg meat	More efficient feed conversion ratio; use of genetically modified feed

Strong points conventional livestock systems	Explanation for strong points provided in the reviewed studies
	ingredients
Lower costs of labour per kg meat	One FTE can manage more broilers (higher stocking density, less regulations, lower slaughter age, more mechanisation)
Lower maintenance cost of outdoor area	-
Lower certification costs per animal	-
Lower costs of health care per animal	Less vaccinations, because no outdoor access
Lower costs for bedding per animal	Less litter per m2
Lower AP and EP per unit product	More efficient feed conversion ratio; shorter production cycle
Lower GWP per unit of product (4 out of 8 studies)	More efficient feed conversion ratio; shorter production cycle
Lower land use per unit product	More efficient feed conversion ratio; shorter production cycle
Lower energy use per unit of product (3 out of 7 studies)	More efficient feed conversion ratio; shorter production cycle
Lower or equal microbiological contamination	No outdoor access; younger slaughter age; less susceptible breed; lower contamination level in feed; lower contamination level at hatchery
Laying hen	
More efficient feed conversion ratio	Less locomotion in cage systems compared to loose housing system
Lower feed costs per animal	Lower feed prices
Lower AP and EP per unit product	More efficient feed conversion ratio; higher crop yield
Lower land use per unit product	More efficient feed conversion ratio; higher crop yield
Less worm infections (cage system)	No outdoor access; less contact with faeces

Table 3

Strong points of organic compared to conventional livestock production systems.

Strong points organic livestock systems	Explanation for strong points provided in the reviewed studies
Dairy cattle	
Higher gross margin per cow	Lower veterinary costs (unclear if only included costs of products or also those of treatment); farm gate price premium
Lower veterinary costs per cow	More stable health situation
Less vulnerable to rising energy prices	Less use of synthetic fertilisers and herbicides
Lower costs of dairy herd replacements	Self-sufficient in replacement stock
Higher employability	More labour intense
Lower AP and EP per land area; lower EP and AP per unit of product in 50% of the studies	No use of synthetic fertiliser; lower fertilisation levels
Lower nitrous oxide emissions (total GWP similar to conventional)	No use of synthetic fertiliser; lower fertilisation levels; use of legumes
Lower carbon dioxide emissions (total GWP similar to conventional)	Lower use of concentrates and processed feed products; no use of synthetic fertilisers and pesticides
Lower energy use per unit of product	No use of synthetic fertiliser; lower use of concentrates and processed feed products
Lower biodiversity loss	No use of synthetic fertiliser; no use of pesticides; lower stocking rate
Better leg health	Better cubicle design; straw supply in lying areas
Higher activity levels	Better cubicle design; straw supply in lying areas
Lower mortality	Lower production level; more stringent biosecurity rules; more grazing
Higher or equal fertility	Lower level of retained placenta; lower level of concentrates
Less infectious diseases (bovine coronavirus, bovine respiratory syncytial virus)	Higher level of biosecurity
Lower levels of antimicrobial resistance	Lower use of antimicrobials; no use of pesticides (co-selection)
Lower levels of (organochlorine) pesticide residues	No use of (organochlorine) pesticides
Similar or better fatty acids composition in milk	More grazing and more fresh grass / vegetation in diet

Strong points organic livestock systems	Explanation for strong points provided in the reviewed studies
Beef cattle	
Lower veterinary costs per head	Less vaccinations and antibiotics (USA)
Lower fertiliser costs per hectare	No use of chemical fertilisers
Lower building costs per head	Housing system also based on outdoor access
Lower GWP per unit of product (higher methane offset by lower nitrous oxide and carbon dioxide emissions)	No use of synthetic fertiliser; lower fertilisation levels; lower use of concentrates and processed feed products
Lower AP and EP per unit of land	No use of synthetic fertiliser; lower fertilisation levels
Lower energy use per unit product	No use of synthetic fertiliser; no use of pesticides; lower use of concentrates and processed feed products
Lower levels of antimicrobial resistance	Lower use of antimicrobials
Pig	
Lower AP and EP per unit of land, and (in some studies) per unit of product	No use of synthetic fertiliser; lower fertilisation levels; use of feed products with low environmental impact; manure management based on solid manure
Better leg health	Outdoor access; lower stocking density
Better ability to cope with (physiological) stress	Outdoor access; lower stocking density
Lower levels of antimicrobial resistance	Lower use of antimicrobials
Broiler	
Lower building and equipment costs per animal	-
Lower AP and EP per unit land	No use of synthetic fertiliser; lower fertilisation levels
Lower energy use per unit product (2 of 7 studies); lower GWP per unit product (4 of 8 studies)	No use of synthetic fertiliser; locally produced feed products
Better leg health	Slow-growing animals; outdoor access; lower stocking density
Better ability to cope with (physiological) stress	Slow-growing animals; outdoor access; lower stocking density
Lower levels of antimicrobial resistance	Lower use of antimicrobials
Laying hen	
Lower building costs per animal	-
Lower AP and EP per unit land	No use of synthetic fertiliser; lower fertilisation levels
Lower levels of antimicrobial resistance	Lower use of antimicrobials

3.4 Lessons learned for sustainable livestock production systems

Based on the identified strong points of both conventional and organic livestock production systems, lessons can be learned that contribute to existing and new (innovative) sustainable livestock production systems.

Farm gate price premiums for system, such as they are paid in the organic market, can be used more broadly through the development of more ‘in-between’ systems, which have an added value for certain consumers which can afford a higher consumer price. Strong points of a livestock production system with such an added value for certain consumers could be used to allow for a farm gate price premium. The farm gate price premium could be balanced against affordability for consumers.

Breeding for and use of high yielding animals could be balanced against animal welfare, environmental performance and veterinary costs. For example, the faster growing broilers used in conventional production have a more efficient feed conversion ratio but also a higher incidence of leg problems compared to the slower growing broilers in organic production. A lower level of leg problems similar to that in organic is observed in broilers with an intermediate growing period (e.g. 56 days), indicating that there may be scope for balancing productivity and welfare. Breeding for robust animals (healthy, productive animals) should not only aim for increasing the output per unit of input but also for reducing welfare problems (e.g. number of involuntarily culled animals) and veterinary costs per animal. For some animal species, such as dairy and beef cattle, productivity of low performing farms can be improved by using higher yielding animals. Within this context, it is also important to recognise the role of livestock grazing on land, which is less suitability to produce human edible protein through e.g. crop production. Even when these animals have lower yields, they value land with low opportunity costs for arable production and, therefore, could play an important role in achieving food security. Increasing production efficiency can reduce the environmental impact of livestock production systems and improve the economic position of farmers per unit of product, the so-called dilution of maintenance (i.e. maintenance feed for the animal's survival as a proportion of total feed use). Benefits of increasing feed production productivity per area of land such as lower land use could be balanced against increased local environmental impact. Best practices and technologies that enhance productivity could help to achieve food security while contributing to environmental and economic sustainability. However, this should be balanced with potential effects of such practices and technologies on other areas of sustainability, for example decreased animal welfare and local environment.

Selection of feed products could be based on a balance between a low environmental impact and well-balanced diet that ensures a high animal productivity and feed efficiency. For example, the use of by-products unsuitable for human consumption can contribute to food security while reducing the environmental impact.

The environmental impact of feed production can also be reduced by balancing in- and outputs of nutrients per area of land, while maintaining or increasing crop yield. The use of synthetic fertiliser and pesticides can be minimised, for example by precision farming, the use of legumes and manure, and application of crop rotation. Growing feed crops in regions were the growth potential is highest due to optimal agro-ecological circumstances might be more favourable than growing feed crops under local but sub-optimal circumstances, because a smaller area of land is needed to produce a certain amount of feed. Benefits of increasing productivity per area of land such as lower land use could be balanced against increased local environmental impact.

Technological application to reduce nutrient losses from manure management (housing, storage and application) or application of manure processing techniques can contribute to reducing waste and improving nutrient cycling and environmental performance of livestock systems.

For animal species that are mostly kept inside in conventional farming, i.e. pigs and chickens, more living space per animal and outdoor access were associated with better leg health. Some evidence was also found for an improved stress resistance or robustness in organic broilers and pigs, caused by the use of different genetics and more living space per animal and outdoor access. However, outdoor access is associated with lower productivity levels and higher risk of microbiological infections and parasites. Especially at low ambient temperatures, animals in an outdoor area require more energy for thermoregulation, lowering productivity. The use of, for example, a covered outdoor area, or a well-structured indoor area, can contribute in diminishing the reduction in productivity without infringing on animal welfare. Other improvements in housing design also offer opportunities to reduce welfare topics, for example improved cubicle design and lying comfort can lead to a strong reduction in hock lesions in dairy cows.

Antibiotics should be used prudently and responsibly. Management, nutrition, health programs, and housing should be designed to ensure healthy animals and minimal use of antibiotics. Sick animals should receive sufficient medication, so animal welfare is not endangered. Implementation of on-farm preventive measures against microbiological hazards could lower the risk of animals getting infected with these hazards.

For dairy cattle, the beneficial fatty acids composition of the milk could be improved by maximising the amount of fresh forage in the ration. This should be balanced against an increased risk of microbiological contamination if the cows have outdoor access longer and against a potentially lower animal productivity.

These lessons learned indicate that for sustainable livestock production systems, indicators in all topics reviewed in this study, i.e. economy, productivity, environment, animal welfare and public health, are of relevance. Sustainability indicators often interact with other sustainability indicators in the same and in other topics, but in opposing directions. The performance on such interacting indicators must be balanced in a sustainable production system. Sustainable livestock production should be approached as a multi-criteria optimisation problem in which a weighted combination of indicators should be optimised, rather than a maximisation problem in which a single indicator is maximised under constraints for other indicators. Maximising the performance of livestock production systems on one indicator could result in suboptimal performance of the system on other indicators.

4 General discussion

This study analysed peer reviewed articles comparing the performance of conventional and organic livestock production systems. In this chapter we discuss a number of issues that should be taken into account when evaluating the results of this study.

Limited number of studies
In total 183 studies were reviewed. All these studies only analysed indicators from one, two or maximum three of the investigated topics economy, productivity, animal welfare, and public health. Per indicator within each topic and per animal species (i.e. dairy cattle, beef cattle, pigs, broilers, or laying hens) only few studies were available. In many studies, the number of farms, processing plants or retail outlets from which analysed samples originated was low. Therefore, for many indicators, insufficient sound evidence was found in the literature to conclude on a quantitative difference between conventional and organic livestock farming.

Publication bias
It is likely that a positive-results bias occurs when authors are more likely to submit, or editors to accept positive compared to negative or inconclusive results. Where publication bias is present, published studies might not be representative of the real world. This bias might distort the results of meta-analyses and systematic review. In the studies reviewed in this study, also studies were identified that described negative or inconclusive results. However, this does not guarantee by itself that no publication bias is present.

Extrapolation to whole population
In the reviewed articles for the topics economy, productivity, animal welfare and public health, the performance on indicators of a sample of conventional farms, processors or retailers was compared to the performance of a sample of organic counterparts. Differences identified in the studies apply to the organisation of organic and conventional sectors during the time of research in the location of research, for example market shares. Care should be taken to extrapolate the identified differences on individual indicators to sector or country level, assuming all production is either conventional or organic.

Interaction between indicators
When extrapolating findings for individual indicator based on a sample out of all farms to sector or country level, the effect extrapolation has on other indicators in the same topic should be considered. Also, the potential effect on indicators in other topics should be considered, for example the effect of the organic price premium on consumer affordability or the effect of productivity on land use. Such interactions must be considered to make a sound extrapolation of the differences identified in this review to sector or country level. Sustainable development of livestock production is a multi-criteria optimisation problem in which a weighted combination of indicators should be optimised, rather than a maximisation problem in which a single indicator is maximised under constraints for the other indicators.

Identified difference on indicators
In this review, several differences between conventional and organic livestock production systems were identified. Explanations for the differences provided in the reviewed studies were also analysed. If the mechanisms underlying the identified differences are sufficiently known, these can provide pathways for development of concrete solutions for sustainable development of both conventional and organic livestock production systems and livestock production in general.

Differences between production practices
In this review, studies that compared conventional to organic livestock production were selected. Although this suggests that all studies refer to the same livestock production systems, farming

practices could differ substantially between the studies, for example due to differences in legislation, standards, climate or habits. A wide variety of livestock production systems has been developed. In this review for the conventional livestock production system, we used the data from production systems the authors of the reviewed studies defined as 'conventional'. Although no clear definition of a 'conventional' system is available, the basic description of the conventional system as provided, was sufficient to verify the correct categorisation as conventional in this review. Nevertheless, differences in farm practices between reviewed studies could exist. Even though relatively clear standards and legislation are available for organic livestock producers, differences between regions and differences in interpretation of standards and legislation can result in differences in farm practices between organic livestock producers. Therefore, care should be taken if extending the results of this study to other livestock producers or to sector level.

Representativeness to the general production practices in North Western Europe
A part of the reviewed studies was conducted in North America and New Zealand. Legislation and standards for livestock production systems in these countries differ from those in Europe. Thus, farm practices could differ from those in Europe. Despite the differences, livestock production systems in these regions do resemble those in Europe. Therefore, we included studies in these regions in this review. However, care should be taken when extrapolating the results from North America and New Zealand to Europe.

Extrapolation to regions outside Europe, North America and New Zealand
The scope of this study is limited to studies performed in Europe, North America and New Zealand. Because livestock production systems in other regions can be substantially different from those in the regions addressed in this study, care should be taken if extending the results of this review to other regions.

Completeness of indicators
In this review, we included the most important topics in livestock production in Europe, North America and New Zealand. Within each selected topic, we selected important indicators for which a comparison between conventional and organic livestock production was available in scientific literature. Of course, more topics and indicators exist next to those selected. Such topics and indicators could be included in a follow-up of this review.

Improving sustainability through knowledge and management
This study focused on identification of directions for sustainable development of livestock production systems. These direction provide guidelines for changes in existing livestock production systems or the design of new livestock production systems. In addition, differences in sustainability performance between individual farmers in existing livestock production systems also provide opportunities to improve sustainability of livestock production. Transfer of knowledge and management of the most sustainable farmers to the other farmers can be an effective method to improve sustainability of livestock production.

5 Conclusions and recommendations

5.1 Conclusions

Both conventional and organic livestock production systems have strong points. From the evaluated literature the following differences between conventional and organic farming were identified. Organic animal production compared to conventional had:

- lower building costs per animal,
- a higher income per animal or full time employee,
- a lower eutrophication and acidification potential per unit of land,
- a lower impact on local biodiversity and fossil phosphorus depletion per unit of product,
- higher activity levels and better leg health,a similar or lower likelihood of antibiotic resistance in bacteria isolated from the farms' environment, animals or animal products,
- and a higher beneficial fatty acid level in cow milk.

Conventional animal production compared to organic had:

- a lower labour need to produce an animal,
- a lower level of income risk per animal,
- a higher output (in kg product) per animal per time unit,
- a better reproductive performanceon,
- a lower feed conversion ratio,
- a lower land use,
- a generally lower acidification and eutrophication potential per unit of product,
- a lower risk of parasitic infections,
- and a similar or lower microbiological contamination in animal products.

These strong points of both conventional and organic livestock production system were used to identify the following lessons for sustainable livestock production systems:

- Best practices and technologies that enhance productivity could help to achieve food security while contributing to environmental sustainability and economic farmer sustainability per unit of product, due to dilution of maintenance. However, potential effects of such practices and technologies on other areas of sustainability, for example on animal welfare and local environment, should not be ignored.
- Selection of feed products could be based on a balance between a low environmental impact and high quality of the feed ration that ensures a high animal productivity and feed efficiency. To enhance future food security, food-feed competition is an important aspect to consider.
- Livestock grazing on marginal land, which is less suitable to produce human edible protein through e.g. crop production, could also play an important role in achieving food security.
- Reducing the environmental impact of feed production can be accomplished by balancing in- and outputs of nutrients per area of land while maintaining or increasing crop yield, and by animal production systems that consume by-products and residues from human food production and bio-energy industries.
- Benefits of increasing feed production productivity per area of land such as lower land use should be balanced against increased local environmental impact.
- Antibiotics should be used prudently, based on a balance of the risk of development of antimicrobial resistance with animal welfare related to treatment of diseases.
- Strong points of a livestock production system with a value for certain consumers could be used to allow for a farm gate price premium, which could be balanced against affordability for consumers.
- The use of high yielding and robust breeds adapted to their environment should be balanced with animal welfare and environmental performance.
- The size of animal living space and size and amount of outdoor access could be balanced between the animal welfare revenues, human pleasure (e.g. of seeing animals outside), lower productivity levels, and higher risk of microbiological infections.

- Technological applications to reduce nutrient losses from manure management or application of manure processing techniques can contribute to reducing waste and improving nutrient cycling and environmental performance of livestock systems.
- Improvements in housing design offer opportunities to reduce welfare issues.

In these lessons sustainability indicators often interacted with other indicators, but in opposing directions. Sustainable livestock production should be approached as a multi-criteria optimisation problem in which a balanced combination of indicators should be optimised.

5.2 Recommendations

For sustainable livestock production, it is recommended:
- to develope a complete picture of sustainable livestock production systems;
- to use the identified strong points of both conventional and organic livestock production systems to improve existing and to develop new livestock production systems;
- to holistically consider all topics reviewed in this study, i.e. economy, productivity, environment, animal welfare and public health, and optimally balance the sustainability indicators within and between these topics;
- and to quantify causal relationships between sustainability indicators accross the sustainability topics in a multicriteria decision-support model, to aid in ex-ante establishing potential solutions for sustainable livestock production systems.

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Appendix 1 Reviewed studies for economy

Table 1.1

Reviewed studies comparing economic performance of organic and conventional livestock farms (significant numbers in bold)

Reference	Country	Sample[1]	Costs				Price Premium (%)	Farm income[2]	Employ-ability (%)	Risk	Explanation of difference
			Unit	Variable (%)	Fixed (%)	Total (%)					
Dairy cattle											
Berentsen et al. (2012)	Netherlands	Panel, 2001/7, 46(O), 302(C)	Cow^{-1}	**-30**[3]			+15	**+11**[a] cow^{-1} **-24**[b] farm^{-1}		+	Costs: more stable health situation. Risk: significant higher variability of milk price, concentrate feed price, milk yields per cow (i.e. more difficult to control milk yield per cow), and gross margin per cow.
Del Prado et al. (2011)	United Kingdom	Model		-				-	+	+/-	Higher risk due to dependency on farm feed. Lower risk due to less dependency on energy inputs.
Jaklič et al. (2014)	Slovenia	Case, 1(O), 1(C)	Ha^{-1}	-72				+35[a] ha^{-1}			Higher market price, lower production costs of grazing-based systems, higher public payments.
Kiefer et al. (2014)	Germany	Model						+66[b] farm^{-1}			n.a.
McBride and Greene (2009)	USA	Panel, 2005, 325(O), 1435(C)	Cwt^{-1}			**+66**	**+44**	**-**[b] cwt^{-1}	**+100**		Less competitive due to smaller scale.
O'Hara and Parsons (2013)	USA	Panel, 2008/10, 33 (O), 129 (C)	Cow^{-1}	-19	-18	-19	+57	+374[b] cow^{-1}	+4[4]		Lower feed expenses due to farm feed. Lower veterinary and interest costs. Higher labour costs.
	Canada	Panel, 2009/11, 32 (O), 379 (C)	Cow^{-1}	-2	+3	-1	+84	+434[b] cow^{-1}	+4[4]		Higher costs of labour. Lower freight and trucking costs.
Pazek and Rozman (2008)	Slovenia	Model					+27	-55[a] farm^{-1}			n.a.
Stonehouse et al. (2001)	Canada	Panel, 92/4, 7(O), 111(C)	Cow^{-1}			-13[5]	0	+10[b] cow^{-1}			Lower material input costs including feed and dairy herd replacements.
Tranter et al. (2007)	United Kingdom	Case, 27 farms					+20	+65[b] ha^{-1}			Highly dependent on price premium.

Reference	Country	Sample[1]	Costs: Unit	Costs: Variable (%)	Costs: Fixed (%)	Costs: Total (%)	Price Premium (%)	Farm income[2]	Employ-ability (%)	Risk	Explanation of difference
		considering conversion									
Beef cattle											
Bjorklund et al. (2014)	USA	Experiment, 16(O), 16(C)	Pen^{-1}			+87	+12	-263[a] pen^{-1}			Lower veterinary costs. Extremely high corn and soybean prices.
Fernández and Woodward (1999)	USA	Experiment, 18(O), 12(C)	Head^{-1}	+52	+13	+					Higher feed and yardage (labour, equipment, bedding) costs.
Gillespie and Nehring (2012)	USA	Panel, 2008, 14(O), 28(C)	Head^{-1}	0	+	+	+	- [b] cow^{-1}			Lower veterinary costs (no antibiotics, less vaccinations). Higher fixed costs due to higher insurance costs, more improved pasture, higher-valued machinery and equipment.
Greer et al. (2008)	New Zealand	Panel, 2002/6, 36(O), 36(C)	Ha^{-1}	-				0 ha^{-1}			Lower veterinary and fertiliser costs. (Potential to expand benefits in case of improved farm management.)
Kumm (2002)	Sweden	Model	Kg^{-1}			-[6]	+		+		Lower building costs.
Salevid and Kumm (2011)	Sweden	Model	100 head^{-1}	+	+		+25[7]	+170[b] 100 head^{-1}			n.a.
Pigs											
Kumm (2002)	Sweden	Model	Kg^{-1}			+	+		+		Lower fertility of sows, lower growth of pigs, higher amounts of feed, lower crop yield, much more work.
Broilers											
Bokkers and De Boer (2009)	Netherlands	Model[8]	Bird^{-1}	+	+	+	+107	+943[b] fte^{-1}	+75		Higher costs of labour, health, feed, bedding. Lower costs of buildings and equipment. Very dependent on market prices and feed costs.
Castellini et al. (2012)	Italy	Case, 2(O), 2(C)	Kg^{-1}	+18	+66	+20		+1200[b] kg^{-1}			Higher feed costs due to lower feed efficiency.

Reference	Country	Sample[1]	Costs				Price Premium (%)	Farm income[2]	Employ-ability (%)	Risk	Explanation of difference
			Unit	Variable (%)	Fixed (%)	Total (%)					
Cobanoglu et al. (2014)	Turkey	Experiment, 400(O), 400(C)	Kg^{-1}	+76	+660	+87	+100	+124[b] $farm^{-1}$	+		Higher costs of feed (mainly due to 50-100% higher prices), labour (slow growing birds, less animals per FTE due to organic regulations, less mechanisation), outdoor maintenance, certification.
Laying hens											
Dekker et al. (2011b)	Netherlands	Model[9]	Hen^{-1}	+65	-		+139	+156[b] fte^{-1}			Much higher egg price, higher feed price, lower # hens per FTE. Lower building costs. Higher land investments.
Leenstra et al. (2014)	Netherlands, Switzerland, France	Model						+23[a] kg^{-1}			n.a.

1 For panel data numbers refer to period covered and # farms. For case studies and experiments, numbers indicate # farms and # animals involved respectively.

2 Reflected as gross margin (a) or whole farm income (b). Cwt: equivalent milk production.

3 Veterinary costs.

4 Direct jobs and indirectly induced jobs in the state.

5 Excluding costs of land.

6 Conventional system is suckler cow based requiring a relatively larger animal stock per kg of meat.

7 Including government aid for organic production.

8 Whole chicken is assumed to be sold as organic.

9 Conventional system is a cage system.

n.a.: not available

Appendix 2 Reviewed studies for productivity

Table 2.1

Reviewed articles comparing productivity aspects in organic and conventional livestock production

Reference	Study country	Sample point	# units / samples: conventional (organic)	Significant effects	Explanation
Dairy cattle					
Adler et al. (2013)	Norway	farm	14 (14) paired farms	Organic farms had lower concentrate intake and tended to have lower milk yield. Milk fat and protein contents were not affected.	
Bennedsgaard et al. (2003)	Denmark	farm	99 (82) paired farms	Milk yield on organic farms was significantly reduced in most of the years included in the study.	
Bennedsgaard et al. (2010)	Denmark	farm	35 (21) neighbouring farms	Milk yield was only numerical but not significant different between both systems.	Organic diets had higher forage proportion, lower crude protein content in forage, and lower levels of concentrate. Interaction with breed. Limited percentage of HF-blood, but more often the use of Jersey breeds in organic flocks.
Berentsen et al. (2012)	Netherlands	farm panel data	302 (46) farms	Milk yield and milk fat content were not significantly different between organic and conventional farms. Organic farms had significant lower milk protein contents.	
Bloksma et al. (2008)	Netherlands	farm	5 (5) neighbouring farms	Differences in productivity were not statistically tested.	
Butler et al. (2009)	Wales	farm	5 (5) farms	Organic farms had significant lower values for milk yield, milk fat and milk protein contents, compared to conventional farms.	Organic diets had higher forage proportion, lower crude protein content in forage, and lower levels of concentrate.
Cho et al. (2006a)	USA (Minnesota)	farm	20 (8) farms	Organic farms had significant lower milk yield, compared to conventional farms.	
Cicconi-Hogan et al. (2013b)	USA (New York, Wisconsin, Oregon)	farm	36 (192) size matched farms	Organic farms had significant lower milk yield, compared to conventional farms.	

Reference	Study country	Sample point	# units / samples: conventional (organic)	Significant effects	Explanation
Fall and Emanuelson (2009)	Sweden	farm	20 (20) farms	Organic farms had significant lower milk yield, compared to conventional farms.	
McBride and Greene (2009)	USA	farm panel data	1435 (325) farms	Organic farms had significant lower milk yield, compared to conventional farms.	
Roesch et al. (2006)	Switzerland	farm	60 (60) size matched neighbouring farms	Organic farms had significant lower values for milk yield, and milk protein contents, compared to conventional farms, whereas milk fat was comparable between both systems.	
van Calker et al. (2007)	Netherlands	farm	Data of 1 (1) experimental farm, representing the Dutch conventional and organic milk sector	Differences in productivity were not statistically tested.	
Beef cattle					
Bjorklund et al. (2014)	USA (Minnesota)	calves	16 (16) calves	Body weight gain of conventional beef cattle was significant higher compared to organic beef cattle.	Poorer forage quality and pasture drought conditions in organic husbandry.
Casey and Holden (2006)	Ireland	farm	5 (5) farms	Differences in productivity were not statistically tested.	The used organic breed is selected for meat quality rather than for daily gain.
Pigs					
Basset-Mens et al. (2006)	France	farm panel data	farm	Differences in productivity were not statistically tested.	
Dourmad et al. (2014)	Denmark, Netherlands, Spain, France, Germany	farm	25 (25) farms	Organic pig reproduction farms weaned significantly lower number of piglets per sow, compared to conventional farms, whereas feed intake per sow was numerically but not significantly higher. Feed conversion ratio of organic growing - finishing pigs was significantly higher compared to conventional pigs.	Longer nursery period in organic systems.
Lindgren et al. (2013)	Sweden	farm	5 (5) neighbouring farms	Organic pig reproduction farms weaned significantly lower number of piglets per sow, compared to conventional farms.	Longer nursery period in organic systems.
Millet et al. (2004)	Belgium	Pig	32 (32) pigs	Conventional pigs had a significant better feed conversion compared to organic pigs.	
van der Werf et al. (2007)	France	farm panel data	farm	Differences in productivity were not statistically tested.	

Reference	Study country	Sample point	# units/samples: conventional (organic)	Significant effects	Explanation
Broilers					
Boggia et al. (2010)	Italy	farm panel data	farm	Differences in productivity were not statistically tested.	
Bokkers and De Boer (2009)	Netherlands	farm panel data	farm	Differences in productivity were not statistically tested.	
Castellini et al. (2012)	Italy	farm	2 (2) farms	Differences in productivity were not statistically tested.	The use of slow-growing strains in organic broiler husbandry is primarily responsible for the difference in productive performance. It is more difficult to meet the nutritional requirements in organic husbandry.
Laying hens					
Dekker et al. (2011a)	Netherlands	farm panel data	farm	Differences in productivity were not statistically tested.	
Englmaierová et al. (2014)		bird	72 (72) birds	Significant reduced levels of egg production and feed conversion in the organic system compared to the system with conventional cages.	
Leenstra et al. (2012)	Switzerland, France, Netherlands	farm	114 (159) farms	Both systems performed similar in Switzerland and France, whereas organic layers in the Netherlands produced significant less eggs compared to conventional layers.	
Leinonen and Kyriazakis (2013)	UK	farm panel data	farm	Differences in productivity were not statistically tested.	

Appendix 3 Reviewed studies for environment

Table 3.1

Reviewed studies comparing environmental between conventional and organic livestock production

Reference	Environmental impact	Study country	Study type	# units/samples: conventional (organic)	Functional unit / system boundary	Value conven-tional	Value organic	Significance
Dairy								
Capper et al. (2008)	GWP[1], AP[1], EP[1], land use	USA	LCA based on national statistics	Average US farm data from national databases (# farms unknown).	kg milk at the farm gate	-	-	Not tested
Cederberg and Mattsson (2000)	GWP, AP, EP, land use, energy use, pesticide use, photo-oxidant formation, depletion of ozone layer	Sweden	LCA based on farm data	1 conventional and 1 organic farm. Farm data within the range of other Swedish farms	ton of energy corrected milk at the farm gate	1	1	Not tested
Del Prado et al. (2011)	GWP, nitrogen and phosphorus losses, biodiversity, soil quality	United Kingdom	Whole farm simulation model	Parameterised to simulate a farm in the Lancashire County (UK)	kg milk at the farm gate	-	-	Not tested
Flysjö et al. (2012)	GWP, land use, land use change	Sweden	LCA based on farm data	9 high yielding conventional farms and 6 organic farms	kg energy corrected milk at the farm gate	9	6	GWP not sign. diff (no p-value); difference of other impacts not statistically measured
Guerci et al. (2013)	GWP, AP, EP, land use, energy use, biodiversity	Denmark	LCA based on farm data	3 conventional and 2 organic farms	kg energy corrected milk at the farm gate	3	2	Not tested
Hörtenhuber et al. (2010)	GWP, land use, land use change	Austria	LCA based on farm data	4 conventional and 4 organic farms from 4 different regions	kg milk at the farm gate	4	4	Not tested
Kiefer et al. (2014)	GWP	Germany	LCA based on farm data	81 dairy farms from southern Germany	kg milk at the farm gate	45	36	GWP higher in organic systems (p=0.014)

Reference	Environmental impact	Study country	Study type	# units/samples: conventional (organic)	Functional unit / system boundary	Value conven-tional	Value organic	Significance
Kristensen et al. (2011)	GWP, land use	Denmark	LCA based on farm data	67 commercial and specialised dairy farms	kg energy corrected milk at the farm gate	35	32	GWP higher in organic systems before allocation ($p<0.05$) but not sign diff after allocation; land use higher in organic systems ($p<0.001$)
Mueller et al. (2014)	Biodiversity	Sweden	LCA based on farm data	15 dairy farms from southern Sweden	litre milk at the farm gate	9	6	Loss of biodiversity lower in organic systems ($p<0.05$)
Refsgaard et al. (2012)	GWP, land use	Norway	LCA based on farm data	341 conventional milk and beef meat systems; 40 conventional milk systems; 23 organic milk and beef meat systems	kg milk at the farm gate	381	23	Not tested
Thomassen et al. (2008)	GWP, AP, EP, land use, energy use	Netherlands	LCA based on farm data	21 commercial dairy farms	kg fat-and-protein-corrected milk at the farm gate	10	11	GWP and AP not sign diff; EP and energy use lower in organic systems ($p<0.001$); land use higher in organic systems ($p<0.001$)
Van der Werf et al. (2009)	GWP, AP, EP, land use, energy use, terrestrial toxicity	France	LCA based on farm data	47 dairy farms from Bretagne, western France	ton fat-and-protein-corrected milk at the farm gate	41	6	No sign diff. except for land use (higher in organic systems; $p<0.01$)
Williams et al. (2006)	GWP, AP, EP, land use, energy use, pesticide use	England and Wales	LCA based on national statistics and year books	Various data sources: yearbooks, Defra statistics, national databases, etc. No number of farms mentioned.	ton milk at the farm gate	?	?	Not tested
Beef								
Casey and Holden (2006)	GWP	Ireland	LCA based on farm data	10 commercial farms	kg live weight at the farm gate	5	5	GWP lower in organic systems ($p<0.05$)
Refsgaard et al. (2012)	GWP, land use	Norway	LCA based on farm data	341 conventional milk and beef meat systems; 33 conventional beef cattle/suckler cow systems; 40 conventional milk systems; 23 organic milk and beef meat systems	kg milk at the farm gate	414	23	Not tested
Williams et al. (2006)	GWP, AP, EP, land use, energy use, pesticide use	England and Wales	LCA based on national statistics and year books	Various data sources: yearbooks, Defra statistics, national databases, etc. No number of farms mentioned.	ton fresh weight at the farm gate	?	?	Not tested

Reference	Environmental impact	Study country	Study type	# units/samples: conventional (organic)	Functional unit / system boundary	Value conven-tional	Value organic	Significance
Pigs								
Basset-Mens and Van der Werf (2005)	GWP, AP, EP, land use, energy use, pesticide use, terrestrial toxicity	France	LCA based on national statistics (conventional) or modelling (organic)	For the conv. farm, data were from national statistics (# farms unknown); for the organic farm, data for technical performance were based on an optimised model.	kg pig live weight at the farm gate ha of land occupied	?	?	GWP, EP, AP not sign diff.; pesticide use sign lower in organic; other impacts sign higher in organic (no p-value)
Dourmad et al. (2014)	GWP, AP, EP, land use, energy use	Denmark Netherlands Spain France Germany	LCA based on farm data	5 to 10 conventional farms from each country; 5 to 10 organic farms from Germany and 5 to 10 from Denmark	kg pig live weight at the farm gate	25-50	10-20	No sign diff. except for land use (higher in organic systems; no p-value)
Van der Werf and Salou (2015)	GWP, EP, land use	France	LCA taken from Agribalyse (French data base)	National database (# farms unknown)	ton pig live weight at the farm gate ha of land occupied	?	?	Not tested
Williams et al. (2006)	GWP, AP, EP, land use, energy use, pesticide use	England and Wales	LCA based on national statistics and year books	Various data sources: yearbooks, Defra statistics, national databases, etc. No number of farms mentioned.	ton fresh weight at the farm gate	?	?	Not tested
Broilers								
Boggia et al. (2010)	GWP, AP, EP, land use, energy use, depletion of ozone layer, eco-toxicity, carcino-gens, respiratory organics, respira-tory inorganics, radiation, mineral use	Italy	LCA based on farm data	1 conventional, 1 organic, and 1 organic plus farm in Central Italy	kg poultry meat at the farm gate	1	2x1	Not tested
Castellini et al. (2012)	GWP, land use, energy use, eco-toxicity	Italy	LCA based on farm data	2 conventional, 2 organic, and 2 organic plus farm central Italy	kg poultry meat at the farm gate	2	2x2	Not tested
Leinonen and Kyriazakis (2013)	GWP, AP, EP, energy use	United Kingdom	Simulation model simulating a standard, organic and free range system	The model was parameterised based on data from the broiler industry (data assumed to be representative for UK)	ton edible carcass weight at the farm gate	-	-	GWP higher in organic compared with standard but no sign diff between organic and free range; AP, EP and energy use higher in organic compared with both standard and free range ($p<0.05$)

Reference	Environmental impact	Study country	Study type	# units/samples: conventional (organic)	Functional unit / system boundary	Value conven-tional	Value organic	Significance
Van der Werf and Salou (2015)	GWP, EP, land use	France	LCA taken from Agribalyse (French data base)	National database (# farms unknown)	ton broiler live weight at the farm gate ha of land occupied	?	?	Not tested
Williams et al. (2006)	GWP, AP, EP, land use, energy use, pesticide use	England and Wales	LCA based on national statistics and year books	Various data sources: yearbooks, Defra statistics, national databases, etc. No number of farms mentioned.	ton fresh weight at the farm gate	?	?	Not tested
Laying hens								
Dekker et al. (2011a)	GWP, AP, land use, energy use, phosphorus use, nitrogen deficit, phosphorus deficit, nitrogen surplus, phosphorus surplus	Netherlands	LCA based on data from national handbooks and expert consultation (barn and free range) or farm data (organic)	# farm of barn and free range system unknown, 20 organic farms	kg eggs at the farm gate	?	20	Not tested
Leinonen and Kyriazakis (2013)	GWP, AP, EP, energy use	United Kingdom	Simulation model of four systems (battery cage excl. in the current report)	The model was parameterised based on data from the egg industry (data assumed to be representative for UK)	ton marketable eggs at the farm gate	-	-	GWP not sign diff; AP, EP and energy use sign higher in organic system compared with barn and compared with free range systems ($p<0.05$)
Moudrý jr. et al. (2014)	GWP	Czech Republic	LCA based on farm data	1 organic and 1 conventional farm (farms assumed to be representative for South Bohemia region)	one egg	1	1	Not tested
Williams et al. (2006)	GWP, AP, EP, land use, energy use, pesticide use	England and Wales	LCA based on national statistics and year books	Various data sources: yearbooks, Defra statistics, national databases, etc. No number of farms mentioned.	ton fresh weight at the farm gate	?	?	Not tested

[1] GWP = Global warming potential, AP = Acidification Potential, EP = Eutrophication Potential

Appendix 4 Reviewed studies for animal welfare

Table 4.1
Reviewed studies comparing welfare indicators between conventional and organic livestock production

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Dairy cows									
Abuelo et al. (2014)	23 metabolites and immunological parameters	Spain	Blood metabolites	1 (2) herds and 22 (40) cows	Concentration	Study gave a large number of p<0.05 differences. Overall, higher prevalence of subclinical ketosis on organic farms and higher levels of Serum amyloid A (an inflammatory agent) on conventional farms			
Abuelo et al. (2015)	4 markers of oxidant production	Spain	Serum	1 (2) herds and 22 (40) cows	Concentration	Study did not give blood values per system, only model estimates.			
Ahlman et al. (2011)	Longevity	Sweden	I&R records	5,335 (402), herds	Days of productive life	1,087	1,154	-	Higher risk of culling on organic farms due to mastitis
Alvasen et al. (2012)	Mortality	Sweden	I&R records	6,898 herds	% mortality	61	55.9	NS	
Bennedsgaard et al. (2003)	Production diseases (Mastitis, retained placenta, ketosis)	Denmark	Milk, treatments	99 (82) herds	Somatic cell count[1] Mastitis treatments per cow per year % calvings with retained placenta treatment % calvings with ketosis treatment	290-360 0.58-0.69 9.1-10.7 1.3-2.4	270-410 0.29-0.63 4-11.5 0.1-1.9		
Bidokhti et al. (2009)	Bovine coronavirus, bovine respiratory syncytial virus	Sweden	Blood ELISA	20 (20); 699 samples from 624 cows	Prevalence: BCV (%) BRSV (%)	 96 91	 78 72	 p<0.05 p<0.05	Less animal trading between organic farms
Brenninkmeyer et al. (2013)	Hock lesions	Germany	Body condition	33 (38) herds, 30 - 50 cows/herd	Prevalence	68	22	p<0.01	Organic better cubicle design and lying comfort
Blanco-Penedo et al. (2014)	Metabolics (Co, Cu, Fe, I, Mn, Mo, Se, Zn)	Sweden	Blood	10 (10) farms, 8 cows per farm, two samples in time	Concentration			NS	

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Blanco-Penedo et al. (2012b)	Metabolics (BHBA, NEFA, insulin, ketosis)	Sweden	Blood	13 (13) farms, 81 samples	Concentration	Significant (P<0.05) lower BHBA and NEFA, not related to ketosis			No reason given, study was aimed at change of feeding legislation on organic farms
Cazer et al. (2013)	*Mycobacterium avium* (for Johne's disease)	USA	Elisa test on Blood	292 farms total ~1/3 organic	Optical density	-	-	NS	Only final model was provided
Cicconi-Hogan et al. (2013a)	Mastitis (Somatic cell count)	USA	Bulk milk tank	100 (192)	Concentration	166,000	195,000	NS	No difference after multivariate modelling
Cicconi-Hogan et al. (2013b)	Mastitis (*S. aureus*)	USA	Bulk milk tank	100 (192)	Positive/negative	42% of tanks	67% of tanks	NS	No difference after multivariate modelling
Fall and Emanuelson (2009)	Mastitis, reproduction	Sweden	Milk production recording	20 (20)	Somatic cell count concentration Percentage success at first insemination,	- -	- -	NS NS	No difference
Fall et al. (2008b)	Diseases (mastitis, ketosis, other)	Sweden	Veterinary treatments	154 (156) cows within 1 split herd 12 years	Treatment	192	198	NS	
Fall et al. (2008a)	Mastitis	Sweden	Milk production recording	156 (154) cows within 1 split herd, 12 years	Somatic cell count Percentage success at first insemination,	- -	- -	NS NS	No difference
Fall et al. (2008a)	Reproduction	Sweden	Calving interval	154 (156) cows within 1 split herd, 12 years	Calving-first insemination interval	75	73	NS	
Fall et al. (2008c)	Metabolic status (NEFA, BHBA, Insulin, glucose, BCS)	Sweden	blood samples	20 (20)	Concentration, level	-	-	NS	No difference
Fossler et al. (2004)	Salmonella	USA (4 states; MI, MN, NY, WI)	Cow faeces	84 (26) farms, 5 visits, 22,417 samples	Prevalence: herd cow	 92.8 4.7	 92.3 4.9	 NS NS	
Fossler et al. (2005a)	Salmonella	USA (4 states, MI, MN, NY, WI)	Cow faeces	97 (32), 5 visits	Prevalence herd	Only regression modelling results were given. No raw or least square estimates were provided. Farm type was NS			

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Fossler et al. (2005b)	Salmonella	USA (4 states, MI, MN, NY, WI)	Calf faeces	97 (32), 5 visits	Prevalence herd	Only regression modelling results were given. No raw or least square estimates were provided. Farm type was NS			
Garmo et al. (2010)	Mastitis (Somatic cell count)	Norway	milk production recording	25 (24)	Concentration Days	- 377	Lower 376	p<0.05 NS	No explanation provided
Hardeng and Edge (2001)	Mastitis, ketosis, milk fever	Norway	Veterinary treatments database	93 (31)	Incidence: mastitis Ketosis Milk fever	 29% 7.8 % 12.3 %	 14% 2.8 % 7.3 %	 p<0.01 p<0.01 p<0.01	Recording bias, while no difference in Somatic cell count. Different types of treatments
Hoglund et al. (2010)	Helminths	Sweden	Bulk milk	105 (105) herds	ODR *O. ostertagi* Incidence *D. vivparus* Incidence *F. hepatica*	0.66 9% 6.7%	0.82 18% 7.6%	p<0.001 NS NS	
Kuhnert et al. (2005)	*E. coli* STEC O157:H7	Switzerland	Cow faeces	60 (60) farms, 500 cows	Herd level STEC O157:H7	100% 17%	100 % 25%	NS NS	
Langford et al. (2009)	Diseases	United Kingdom	Questionnaire (farmer reported)	40 (40) farms, 2 visits per farm	Yearly incidence of: Culling Endometritis Cystic ovaries Retained placenta Lameness Mastitis Ketosis Milk fever Displaced abomasum	 26.3 10.8 6 10.4 31.9 41.6 2.3 14.9 1.8	 19.6 6.1 5 7 36.5 30.1 2.1 7.8 1.1	 p<0.01 p<0.05 NS NS NS NS NS p<0.05 NS	Different feeding regime and milk production level on organic farms. Note: these are farmer reported data and biased with treatment strategy
Langford et al. (2011)	Aggression feeding gate	United Kingdom	Animal behaviour	20 (20) herds	Frequency	30	36	p<0.05	Conventional better roughage quality: less aggression
Langford et al. (2011)	Lying post-feeding	United Kingdom	Animal behaviour	20 (20) herds	Percentage of time spent lying	43	38	p<0.01	Organic better leg health? Correlation lying and lameness
Loef et al. (2007)	Reproduction	Sweden	Breeding data from milk production recording database	2,258 (170)	Calving interval Calving - 1st AI Calving - last AI AI/animal Culling	403 91 122 1	399 88 127 OR=0.8	p=0.04 p<0.05 p<0.01 NS p<0.001	Least square means are provided. No explanation provided

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Mueller and Sauerwein (2010)	Mastitis	Germany	Bulk milk tank	33 (35) farms	Somatic cell count Cow prevalence elevated cow Somatic cell count	205,790 36 %	218,750 44%	NS NS	Farms were equal despite that dry cow therapy was not provided on organic farms
Nauta et al. (2006)	Mastitis	The Netherlands	Milk production recording	966 (404)	Somatic cell scores calving interval Score	- -	+50.000 -	p<0.05 NS	Dry cow therapy, deep litter stalls
Park et al. (2012)	Mastitis	USA	Milk bacteriology	2 farms, before and after transition	Prevalence At parturition At drying off	 47 45	 70 42	 0.006 NS	Paper gives differences in text and table. Cannot be interpreted
Reksen et al. (1999)	Reproduction	Norway	Breeding data	87 (29) farms, 3 years of data	Days open Calving interval	117 374	119 383	NS p<0.01	The energy requirements might be managed less well on organic farms
Roesch et al. (2007)	Mastitis	Switzerland	California mastitis test on quarter samples	60 (60)	Prevalence	12-15%	15-18%	p<0.02	Dry cow management
Roesch et al. (2005)	Metabolic disorders	Switzerland	Blood	60 (60), 1,000 cows	Concentration	No differences in blood parameters glucose, NEFA, BHBA			
Rutherford et al. (2009)	Lameness	United Kingdom	Locomotion scores	40 (40) matched farms (straw or cubicles), 2 or 3 visits,	Prevalence during : Autumn, straw Autumn cubicles Winter straw Winter cubicles Spring straw Spring cubicles	 14.5 19.1 15.3 21 17.8 23.1	 8.3 16 9 16 12.4 18		In final model, significant difference for winter period (LSM: 14.2 organic and 19.9 for conventional farms). No explanation given.
Sato et al. (2005a)	Mastitis, parasitic disease	USA	Bulk milk tank	30 (30) farms	Somatic cell count *O. ostertagi*	285,000 ?	263,000 ?	NS p<0.05	Grazing
Silverlas and Blanco-Penedo (2013)	*Cryptosporidium*	Sweden	Faeces	13 (13) farms, 221 calves and 259 cows	Prevalence: Calves Cows	 52.3 3.8	 44.7 3.1	 NS NS	
Stiglbauer et al. (2013)	Mastitis	USA	Bulk milk tank	100 (192) samples	Somatic cell count Concentration	210,000	221,000	NS	No difference after multivariate modelling

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Sundberg et al. (2009)	Mastitis	Sweden	milk production records over 7 years	6,567 (471) herds	Monthly average somatic cell count, averaged per lactation: Parity 1 Parity 2 Parity 3	 55,093 71,641 93,963	 57,760 76,322 99,959	 NS NS NS	Difference in raw data disappeared after correction for milk production level
Sundberg et al. (2009)	Reproduction	Sweden	Breeding data records of 7 years	6,567 (471) herds	Calving interval: Parity 1 Parity 2 Parity 3	 409 401 397	 415 408 402	 p<0.05 p<0.05 p<0.05	Some other reproduction parameters were also significant. No explanation given
Thatcher et al. (2014)	Mastitis	New Zealand	Bulk milk tank	1 experimental farm, split up in two herds with 51 (46) cows	Average somatic cell count over 5 years	152,000	163,000	p<0.05	In first years, differences were significant, later not. Management on organic farms was adjusted
Thomsen et al. (2006)	Mortality	Denmark	I&R data	6,839 herds of which 5 % organic	Risk of mortality (herd level; LSM)	15.9	0	p<0.001	Study was aimed at mortality, not specifically at organic farming. No explanation given.
Thomsen et al. (2007)	Loser cows	Denmark	Cow observations	40 random herds, 3 visits	Prevalence	No quantitative descriptive results of loser cows in relation to farm system were described. Organic farming had OR of 4.8 compared to conventional farms			No explanation provided
Vaarst and Bennedsgaard (2001)	Mastitis	Denmark	Bulk milk tank	57 (27) samples	Somatic cell count	No averages nor a significance level were provided. Somatic cell count was higher on organic farms			Not given
Vaarst et al. (1998)	Lameness	Denmark	Sole disorders observations	7 (6) farms, cow observations from claw trimmer	Percentage without disorders	59%	41%	NS	

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Valle et al. (2007)	Culling and diseases	Norway	Questionnaire	159 (149)	Somatic cell count (* 1,000)	118	126	NS	Higher activity of organic farmers in health handling
					Calving interval	390	388	NS	Because of the link to treatment, disease results are biased.
					Culling rate	43	37	p<0.05	
					Mastitis treatment	31	17	p<0.05	
					Milk fever treat	5.4	4.8	NS	
					Ketosis treatment	6.3	3.4	p<0.05	
					Retained placenta treatment	2.8	1.8	p<0.05	
Weller and Cooper (1996)	Mastitis, lameness, vulval discharge, retained placenta, milk fever, ketosis	United Kingdom	Farmer recorded	11 farmers, before and after conversion	Prevalence:				No significances are described. Difference in lameness due to high forage diet.
					Mastitis	40.5	45.8	-	
					Lameness	27.9	24.5	-	
					Vulval discharge	8.5	5	-	
					Retained placenta	3.8	3.3	-	
					Milk fever	4.9	4.9	-	
					Ketosis	0.4	0.5	-	
Beef cattle									
Blanco-Penedo et al. (2012c)	Mastitis, reproductive disorders, abortion, podal disorders, milk fever, ketosis	Spain	Farmer reported veterinary treatments	26 (24) farmers, farm visit, interview	Prevalence:				Farmer reported data, so there is a bias in management and reporting.
					Mastitis	0.1%	0,2%	NS	
					Reproductive disorders	0.4%	3.8%	p<0.05	
					Abortion	3.4%	6.6%	NS	
					Podal disorders	0.1%	3.2%	NS	
					Milk fever	0	0.4%	NS	
					Ketosis	0	0.2	NS	
Pigs									
Eijck and Borgsteede (2005)	Coccidia infections	Netherlands	fecal	9 (11) herds, 10 (10) samples	Prevalence	67	91	NS	
Eijck and Borgsteede (2005)	Ascarid infections	Netherlands	fecal	9 (11) herds, 10 (10) samples	Prevalence	11	73	p<0.05	Conventional housing reduces the risk of worm infections
Knage-Rasmussen et al. (2014)	Lameness	Denmark	behaviour	44 (9) herds, 30 samples	Prevalence	24	5	p<0.05	Organic sows less lameness due to outdoor access and space

Reference	Welfare indicator	Study country	Sample type	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Millet et al. (2005a)	Haptoglobin	Belgium	blood	Experiment: 8 (8) groups of 4 pigs	Log concentration	0	-0.6	p<0.05	Organic better ability to cope with stress
Millet et al. (2005a)	Lactate	Belgium	blood	Experiment: 8 (8) groups of 4 pigs	Concentration	7.5	5	p<0.05	Organic better ability to cope with stress
Broilers									
Van Overbeke et al. (2006)	Newcastle Disease	Belgium	blood	11 (9) flocks, 20 (20) samples	Mean antibody titers	5	3	NS	
Van Overbeke et al. (2006)	Infectious Bursitis	Belgium	blood	11 (9) flocks, 20 (20) samples	Mean antibody titers	2800	6500	p<0.001	Timing of vaccination with regard to slaughter age organic
Van Overbeke et al. (2006)	Infectious Bronchitis	Belgium	blood	11 (9) flocks, 20 (20) samples	Mean antibody titers	5000	1000	p<0.01	Poorer respiratory health conventional (no clinical signs)
Tuyttens et al. (2008)	Acute Phase Proteins	Belgium	blood	7 (7) flocks, 10 (10) samples	Concentration	5.45	6.21	p<0.01	Organic better ability to cope with stress
Tuyttens et al. (2008)	Latency to lie	Belgium	behaviour test	7 (7) flocks, 10 (10) samples	Latency time (s)	256	547	p<0.001	Organic better leg health
Tuyttens et al. (2008)	Hock lesions	Belgium	body condition	7 (7) flocks, 10 (10) samples	Condition (scale: 0=very good to 3=very bad)	1.64	0.3	p<0.001	Organic better leg health, more active
Williams et al. (2013)	Hock lesions	United Kingdom	body condition	Experiment: 4 groups of 60 birds	Incidence after challenge	45	22	p<0.05	Organic better ability to cope with stress
Williams et al. (2013)	Footpad lesions	United Kingdom	body condition	Experiment: 4 groups of 60 birds	Incidence after challenge	32	2	p<0.05	Organic better ability to cope with stress
Laying hens									
Jansson et al. (2010)	Worm infections	Sweden	fecal	134 (35) flocks, 26 (26) samples	Prevalence	2	75	p<0.05	Cage housing reduces risk of worm infections

[1] Provided are the minimum and maximum values for conventional and organic farms over the years. E.g. somatic cell count on conventional farms varied from 290.000 to 360.000 cells per cow per year and cell count on organic farms varied from 270.000 to 410.000 cells per cow per year.

Appendix 5 Reviewed studies for public health

Table 5.1

Reviewed studies comparing microbiological hazards in organic and conventional livestock production

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Dairy cattle									
Bennedsgaard et al. (2006)	*Staphylococcus aureus*	Denmark	quarter milk / farm	20 (18) herds, 30 cows per herd	cow prevalence (%)	23	25	p>0.05	not mentioned
Bombyk et al. (2008)	*Staphylococcus*	USA (Minnesota)	composite quarter milk / farm	8 (8) farms, 339 (501) cows	sample prevalence (%)	49	47.7	p>0.05	different profiles of S types, due to pasture, fly bites, dry cow antibiotic treatment
Cho et al. (2006a)	Shiga Toxin-encoding bacteria	USA (Minnesota)	Fecal / farm	20 (8) farms, 1750 (458) samples	herd prevalence (%)	66.7	87.5	p=0.37	Housing type, pasture access, feeding practices, age differences, season, culture methods
Cho et al. (2006a)	Shiga Toxin-encoding bacteria	USA (Minnesota)	fecal / farm	20 (8) farms, 1750 (458) samples	sample prevalence (%)	4	6.6	p=0.06	Housing type, pasture access, feeding practices, age differences, season, culture methods
Cho et al. (2006a)	Shiga Toxigenic *Escherichia Coli*	USA (Minnesota)	fecal / farm	20 (8) farms, 1750 (458) samples	virulence genes prevalence (%)	-	-	p>0.05	Housing type, pasture access, feeding practices, age differences, season, culture methods
Cho et al. (2006b)	*Escherichia Coli* O157	USA (Minnesota)	rectal fecal / farm	18 (8) farms, 271 (166) samples	sample prevalence (%)	3	8.4	p=0.15	org: smaller herds size, tie stalls, lower rolling herd average, less likely affiliated with Dairy Herd Improvement Association; general: region, season, detection method
Coorevits et al. (2008)	spore forming bacteria (*Bacillus*)	Belgium	bulk milk tank / farm	5 (5) farms	sample prevalence (%)	56.3	43.7	p<0.01	seasonal variation, soil ingestion (less in winter or indoor), concentrated feed
Čuboň et al. (2008)	total bacteria count	Slovakia	bulk milk tank / farm	1 (1) farm, 10 (10) samples	1 000 CFU/ml	51	86	p=++	not mentioned
Čuboň et al. (2008)	coliform organisms	Slovakia	bulk milk tank / farm	1 (1) farm, 10 (10) samples	1 000 CFU/ml	269	554	p=+	not mentioned

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Garmo et al. (2010)	*Staphylococcus aureus*	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	3.3	3.4	p>0.05	not mentioned
Garmo et al. (2010)	*Streptococcus dysgalactiae*	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	1.3	1.7	p>0.05	conv: higher motivation to improve udder health and more use of dry cow therapy
Garmo et al. (2010)	*Streptococcus uberis*	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	1.2	0.6	p>0.05	not mentioned
Garmo et al. (2010)	other *Streptococcus*	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	0.2	0.3	p>0.05	not mentioned
Garmo et al. (2010)	*Escherichia Coli*	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	0	0.2	p>0.05	not mentioned
Garmo et al. (2010)	*Enterococcus* spp.	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	1.4	0.5	p>0.05	not mentioned
Garmo et al. (2010)	bacteria negative	Norway	quarter milk of mastitis cows / farm	25 (24) herds, 2092 (1948) samples	sample prevalence (%)	84.5	82.8	p>0.05	not mentioned
Kouřimská et al. (2014)	coliform bacteria count	Czech Republic	bulk milk tank / farm	473 (101) samples	CFU/ml	480	450	p=0.682	farm size, disinfection milking equipment
Kouřimská et al. (2014)	total mesophilic bacteria count	Czech Republic	bulk milk tank / farm	1168 (218) samples	1 000 CFU/ml	19	28	p<0.001	farm size, disinfection milking equipment
Kuhnert et al. (2005)	*Shiga Toxigenic Escherichia Coli*	Switzerland	rectal fecal / farm	60 (60) farms, 485 (481) samples	farm prevalence (%)	100	100	not significant	not mentioned
Kuhnert et al. (2005)	*STEC* O157:H7	Switzerland	rectal fecal / farm	60 (60) farms, 485 (481) samples	farm prevalence (%)	17	25	not significant	not mentioned
Miranda et al. (2009b)	*Escherichia coli*	Spain	pasteurized cheese / supermarket	67 (60) cheeses, 10 (12) samples of same brand	sample prevalence (%)	86.6	71.7	p>0.05	heat treatment and hygiene during manufacture, packaging and handling more important than type of milk for pasteurised cheese

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Miranda et al. (2009b)	*Staphylococcus aureus*	Spain	pasteurized cheese / supermarket	67 (60) cheeses, 10 (12) samples of same brand	sample prevalence (%)	74.6	83.3	p>0.05	heat treatment and hygiene during manufacture, packaging and handling more important than type of milk for pasteurised cheese
Miranda et al. (2009b)	*Salmonella* spp.	Spain	pasteurized cheese / supermarket	67 (60) cheeses, 10 (12) samples of same brand	sample prevalence (%)	97	100	p>0.05	heat treatment and hygiene during manufacture, packaging and handling more important than type of milk for pasteurised cheese
Miranda et al. (2009b)	*Listeria monocytogenes*	Spain	pasteurized cheese / supermarket	67 (60) cheeses, 10 (12) samples of same brand	sample prevalence (%)	98.5	100	p>0.05	heat treatment and hygiene during manufacture, packaging and handling more important than type of milk for pasteurised cheese
Sato et al. (2004a)	*Campylobacter* spp.	USA (Wisconsin)	Fecal / farm	30 (30) neighbouring farms, 2 visits per farm	farm prevalence (%)	29.1	26.7	p=0.5253	general: location, season, transport medium, time before processing, enrichment media, isolation method
Sato et al. (2004b)	*Staphylococcus aureus*	Denmark	bulk milk tank / farm	20 (20) farms, 2 visits per farm	farm prevalence (%)	85	50	not provided	not mentioned
Sato et al. (2004b)	*Staphylococcus aureus*	USA (Wisconsin)	bulk milk tank / farm	30 (30) neighbouring farms, 2 visits per farm	farm prevalence (%)	73	87	not provided	conventional farms somewhat larger
Sato et al. (2005b)	*Escherichia Coli*	USA (Wisconsin)	rectal fecal / farm	30 (30) neighbouring farms, 20 samples per farm	sample prevalence (%)	95.8	92.4	p>0.05	not mentioned
Silverlas and Blanco-Penedo (2013)	*Cryptosporidium* spp.	Sweden	rectal fecal / farm	13 (13) herds, 107 (114) calves	herd prevalence calves (%)	52.3	44.7	p>0.05	weather conditions, attitude towards biosecurity, livestock renewal strategy
Silverlas and Blanco-Penedo (2013)	*Cryptosporidium* spp.	Sweden	rectal fecal / farm	13 (13) herds, 130 (129) calves	herd prevalence cows (%)	3.8	3.1	p>0.05	weather conditions, attitude towards biosecurity, livestock renewal strategy
Tikofsky et al. (2003)	*Staphylococcus aureus*	USA (New York, Vermont)	composite quarter milk / farm	16 (22) herds	sample prevalence (%)	21.86	15.94	p=0.161	not mentioned

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Beef cattle									
Blanco-Penedo et al. (2009b)	liver condemnations	Spain	Liver / slaughter house	3021 (244) calves	calf prevalence (%)	16.8	10.7	p=0.000	org: abscesses: low fraction of concentrate in ration; less crowded pens. Parasites: org: hygiene level, grazing
Blanco-Penedo et al. (2009b)	lung condemnations	Spain	lung / slaughter house	3021 (244) calves	calf prevalence (%)	35.2	23.8	p=0.000	conv: more crowded pens; bad indoor climate
Blanco-Penedo et al. (2009b)	kidney condemnations	Spain	Kidney / slaughter house	3021 (244) calves	calf prevalence (%)	11.2	3.7	p=0.000	not mentioned
Blanco-Penedo et al. (2009b)	digestive tract condemnations	Spain	digestive tract / slaughter house	3021 (244) calves	calf prevalence (%)	8.1	32	p=0.000	org: feeding behaviour, feed supply outdoor
Blanco-Penedo et al. (2009b)	heart condemnations	Spain	heart / slaughter house	3021 (244) calves	calf prevalence (%)	0.5	0.4	p=0.849	not mentioned
Blanco-Penedo et al. (2009b)	leg condemnations	Spain	leg / slaughter house	3021 (244) calves	calf prevalence (%)	0.2	0.8	p=0.039	not mentioned
Guarddon et al. (2014)	Mesophilic aerobic bacteria	Spain	beef steaks / supermarket	18 supermarkets, 2 organic retail stores, 30 (30) steaks	log CFU/g	5	5.9	p<0.05	not mentioned
Guarddon et al. (2014)	Enterobacteriaceae	Spain	beef steaks / supermarket	18 supermarkets, 2 organic retail stores, 30 (30) steaks	log CFU/g	3	3.4	p>0.05	not mentioned
Miranda et al. (2009a)	*Escherichia coli*	? Spain	packaged beef / supermarket	75 (75) packages	sample prevalence (%)	42.7	48	p=0.6227	no difference due to contamination at slaughter houses and processing and via food handlers
Miranda et al. (2009a)	*Staphylococcus aureus*	? Spain	packaged beef / supermarket	75 (75) packages	sample prevalence (%)	54.7	50.7	p=0.7436	no difference due to contamination at slaughter houses and processing and via food handlers
Miranda et al. (2009a)	*Listeria monocytogenes*	? Spain	packaged beef / supermarket	75 (75) packages	sample prevalence (%)	29.3	36	p=0.4862	no difference due to contamination at slaughter houses and processing and via food handlers
Miranda et al. (2009a)	*Salmonella* spp.	? Spain	packaged beef / supermarket	75 (75) packages	sample prevalence (%)	0	0	n.d.	no difference due to contamination at slaughter houses and processing and via food handlers
Pigs									
Bonde and Sørensen (2012)	*Salmonella*	Denmark	fecal / farm	11 (11) herds, 449 (534) animals	pig prevalence (%)	2.4	0.2	p=0.13	org: infection early in life, so no more shedding just before slaughter, more resistance

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Bonde and Sørensen (2012)	*Salmonella*	Denmark	fecal / farm	11 (11) herds, 449 (534) animals	pig prevalence at abattoir (%)	4.2	1.9	p=0.82	org: infection early in life, so no more shedding just before slaughter, more resistance
Bonde and Sørensen (2012)	*Salmonella*	Denmark	meat juice / slaughter house	11 (11) herds, 449 (534) animals	pig prevalence meat juice (%)	4.2	7.1	p=0.88	org: infection early in life, so no more shedding just before slaughter, more resistance
Guarddon et al. (2014)	mesophilic aerobic bacteria	Spain	Steaks / supermarket	18 supermarkets, 2 organic retail stores, 40 (40) steaks	log CFU/g	4.7	5.1	p>0.05	not mentioned
Guarddon et al. (2014)	Enterobacteriaceae	Spain	Steaks / supermarket	18 supermarkets, 2 organic retail stores, 40 (40) steaks	log CFU/g	3	2.8	p>0.05	not mentioned
Hellstrom et al. (2010)	*Listeria monocytogenes*	Finland	rectal swap / farm	10 (5) farms, 21 to 26 pigs per farm	pig prevalence (%)	0	3	p<0.01	org: large group size (more pig-pig contact), access to outdoor, coarse feed (also between farms: treatment manure, hygiene practices, drinking from through)
Hellstrom et al. (2010)	*Listeria monocytogenes*	Finland	intestinal tract / slaughter house	10 (5) farms, 21 to 26 pigs per farm	intestinal tract prevalence (%)	0	3	p<0.01	Org: lack of proper cleaning and disinfection and good operating protocols at slaughter plant; environment in cutting plant
Hellstrom et al. (2010)	*Listeria monocytogenes*	Finland	Tonsil / slaughter house	10 (5) farms, 21 to 26 pigs per farm	tonsil prevalence (%)	12	47	p<0.01	Org: lack of proper cleaning and disinfection and good operating protocols at slaughter plant; environment in cutting plant
Hellstrom et al. (2010)	*Listeria monocytogenes*	Finland	pluck set / slaughter house	10 (5) farms, 21 to 26 pigs per farm	pluck set prevalence (%)	1	13	p<0.01	Org: lack of proper cleaning and disinfection and good operating protocols at slaughter plant; environment in cutting plant
Hellstrom et al. (2010)	*Listeria monocytogenes*	Finland	carcass / slaughter house	10 (5) farms, 21 to 26 pigs per farm	carcass prevalence (%)	0	2	p<0.01	Org: lack of proper cleaning and disinfection and good operating protocols at slaughter plant; environment in cutting plant
Hoogenboom et al. (2008)	*Salmonella*	Netherlands	fecal / farm	national (30) farms, (12 pigs per farm)	pig faeces sample prevalence (%)	0	27	similar to conventional	org: positive farms were recently switched to organic (7 of 8) and the other was a stable with piglets bought elsewhere

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Hoogenboom et al. (2008)	*Campylobacter*	Netherlands	fecal / farm	national (30) farms, (12 pigs per farm)	pig faeces sample prevalence (%)	0	56	similar to conventional	not mentioned
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	rectal swap / farm	10 (5) farms, 21 to 26 pigs/farm	pig prevalence (%)	3	19	p<0.05	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	rectal swap / farm	10 (5) farms, 21 to 26 pigs/farm	sample prevalence (%)	3	19	not mentioned	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	intestinal tract / slaughter house	10 (5) farms, 21 to 26 pigs/farm, 239 (119) swaps	intestinal tract prevalence (%)	5	9	not mentioned	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	tonsil / slaughter house	10 (5) farms, 21 to 26 pigs/farm, 231 (119) swaps	tonsil prevalence (%)	3	24	not mentioned	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	pluck set / slaughter house	10 (5) farms, 21 to 26 pigs/farm, 234 (120) swaps	pluck set prevalence (%)	0.4	4	not mentioned	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Laukkanen et al. (2008)	*Yersinia pseudotuberculosis*	Finland	carcass swap / slaughter house	10 (5) farms, 21 to 26 pigs/farm, 239 (120) swaps	carcass prevalence (%)	0	8	not mentioned	org: more contact with pest and pet animals and outside environment; between-farm: number of pigs, drinking troughs
Miranda et al. (2008b)	*Escherichia coli*	Spain	Loin / supermarket	14 (3) brands, 67 (54) loins	sample prevalence (%)	47.8	64.8	p=0.0231	use of antimicrobial agents in conventional
Miranda et al. (2008b)	*Escherichia coli*	Spain	Loin / supermarket	14 (3) brands, 67 (54) loins	sample prevalence with load >2 log cfu/g (%)	3	16.7	p=0.0231	use of antimicrobial agents in conventional

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Nowak et al. (2006)	*Yersinia enterocolitica*	Germany	rectal swap / farm	6 (3) farms, 210 (200) pigs	pig prevalence (%)	29	18	p=0.014	conv: varying piglet suppliers, commercial feed and transport to slaughterhouse; different slaughterhouses (cross-contamination risk), all slaughtered early in morning (later, more risk due to higher probability intake faeces other animals)
Nowak et al. (2006)	*Yersinia enterocolitica*	Germany	tonsil / slaughter house	6 (3) farms, 210 (200) pigs	tonsil prevalence (%)	22	11	p=0.025	conv: varying piglet suppliers, commercial feed and transport to slaughterhouse; different slaughterhouses (cross-contamination risk), all slaughtered early in morning (later, more risk due to higher probability intake faeces other animals)
Nowak et al. (2006)	*Yersinia enterocolitica*	Germany	Caecum / slaughter house	6 (3) farms, 210 (200) pigs	caecal prevalence (%)	10	5	p=0.243	conv: varying piglet suppliers, commercial feed and transport to slaughterhouse; different slaughterhouses (cross-contamination risk), all slaughtered early in morning (later, more risk due to higher probability intake faeces other animals)
Nowak et al. (2006)	*Yersinia enterocolitica*	Germany	lymph nodes / slaughter house	6 (3) farms, 210 (200) pigs	lymph nodes prevalence (%)	7	2	p=0.049	conv: varying piglet suppliers, commercial feed and transport to slaughterhouse; different slaughterhouses (cross-contamination risk), all slaughtered early in morning (later, more risk due to higher probability intake faeces other animals)
Ranta et al. (2010)	*Listeria monocytogenes*, *Yersinia enterocolitica*, *Yersinia pseudotuberculosis*	Finland	fecal / farm	10 (5) farms, about 25 pigs per farm	sample prevalence (%)	-	-	small conventional less than large conventional and organic	not mentioned
Rutjes et al. (2014)	Hepatitis E virus	Netherlands	Blood / farm	24 (42) farms, 265 (417) pigs	pig seroprevalence (%)	72	89	p=0.04	feed supply, org: more repetitive exposure due to housing conditions e.g. more contact frequency between pigs, more exposure to manure

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Rutjes et al. (2014)	Hepatitis E virus	Netherlands	Blood / farm	24 (42) farms, 265 (417) pigs	farm prevalence (%)	100	98	not provided	feed supply, org: more repetitive exposure due to housing conditions e.g. more contact frequency between pigs, more exposure to manure
Rutjes et al. (2014)	Hepatitis E virus	Netherlands	Blood / farm	24 (42) farms, 265 (417) pigs	per cent farms with pig seroprevalence > 95%	40	60	not provided	feed supply, org: more repetitive exposure due to housing conditions e.g. more contact frequency between pigs, more exposure to manure
Broilers									
Alali et al. (2010)	*Salmonella* spp.	USA (North Carolina)	fecal droppings / farm	4 (3) farms from 1 company, 1 house each farm, 2 flocks per house, 15 samples per flock	fecal sample prevalence (%)	38.8	5.6	p<0.0001	conv: salmonella contaminated feed, different breeder flocks,
Alali et al. (2010)	*Salmonella* spp.	USA (North Carolina)	Feed / farm	4 (3) farms from 1 company, 1 house each farm, 2 flocks per house, 5 samples per flock	feed sample prevalence (%)	27.5	5	p=0.007	conv: salmonella contaminated feed, different breeder flocks,
Alali et al. (2010)	*Salmonella* spp.	USA (North Carolina)	Water / farm	4 (3) farms from 1 company, 1 house each farm, 2 flocks per house, 5 samples per flock	water sample prevalence (%)	0	0	no difference	conv: salmonella contaminated feed, different breeder flocks,
Álvarez-Fernández et al. (2013)	Psychotrophs (indicator for keeping quality)	Spain	Carcass / supermarket	8 retail outlets, 30 (30) carcasses	log CFU/g skin	4.97	5.73	p<0.05	not mentioned
Álvarez-Fernández et al. (2013)	Faecal coliforms	Spain	Carcass / supermarket	8 retail outlets, 30 (30) carcasses	log CFU/g skin	2.95	2.07	p<0.05	not mentioned
Cui et al. (2005)	*Salmonella* spp.	USA (Maryland)	Carcass / supermarket	3 (3) retail stores, 61 (198) carcasses	sample prevalence (%)	44	61	not provided	not mentioned
Cui et al. (2005)	*Campylobacter* spp.	USA (Maryland)	Carcass / supermarket	3 (3) retail stores, 61 (198) carcasses	sample prevalence (%)	74	76	not provided	not mentioned

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Guarddon et al. (2014)	Mesophilic aerobic bacteria	Spain	Thighs / supermarket	18 supermarkets, 2 organic retail stores, 30 (30) thighs	log CFU/g	5.3	4.7	p>0.05	not mentioned
Guarddon et al. (2014)	Enterobacteriaceae	Spain	Thighs / supermarket	18 supermarkets, 2 organic retail stores, 30 (30) thighs	log CFU/g	3.7	2.8	p<0.05	not mentioned
Han et al. (2009)	*Campylobacter* spp.	USA (Louisiana)	Carcass / supermarket	26 (1) retail stores, 141 (53) carcasses	sample prevalence (%)	43.3	43.4	p>0.05	geographical region, chicken producer
Hardy et al. (2013)	Aerobic bacteria	USA (Tennessee)	whole broiler carcass / supermarket	2 (2) brands, 50 (50) carcasses	log cfu/g	-	-	one organic brand highest, other organic brand lowest, 2 conventional brands in between	not mentioned
Hardy et al. (2013)	*Campylobacter* spp.	USA (Tennessee)	whole broiler carcass / supermarket	2 (2) brands, 50 (50) carcasses	log cfu/g	-	-	one organic brand highest, other organic brand lowest, 2 conventional brands in between	org: longer rearing period, so more time to colonise; higher vulnerability of breed; more contact with other animals and birds
Hardy et al. (2013)	*Salmonella* spp.	USA (Tennessee)	whole broiler carcass / supermarket	2 (2) brands, 50 (50) carcasses	sample prevalence (%)	0	5	p>0.05	not mentioned
Hardy et al. (2013)	*Staphylococcus* spp.	USA (Tennessee)	whole broiler carcass / supermarket	2 (2) brands, 50 (50) carcasses	log cfu/g	-	-	one organic brand highest, other organic brand lowest, 2 conventional brands in between	unclear why difference

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Heuer et al. (2001)	*Campylobacter* spp.	Denmark	cloacal swap / farm	18 (12) farms, 79 (22) flocks, 10 boilers per flock	flock prevalence (%)	36.7	100	p<0.001	org: access to soil and water in the open, high age at slaughter (slow growing breed), other breed
Heuer et al. (2001)	*Campylobacter* spp.	Denmark	cloacal swap / farm	18 (12) farms, 79 (22) flocks, 10 boilers per flock	broiler prevalence (%)	60	65	no significant difference	not mentioned
Hoogenboom et al. (2008)	*Campylobacter* spp.	Netherlands	Faeces / farm	national average (9) farms, national average (45) samples	farm prevalence (%)	0	100	conventional much lower	not mentioned
Hoogenboom et al. (2008)	*Campylobacter* spp.	Netherlands	Faeces / farm	national average (9) farms, national average (45) samples	sample prevalence (%)	0	71.1	conventional much lower	not mentioned
Lestari et al. (2009)	*Salmonella* spp.	USA (Louisiana)	Carcass / supermarket	26 (1) retail stores, 141 (53) carcasses	sample prevalence (%)	22	20.8	p>0.05	larger slaughter house less contamination, test methodology, nature of sample, location in supply chain
Luangtongkum et al. (2006)	*Campylobacter* spp.	USA (Ohio)	intestinal tract / slaughter house	8 (5) farms, 345 (355) tracts	farm prevalence (%)	100	100	not provided	not mentioned
Luangtongkum et al. (2006)	*Campylobacter* spp.	USA (Ohio)	intestinal tract / slaughter house	9 (5) farms, 345 (355) tracts	sample prevalence (%)	65.8	89.3	p<0.05	org: 2 to 4 weeks older birds
Luangtongkum et al. (2006)	*Campylobacter jejuni*	USA (Ohio)	intestinal tract / slaughter house	10 (5) farms, 345 (355) tracts	sample prevalence (%)	63.8	64.5	not provided	not mentioned
Luangtongkum et al. (2006)	*Campylobacter coli*	USA (Ohio)	intestinal tract / slaughter house	10 (5) farms, 345 (355) tracts	sample prevalence (%)	2	24.8	not provided	not mentioned
Mazengia et al. (2014)	*Salmonella* spp.	USA (Washington state)	raw chicken packages / supermarket	1094 (228) packages	sample prevalence (%)	10.5	15.4	p=0.0394	sample taking, handling of poultry carcasses during slaughtering
Miranda et al. (2007)	*Enterococcus* spp.	Spain	skin-on drumsticks / supermarket	30 (5) supermarkets, 30 (30) drumsticks	log cfu/g	2.06	3.18	p=0.0002	org: less antibiotic use
Miranda et al. (2008c)	*Escherichia coli*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	sample prevalence (%)	62.3	81.8	p<0.05	not mentioned

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Miranda et al. (2008c)	*Escherichia coli*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	positive sample log cfu/g	1.36	1.82	p=0.0001	not mentioned
Miranda et al. (2008c)	*Staphylococcus aureus*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	sample prevalence (%)	41	49.1	both p<0.05 and p>0.05 mentioned	food handlers maybe more important than contamination from farm
Miranda et al. (2008c)	*Staphylococcus aureus*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	positive sample log cfu/g	0.785	0.942	p=0.6917	food handlers maybe more important than contamination from farm
Miranda et al. (2008c)	*Listeria monocytogenes*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	sample prevalence (%)	57.3	67.3	p>0.05	food handlers maybe more important than contamination from farm
Miranda et al. (2008c)	*Listeria monocytogenes*	Spain	skin-on drumsticks / supermarket	12 (5) supermarkets, 61 (55) drumsticks	positive sample log cfu/g	2.13	2.15	p=0.2756	food handlers maybe more important than contamination from farm
Miranda et al. (2008a)	Enterobacteriaceae	Spain	skin-on drumsticks / supermarket	30 (5) supermarkets, 30 (30) drumsticks	log cfu/g	2.66	3.81	p<0.0001	special characteristics of organic farming
Mollenkopf et al. (2014)	*Salmonella* spp.	USA (Ohio, Michigan, Pennsylvania)	chicken breast / supermarket	27 processing plants, 17 store chains, 99 stores, 95 (40) breasts	sample prevalence (%)	25	18	no differences	origin contamination hatchery, parent stock, management slaughter/processing plant
Mollenkopf et al. (2014)	*Campylobacter* spp.	USA (Ohio, Michigan, Pennsylvania)	chicken breast / supermarket	27 processing plants, 17 store chains, 99 stores, 95 (40) breasts	sample prevalence (%)	13	5	no differences	origin contamination hatchery, parent stock, management slaughter/processing plant
Pieskus et al. (2008)	*Salmonella* spp.	Netherlands	dust, litter, water caecum / farm	18 (108) flocks, 771 (439) samples	flock prevalence (%)	11	3.7	not provided	org: slow growing, so at slaughter shedding below detection
Pieskus et al. (2008)	*Salmonella* spp.	Italy	dust, litter, water caecum / farm	10 (11) flocks, 110 (100) samples	flock prevalence (%)	20	18.1	not provided	not provided
Rosenquist et al. (2013)	*Campylobacter* spp.	Denmark	carcass after chilling / processing	228 (52) flocks, 228 (208) carcasses	carcass prevalence (%)	19.7	54.2	significant	org: earlier exposure through outdoor environment, so less shedding at slaughter

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Rosenquist et al. (2013)	*Campylobacter* spp.	Denmark	carcass after chilling / processing	228 (52) flocks, 228 (208) carcasses	mean concentration on positive carcasses (log(10) cfu/g)	2.1	2	p=0.428	org: earlier exposure through outdoor environment, so less shedding at slaughter
Sapkota et al. (2014)	*Salmonella* spp.	USA (Mid-Atlantic states)	litter, water, feed / farm	5 (5) farms, 2 houses each farm, 3/2/1 litter/water/feed samples per house	poultry house prevalence (%)	30	80	p=0.03	different states, farm management, feed practices and season; org.: relatively high density
Sapkota et al. (2014)	*Salmonella* spp.	USA (Mid-Atlantic states)	litter, water, feed / farm	5 (5) farms, 2 houses each farm, 3/2/1 litter/water/feed samples per house	farm prevalence (%)	40	100	not provided	different states, farm management, feed practices and season; org.: relatively high density
Sapkota et al. (2014)	Enterococcus spp.	USA (Mid-Atlantic states)	litter, water, feed / farm	5 (5) farms, 2 houses each farm, 3/2/1 litter/water/feed samples per house	poultry house prevalence (%)	100	100	no difference	not mentioned
Van Overbeke et al. (2006)	*Salmonella* spp.	Belgium	hatching papers, overshoes / farm	11 (9) farms from 1 integration	flock prevalence (%)	0	0	no significant difference	org: higher: outdoor access, less use antimicrobials; lower: older slaughter, less stress for animals, higher resistance because older at challenge
Van Overbeke et al. (2006)	*Campylobacter* spp.	Belgium	hatching papers, cecal droppings / farm	11 (9) farms from 1 integration	flock prevalence (%)	0	0	no significant difference	org: higher: exposure soil/water in outdoor environment, longer rearing period, more susceptible breed
Van Overbeke et al. (2006)	*Salmonella* spp.	Belgium	gastrointestinal tract / slaughter house	11 (9) farms from 1 integration, 30 (30) broilers	gastrointestinal tract prevalence (%)	0	0	no significant difference	org: higher: outdoor access, less use antimicrobials; lower: older slaughter, less stress for animals, higher resistance because older at challenge
Van Overbeke et al. (2006)	*Campylobacter* spp.	Belgium	gastrointestinal tract / slaughter house	11 (9) farms from 1 integration, 30 (30) broilers	cecum prevalence (%)	28	75	p=0.024	org: higher: exposure soil/water in outdoor environment, longer rearing period, more susceptible breed
Van Overbeke et al. (2006)	*Campylobacter* spp.	Belgium	gastrointestinal tract / slaughter house	11 (9) farms from 1 integration, 30 (30) broilers	duodenum prevalence (%)	18	75	p=0.036	org: higher: exposure soil/water in outdoor environment, longer rearing period, more susceptible breed

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Laying hens (hen)									
Álvarez-Fernández et al. (2012)	aerobic bacteria	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	2.34	2.25	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	Psychotrophs	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	1.54	1.41	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	Enterobacteriaceae	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	0.91	0.9	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	coliforms	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	0.1	0.25	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	*Pseudomonas* spp.	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	1.94	1.49	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	*Enterococcus* spp.	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	0.13	0.27	p>0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	*Staphylococcus* spp.	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	2.14	1.36	p<0.05	farm construction, management, handling in supply chain
Álvarez-Fernández et al. (2012)	Moulds and yeasts	Spain	egg shell / supermarket	10 (10) boxes with 12 eggs, 40 (40) eggs	log cfu/square cm	1.02	1.3	p>0.05	farm construction, management, handling in supply chain
De Reu et al. (2006)	gram-negative bacteria	? Belgium	egg shell / farm	2 (1) farm, 40 (40) eggs	log cfu/egg shell	3.85	3.31	p<0.001	not mentioned
De Reu et al. (2006)	total aerobic bacteria	? Belgium	egg shell / farm	2 (1) farm, 40 (40) eggs	log cfu/egg shell	5.08	5.46	p<0.001	not mentioned
Galis et al. (2011)	total microorganisms on shell	Romania	Eggs / local market	64 (64) eggs	cfu/g	50.9-106	111.4	not provided	org: contact with environment (laying on soil, eating insects/worms/vegetation)
Galis et al. (2011)	total microorganisms in yolk	Romania	Eggs / local market	64 (64) eggs	cfu/g	7.12-15.14	23.83	not provided	org: contact with environment (laying on soil, eating insects/worms/vegetation)
Galis et al. (2011)	total microorganisms in albumen	Romania	Eggs / local market	64 (64) eggs	cfu/g	1.36-31.47	51.76	not provided	org: contact with environment (laying on soil, eating insects/worms/vegetation)

Reference	Hazard	Study country	Sample type / sample point	# units/samples: conventional (organic)	Unit	Value conventional	Value organic	Significance	Explanation observed differences
Galis et al. (2011)	*Salmonella* spp.	Romania	Eggs / local market	64 (64) eggs	sample prevalence (%)	6-19	20-23	not provided	conv: stricter hygiene control compared to other systems
Messens et al. (2007)	*Salmonella enterica*, *Salmonella enteritidis*	? Belgium	commercially available eggs / farm	not mentioned	egg shell penetration	0	0	not traceable to housing system	older hens lower penetration, moulting, feed composition, breed
Schwaiger et al. (2008)	*Salmonella* spp.	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	cloacal swab prevalence (%)	1.8	3.5	not statistically significant	not mentioned
Schwaiger et al. (2008)	*Campylobacter* spp.	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	cloacal swab prevalence (%)	29	34.8	marginally higher	org analysed within 72 hours, conventional in up to 5 days, which could have led to conspicuous decrease in isolation rate
Schwaiger et al. (2008)	*Escherichia coli* spp.	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	cloacal swab prevalence (%)	69	64.4	no relevant difference	not mentioned
Schwaiger et al. (2008)	*Citrobacter*, *Enterobacter*, Pantoea	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	cloacal swab prevalence (%)	0	0	only single cases	not mentioned
Schwaiger et al. (2010)	*Enterococcus* spp.	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	isolate cloacal swab prevalence (%)	1.2025	1.107769 42	not provided	conv: forget to disinfect technical equipment as ventilators, lighting; org: bacteria killed by sun outdoor, lower stocking density slows bird-bird spread
Schwaiger et al. (2010)	*Listeria* spp.	Germany	cloacal swap / farm	10 (10) farms, 400 (399) swaps	isolate cloacal swab prevalence (%)	1.75	1.253132 83	not provided	conv: forget to disinfect technical equipment as ventilators, lighting; org: bacteria killed by sun outdoor, lower stocking density slows bird-bird spread
Schwaiger et al. (2010)	*Enterococcus* spp.	Germany	egg content / farm	10 (10) farms, 40 (40) eggs	isolate egg content prevalence (%)	27.5	20	not provided	direct contact with dust, soil and faeces in house, cross-contamination at packaging
Schwaiger et al. (2010)	*Enterococcus* spp.	Germany	egg shell / farm	10 (10) farms, 40 (40) eggs	isolate eggshell prevalence (%)	60	60	not provided	direct contact with dust, soil and faeces in house, cross-contamination at packaging
Schwaiger et al. (2010)	*Listeria* spp.	Germany	egg content / farm	10 (10) farms, 40 (40) eggs	isolate egg content prevalence (%)	2.5	0	not provided	not mentioned
Schwaiger et al. (2010)	*Listeria* spp.	Germany	egg shell / farm	10 (10) farms, 40 (40) eggs	isolate eggshell prevalence (%)	0	0	not provided	not mentioned

Table 5.2

Reviewed studies comparing antibiotic resistance in organic and conventional livestock production

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Dairy cattle								
Bennedsgaard et al. (2006)	*Staphylococcus aureus*	Penicillin	Denmark	farm	quarter milk	20 (18) farms, 493 (391) cows	no difference between prevalence	not mentioned
Berge et al. (2010)	*Escherichia coli*	Amikacin, amoxicillin-clavulanic acid, ampicillin, cefazolin, ceftiofur, chloramphenicol, gentamicin, nalidixic acid, streptomycin, sulfisoxazole, tetracycline, trimethoprim-sulfamethoxazole	USA (California, Oregon, Washington)	farm	fecal	11 (7) farms, 607 (345) isolates	MDR conventional odds ratio 2.58 (p=0.02)	use of antimicrobials, genetically linked resistance to more antimicrobials
Bombyk et al. (2008)	*Staphylococcus*	Erythromycin, penicillin, pirlimycin, tetracycline	USA (Minnesota)	farm	milk from teat	8 (8) farms, 339 (501) cows	conventional: less susceptible for pirlimycin, tetracycline (p<0.044)	mechanisms behind difference remains unclear (management practices)
Cho et al. (2006b)	*Escherichia coli* O157	Amikacin, amoxicillin-clavulanic acid, ampicillin, cefazolin, cefoxitin, ceftiofur, cephalothin, chloramphenicol, enrofloxacin, gentamicin, imipenem, orbifloxacin, spectinomycin, sulfadimethoxine, tetracycline, ticarcillin, ticarcillin-clavulanic acid, trimethoprim-sulfamethoxazole	USA (Minnesota)	farm	fecal	18 (8) farms, 271 (166) fecal samples	no differences in resistance profiles of isolates	use of antimicrobials
Cho et al. (2007)	Shiga Toxigenic *Escherichia coli*	Amikacin, amoxicillin-clavulanic acid, ampicillin, cefazolin, cefoxitin, ceftiofur, cephalothin, chloramphenicol, enrofloxacin, gentamicin, imipenem, orbifloxacin, spectinomycin, sulfadimethoxine, tetracycline, ticarcillin, ticarcillin-clavulanic acid, trimethoprim-sulfamethoxazole	USA (Minnesota)	farm	rectal fecal, milk filter	20 (8) farms, 29 (23) isolates	conventional (spectomycin) (p<0.05) MDR no difference	unable to compare use of antimicrobials due to too few isolates

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Cicconi-Hogan et al. (2014)	coagulase-negative staphylococci	Methicillin	USA (New York, Wisconsin, Oregon)	farm	bulk milk tank	100 (192) farms, 100 (192) samples	no difference in farm prevalence	use of antimicrobials
Dolejska et al. (2011)	ESBL-producing *Escherichia coli*		Czech Republic	farm	rectal swap, milk filter	1 (1) farms, 309 (154) rectal swaps, 2 (2) milk filters	Conventional: prevalence rectal swaps 39% (<1%) conventional 1 positive milk filter (0)	use of antimicrobials, farm management practices
Garmo et al. (2010)	*Staphylococcus aureus*, coagulase-negative staphylococci	Penicillin	Norway	farm	quarter milk	25 (24) herds, 523 (487) cows	no difference between prevalence	late indoor season higher prevalence
Halbert et al. (2006b)	*Campylobacter* spp.	Azithromycin, chloramphenicol, ciprofloxacin, clindamycin, erythromycin, gentamicin, nalidixic acid, tetracycline	USA (Michigan, Minnesota, New York, Wisconsin)	farm	fecal, bulk milk tank, milk line, water source, feed bunks, housing	total 128 farms, 912 (304) isolates	conventional: more tetracycline resistant isolates ($p<0.01$)	no clear relation between use of antimicrobials and resistance patterns, contact with wildlife
Halbert et al. (2006a)	*Campylobacter* spp.	Amoxicillin-clavulanic acid, ampicillin, azithromycin, ceftiofur, ceftriaxone, cephalothin, chloramphenicol, ciprofloxacin, clindamycin, erythromycin, florfenicol, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfamethoxazole, tetracycline, trimethoprim-sulfamethoxazole	USA (Michigan, Minnesota, New York, Wisconsin)	farm	fecal, bulk milk tank, milk line, water source, feed bunks, housing	total 128 farms, 1570 (460) isolates	conventional: more tetracycline resistant isolates ($p=0.007$)	use of antimicrobials
Johnston (2002)	bacteria	Penicillin g	USA (Minnesota)	farm	fecal	5 (5) farms, 30 (30) samples, 90 (90) isolates	no difference in minimum inhibitory concentration ($p=0.147$)	no difference, because different bacterial isolates and large standard deviation in MIC

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
McKinney et al. (2010)	genes (tet(O), tet(W), sul (I), sul(II))	Tetracycline, sulfonamide	USA (west)	farm	manure lagoon	2 (1) farms, 63 (87) samples	conventional: 4 concentration in water solubles higher ($p<0.0212$), 3 concentrations in settles solids higher ($p<0.0236$), sul(II) no difference	use of antimicrobials
Miranda et al. (2009b)	*Escherichia coli*, *Staphylococcus aureus*	Ampicillin, aztreonam, cephalotin, chloramphenicol, cyprofloxacin, doxycycline, fosfomycin, gentamicin, nitrofurantoin, streptomycin, sulfisoxazole	Spain	retail	Arzua-Ulloa pasteurised milk-cheese	67 (60) samples	conventional: *E. coli*: ampicillin, streptomycin ($p<0.05$); *S. aureus*: cephalotin, fosfomycin, gentamicin, streptomycin ($p<0.05$) organic: *E. coli*: doxycycline ($p<0.05$); *S. aureus*: ampicillin, doxycycline, sulfisoxazole ($p<0.05$) MDR: no difference in resistance patterns	use of antimicrobials, contamination by environment and meat handlers
Ray et al. (2006)	*Salmonella* spp.	Amoxicillin-clavulanic acid, ampicillin, ceftriaxone, ceftiofur, cephalothin, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfamethoxazole, tetracycline, trimethoprim-sulfamethoxazole	USA (Michigan, Minnesota, New York, Wisconsin)	farm	bulk milk tank, fecal, floors, feed bunk, manure storage, bird droppings	69 (26) farms	conventional: at least 1 streptomycin resistant isolate (odds ratio 7.5, $p<0.05$), conventional more isolates resistant to streptomycin (OR 5.4) and sulfamethoxazole (OR 4.2) ($p<0.05$)	use of antimicrobials, previous use before conversion to organic, cross-resistance, biocide use, movement of animals, people, vehicles, wildlife between herds; herd size
Roesch et al. (2006)	*Staphylococcus aureus*, nonaureus staphylococcus spp., *Streptococcus uberis*, *Streptococcus dysgalactiae*	Amoxicillin-clavulanic acid (2:1), ceftiofur, chloramphenicol, clindamycin, enrofloxacin, eryhtromycin, gentamicin, oxacillin, penicillin, quinupristin-dalfopristin, tertracycline, vancomycin	Switzerland	farm	quarter milk	60 (60) farms, 487 (483) cows	no difference between prevalence MDR no difference	no explanation why no difference
Sato et al. (2004a)	*Campylobacter*	Cyprofloxacin, gentamicin, eryhtromycin, tertracylcine	USA (Wisconsin)	farm	fecal	30 (30) farms, 300 (300) samples	No evidence for difference in resistance	no evidence for use of antimicrobials as a reason

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Sato et al. (2004b)	*Staphylococcus aureus*	Bacitracin, cephapirin, chloramphenicol, ciprofloxacin, erythromycin, gentamicin, kanamycin, oxacillin, penicillin, streptomycin, sulphamethoxazole, quinupristin/dalfopristin, tetracycline, trimethoprim, vancomycin	USA (Wisconsin)	farm	bulk milk tank	USA: 30 (30) neighbouring farms, 152 (179) isolates	conventional: higher probability reduced susceptibility ciprofloxacin (OR=3.33, $p<0.05$)	use of antimicrobials, conventional: relatively small farm size, many organic farms in neighbourhood could have changed their philosophy regarding antimicrobials use
Sato et al. (2004b)	*Staphylococcus aureus*	Avilamycin, bacitracin, cephapirin, chloramphenicol, ciprofloxacin, erythromycin, gentamicin, kanamycin, oxacillin, penicillin, streptomycin, sulphamethoxazole, quinupristin/dalfopristin, tetracycline, trimethoprim, vancomycin	Denmark	farm	bulk milk tank	Denmark 20 (20) farms, 77 (75) isolates	organic: higher probability reduced susceptibility avilamycin (OR=0.15, $p<0.05$)	use of antimicrobials
Sato et al. (2005b)	*Escherichia coli*	Ampicillin, amoxicillin-clavulanic acid, cephalotin, cefoxitin, ceftiofur, ceftriaxone, streptomycin, kanamycin, gentamicin, apramycin, amikacin, chloramphenicol, tetracycline, sulfamethoxazole, trimethoprim-sulfamethoxazole, nalidixic acid, cyprofloxacin	USA (Wisconsin)	farm	rectal fecal	30 (30) farms, 595 (596) samples	conventional: ampicillin ($p<0.001$), streptomycin ($p=0.002$), kanamycin ($p<0.001$), gentamicin ($p=0.008$), chloramphenicol ($p=0.003$), tetracycline ($p<0.001$), sulfamethoxazole ($p=0.021$) MDR cows no difference ($p=0.434$) MDR calves conventional ($p<0.001$)	use of antimicrobials, preservation of resistant strains for many years
Tikofsky et al. (2003)	*Staphylococcus aureus*	Ampicillin, cephalothin, erythromycin, novobiocin, oxacillin, penicillin, penicillin-novobiocin, pirlimycin, tetracycline, vancomycin	USA (New York, Vermont)	farm	milk from teat	16 (22) farms, 117 (144) isolates	conventional: lower susceptibility ampicillin ($p=0.0007$), penicillin ($p=0.0106$), tetracycline ($p=0.00003$)	use of antimicrobials (little selection pressure), mechanisms of resistance in pathogens, population of pathogens, susceptibility of a strain

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Walk et al. (2007)	*Escherichia coli*	Ampicillin, amoxicillin-clavulanic acid, cephalothin, cefoxitin, ceftiofur, ceftriaxone, streptomycin, kanamycin, gentamicin, apramycin, amikacin, tetracycline, sulfamethoxazole, trimethoprim-sulfamethoxazole, nalidixic acid, ciprofloxacin	USA (Wisconsin)	farm	fecal	30 (30) matched farms, 300 (300) samples	MDR conventional: higher	use of antimicrobials
Beef cattle								
Guarddon et al. (2014)	mesophillic aerobic bacteria, *Enterobacteriaceae*	Tetracycline	Spain	retail	chicken thighs	30 (30) beef steaks	no difference in total tetracycline-resistant bacteria counts and bacteria harbouring tet(A), tet(B) or tet(A)+tet(B)	use of antimicrobials, higher than expected in organic production
Miranda et al. (2009a)	*Escherichia coli*	Ampicillin, aztreonam, cephalotin, chloramphenicol, doxycycline, ciprofloxacin, fosfomycin, gentamycin, nitrofurantoin, streptomycin, sulfisoxazole	? Spain	retail	pre-packaged beef steaks	75 (75) beef steaks	conventional: ampicillin 44.8% (36.6%) (p=0.0028), doxycycline 28.7% (17.2%) (p=0.0049), gentamycin 2.3% (1.1%) (p=0.0278), sulfisoxazole 62.1% (41.9%) (p=0.034) organic ciprofloxacin 7.5% (1.1%) (p=0.0382)	use of antimicrobials
Miranda et al. (2009a)	*Staphylococcus aureus*	Chloramphenicol, clindamycin, ciprofloxacin, doxycycline, erythromycin, gentamycin, penicillin, oxacillin, nitrofurantoin, rifampin, sulfisoxazole	? Spain	retail	pre-packaged beef steaks	75 (75) beef steaks	conventional: ciprofloxacin 20.8% (10.7%) (p=0.0014), doxycycline 16.7% (4.8%) (p=0.0093) organic: gentamycin 7.1% (0.0%) (p=0.0237)	use of antimicrobials
Miranda et al. (2009a)	*Listeria monocytogenes*	Cephalotin, chloramphenicol, doxycycline, enrofloxacin, erythromycin, gentamycin, rifampin, sulfisoxazole, vancomycin	? Spain	retail	pre-packaged beef steaks	75 (75) beef steaks	no difference	external factors as environment or (meat) handlers in chain

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Pigs								
Garcia-Migura et al. (2005)	vancomycin-resistant *Enterococcus faecium*	Nitrofurantoin, penicillin, tetracycline, erythromycin, ciprofloxacin, gentamicin, streptomycin, kanamycin, quinupristin-dalfospristin, vancomycin, teicoplanin, chloramphenicol, florfenicol, bacitracin, flavomycin, salinomycin	England, Wales	farm	fecal	7 (5) farms	MDR: traits did not appear to be specific to individual farms or sample types	use of antimicrobials, insufficient cleaning and disinfection could have allowed for persistence of VREF, new contaminated stocks, environment (domestic or wild animals, feed, litter, water)
Guarddon et al. (2014)	mesophillic aerobic bacteria, *Enterobacteriaceae*	Tetracycline	Spain	retail	pork steaks	40 (40) samples	no difference in total tetracycline-resistant bacteria counts conventional total count of bacteria harbouring tet(B) 3.2 log CFU/g (2.7) ($p<0.05$)	use of antimicrobials, higher than expected in organic production
Hoogenboom et al. (2008)	*Escherichia Coli, Enterococcus faecium, Campylobacter* spp.	Amoxicillin, cefotaxim, ciprofloxacin, chloramphenicol, gentamicin, neomycin, tertracycline, sulfamethooxazole, trimethoprim, nalidixic acid, florfenicol, linezolid, doxycycline, erythromycin, vancomycin, flavomycin, salinomycin, synercid, streptomycin, metronidazole, trimethoprim-sulfamethoxazole	Netherlands	farm	fecal	national data (31) farms, (155) samples	conventional: much higher incidence of antibiotic resistant bacteria	use of antimicrobials
Miranda et al. (2008b)	*Escherichia coli*	Ampicillin, cephalotin, chloramphenicol, doxycycline, enrofloxacin, gentamicin, nitrofurantoin, streptomycin, sulfisoxazole	Spain	retail	loin meat	67 (54) samples	conventional: ampicillin ($p<0.0001$), oxycycline ($p<0.0001$), sulfisoxazole ($p<0.0001$) MDR conventional: resistance to ≥ two agents higher ($p<0.0001$)	use of antimicrobials

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Nulsen et al. (2008)	*Escherichia coli*	Ampicillin, gentamicin, streptomycin, tetracycline, ciprofl oxacin, cotrimoxazole, neomycin	New Zealand (North Island)	farm	fecal	3 (1) farms	ampicillin conventional 3%, organic 0%; ciprfloxacin conventional 0%, organic 0%; co-trimoxazole conventional 11%, organic 0%; Gentamicin conventional 1%, organic 0%; neomycin conventional 1%, organic 1%; streptomiycin conventional 25%, organic 3%; tetracycline conventional 60%, organic 5%	use of antimicrobials, introduction of breeding stock with antimicrobial use history
Nulsen et al. (2008)	*Enterococcus* spp.	Ampicillin, gentamicin, streptomycin, tetracycline, vancomycin, erythromycin, virginiamycin	New Zealand (North Island)	farm	fecal	3 (1) farms	ampicillin conventional 0%, organic 0%; erythromycin conventional 69%, organic 1%; Gentamicin conventional 0%, organic 0%; streptomiycin conventional 54%, organic 0%; tetracycline conventional 67%, organic 5%; vancomycin conventional 0%, organic 0%; virginiamycin conventional 50%, organic 0%	use of antimicrobials, introduction of breeding stock with antimicrobial use history

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Broilers								
Alali et al. (2010)	*Salmonella*	Ampicillin, amoxicillin/clavulanic acid, amikacin, cefoxitin, ceftriaxone, ceftiofur, cephalothin, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfamethoxazole, tetracycline, trimethoprim/sulfamethoxazole	USA (North Carolina)	farm	fecal, feed, water	4 (3) farms from same company, 240 (180) fecal samples, 80 (60) feed samples, 80 (60) water samples	conventional: Cefoxitin 55.2% of isolates resistant (8.3%) (p=0.004), Ceftiofur 53.5% (8.3%) (p=0.004), Streptomycin 91.4% (58.3%) (p=0.01), Sulfisoxazole 25.0% (1.72%) (p=0.014) organic: tetracycline 33.3% (6.9%) (p=0.025) MDR conventional ≥ two antibiotics 62% (41% organic), single antibiotic 36.2% (33.3%), pan susceptible 1.7% (25%)	use of antimicrobials
Álvarez-Fernández et al. (2013)	*Escherichia coli*	Gentamicin, ampicillin, amoxicillin-clavulanic acid, piperacillin-tazobactam, cefotaxime, sulphamethoxazole-trimethoprim, chloramphenicol, tetracycline, nalidixic acid, ciprofloxacin, fosfomycin, nitrofurantoin	Spain	retail	chicken carcasses	30 (30) carcasses	conventional: resistance prevalence gentamicin 40.0% (org. 0.0%), ampicillin 100% (53.3%), amoxicillin-clavulanic acid 73.3% (20.0%), nalidixic acid 100.0% (40.0%) MDR conventional: average number of resistances per strain 5.20 (2.53) (p<0.05) ciprofloxacin 73.3% (26.7%)	use of antimicrobials, co-selection for resistance, exchange resistance genes between bacteria
Cohen Stuart et al. (2012)	ESBL producing bacteria		Netherlands	retail	chicken breast	12 stores, 60 (38) samples	conventional: prevalence 100% (84% organic) (p<0.001); mean load 80 (20) (p=0.001); Co-resistance rate tetracycline 73% (46%) (p<0.001)	use of antimicrobials, colonised 1-day-old chicks, cross-contamination from conventional to organic during rearing or slaughter, or from environment (soil, surface water)
Cui et al. (2005)	*Campylobacter* spp.	Chloramphnicol, ciprofloxacin, erythrmycin, tertracycline	USA (Maryland)	retail	chicken carcasses	3 (3) stores, 61 (198) carcasses	conventional: ciprofloxacin 20% (5%) (p<0.05)	not mentioned

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Cui et al. (2005)	*Salmonella* spp.	Amikacin, amoxicillin-clavulanic acid, ampicillin, apramycin, ceftiofur, ceftriaxone, cephalothin, chloramphenicol, ciprofloxacin, florfenicol, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfamethoxazole, tetracycline, trimethoprim-sulfamethoxazole	USA (Maryland)	retail	chicken carcasses	3 (3) stores, 61 (198) carcasses	MDR conventional: S. Typhimurium 100% isolates resistant 5-7 antibiotics, organic 79% isolates susceptible to all antibiotics	not mentioned
Garcia-Migura et al. (2005)	vancomycin-resistant *Enterococcus faecium*	Nitrofurantoin, penicillin, tetracycline, erythromycin, ciprofloxacin, gentamicin, streptomycin, kanamycin, quinupristin-dalfospristin, vancomycin, teicoplanin, chloramphenicol, florfenicol, bacitracin, flavomycin, salinomycin	England, Wales	farm	fecal	6 (7) farms	MDR: traits did not appear to be specific to individual farms or sample types	use of antimicrobials, insufficient cleaning and disinfection could have allowed for persistence of VREF, new contaminated stocks, environment (domestic or wild animals, feed, litter, water)
Guarddon et al. (2014)	mesophilic aerobic bacteria, *Enterobacteriaceae*	Tetracycline	Spain	retail	chicken thighs	30 (30) thighs	no difference in total tetracycline-resistant bacteria count conventional: total count of bacteria harbouring tet(B) 2.8 log CFU/g (1.8) $p<0.05$ and tet(A)+tet(B) 3.3 log CFU/g (2.8)	use of antimicrobials
Han et al. (2009)	*Campylobacter* spp.	Ciprofloxacin, erythromycin, gentamicin, tetracycline	USA (Louisiana)	retail	chicken carcasses	26 (1) stores, 141 (53) carcasses	conventional: ciprofloxacin (8.5% (0.0%) ($p<0.05$), erythromycin 23.9% (10.4%) ($p<0.05$)	use of antimicrobial, geographic region, chicken producer, environment
Heuer et al. (2001)	*Campylobacter* spp.	Tetracycline, ampicillin, erythromycin, enrofloxacin, streptomycin	Denmark	processin g	cloacal swap	79 (22) flocks, 790 (220) samples	antibiotic resistance scarce among isolates from all rearing systems	not established
Heuer et al. (2002)	vancomycin-resistant Enterococci	Vancomycin	Denmark	processin g	cloacal swap	24 (12) farms, 140 (22) flocks	conventional: 74.3% flock prevalence (9.1%) ($p<0.0001$)	use of antimicrobials, persistence in environment

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Hoogenboom et al. (2008)	*Escherichia Coli, Enterococcus faecium, Campylobacter* spp.	Amoxicillin, cefotaxim, ciprofloxacin, chloramphenicol, gentamicin, neomycin, tertracycline, sulfamethooxazole, trimethoprim, nalidixic acid, florfenicol, linezolid, doxycycline, erythromycin, vancomycin, flavomycin, salinomycin, synercid, streptomycin, metronidazole, trimethoprim-sulfamethoxazole	Netherlands	farm	fecal	national data (9) farms, (45) samples	conventional: much higher incidence of antibiotic resistant E. coli and E. faecium no difference Campylobacter	absence of selection pressure in organic animals (no use of antimicrobials)
Kola et al. (2012)	ESBL		Germany	retail	chicken breast and leg	9 supermarkets, (4 organic food stores), 1 butcher	no difference	use of antimicrobials, colonised 1-day-old chicks, cross-contamination from conventional to organic during rearing or slaughter, or from environment
Lestari et al. (2009)	*Salmonella* spp.	Amikacin, amoxicillin-clavulanic acid, ampicillin, cefoxitin, ceftiofur, ceftriaxone, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfisoxazole, tetracycline, trimethoprim-sulfamethoxazole	USA (Louisiana)	retail	chicken carcasses	26 (1) stores, 141 (53) carcasses	conventional: amoxicillin-clavulanic acid 19.4% (9.1%) ($p<0.05$), cefoxitin 19.4% (9.1%) ($p<0.05$) organic: streptomycin 66.7% (46.2%) ($p<0.05$), tetracycline 63.6% (41.9%) ($p<0.05$) MDR conventional 48.2% (33.3%) isolates susceptible to all antibiotics	transfer of resistant genes to other serovars
Luangtongkum et al. (2006)	*Campylobacter* spp.	Ampicillin, tetracycline, gentamicin, kanamycin, clindamycin, erythromycin, ciprofloxacin, norfloxacin, nalidixic acid	USA (Ohio)	processin g	intestinal tracts	10 (5) farms, 345 (355) tracts, 167 (165) isolates	conventional: tetracycline, ciprofloxacin, norfloxacin, nalidixic acid ($p<0.05$) organic: erythromycin ($p<0.05$) MDR no difference ($p>0.05$)	use of antimicrobials, transmission of resistant isolates without selection pressure

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Mazengia et al. (2014)	*Salmonella* spp.	Amoxicillin-clavulanic acid, ampicillin, cefoxitin, ceftriaxone, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, nalidixic acid, tetracycline, trimethoprim-sulfamethoxazole	USA (Washington state)	retail	raw chicken packages	total 18 stores, 1094 (228) packages	conventional: significantly higher resistant rates than organic MDR conventional: all isolates resistant to ≥ two antibiotics from conventional	antibiotic treatment of animals
Miranda et al. (2007)	*Enterococcus* spp.	Ampicillin, chloramphenicol, doxycycline, ciprofloxacin, erythromycin, gentamicin, nitrofurantoin, vancomycin	Spain	retail	skin-on drum stick	30 (30) samples	conventional: higher resistance ampicillin ($p=0.0067$), chloramphenicol ($p=0.0154$), doxycycline ($p=0.0277$), ciprofloxacin ($p=0.0024$), erythromycin ($p=0.0028$), vancomycin ($p=0.0241$) MDR conventional 33.3% (11.67%) ($p=0.0021$)	use of antimicrobials
Miranda et al. (2008c)	*Escherichia coli*	Ampicillin, cephalothin, chloramphenicol, doxycycline, ciprofloxacin, fosfomycin, gentamicin, nitrofurantoin, streptomycin, sulfisoxazole	Spain	retail	drum sticks	61 (55) drum sticks	conventional: ampicillin 53.9% (21.9%) ($p<0.0001$), cephalothin 34.8% (4.8%) ($p<0.0001$), ciprofloxacin 27.8% (9.5%) ($p=0.0026$), doxycycline 47.8% (25.7%) ($p<0.0001$), gentamicin 9.6% (1%) ($p<0.0001$), streptomycin 46.1% (23.8%) ($p<0.0001$), sulfisoxazole 36.5% (21.9%) ($p=0.0021$) conventional MDR 76.5% (34.3%) ($p<0.0001$)	use of antimicrobials
Miranda et al. (2008c)	*Staphylococcus aureus*	Chloramphenicol, doxycycline, ciprofloxacin, clindamycin, erythromycin, gentamicin, nitrofurantoin, oxacillin, sulfisoxazole	Spain	retail	drum sticks	61 (55) drum sticks	conventional: Doxycycline 58.4% (34.1%) ($p=0.0001$); organic: Clindamycin 83.5% (67.3%) ($p=0.0239$) MDR no difference ($p=0.0826$)	not mentioned

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Miranda et al. (2008c)	*Listeria monocytogenes*	Chloramphenicol, doxycycline, erythromycin, gentamicin, sulfisoxazole, vancomycin	Spain	retail	drum sticks	61 (55) drum sticks	conventional: doxycycline 18.8% (2.6%) (p=0.0446) MDR no difference (p=0.2409)	not mentioned
Miranda et al. (2008a)	Enterobacteriaceae	Ampicillin, cephalothin, chloramphenicol, doxycycline, ciprofloxacin, gentamicin, nitrofurantoin, sulfisoxazole	Spain	retail	skin-on drum stick	30 (30) samples	conventional: higher resistance ampicillin (p=0.0001), chloramphenicol (p=0.0004), doxycycline (p=0.0013), ciprofloxacin (p=0.0034), gentamicin (p=0.0295) and sulfisoxazole (p=0.0442) MDR conventional 63.3% (organic 41.7%) (p=0.0197)	use of antimicrobials
Mollenkopf et al. (2014)	bla(CMY-2) *Salmonella* spp.		USA (Ohio, Michigan, Pennsylvania)	retail	pre-packaged chicken breasts	total 99 stores, 95 (40) packages	no difference	not mentioned
Mollenkopf et al. (2014)	bla(CMY-2), bla(CTX-M), quinolone-resistant determining regions *E. coli*		USA (Ohio, Michigan, Pennsylvania)	retail	pre-packaged chicken breasts	total 99 stores, 95 (40) packages	conventional: QRDR 18% (0% organic), bla(CMY-2), bla(CTX-M) no difference	not mentioned
Mollenkopf et al. (2014)	*Campylobacter* spp.	Cirpofloxacin, clindamycin, erythromycin, florfenicol, gentamicin, naladixic acid, telithromycin, tertracycline	USA (Ohio, Michigan, Pennsylvania)	retail	pre-packaged chicken breasts	total 99 stores, 95 (40) packages	no difference in proportion with increased resistance	not mentioned
Mollenkopf et al. (2014)	*Salmonella* spp.	Amoxicillin/clavulanic acid, ampicillin, azithromycin, ceftoxitin, ceftiofur, ceftriaxone, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, naladixic acid, streptomycin, sulfisoxazole, tertracycline, trimethoprim-sulfamethoxazole	USA (Ohio, Michigan, Pennsylvania)	retail	pre-packaged chicken breasts	total 99 stores, 95 (40) packages	no difference in proportion with increased resistance	not mentioned

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Mollenkopf et al. (2014)	*Escherichia coli*	Amoxicillin/clavulanic acid, ampicillin, azithromycin, ceftoxitin, ceftiofur, ceftriaxone, chloramphenicol, ciprofloxacin, gentamicin, kanamycin, naladixic acid, streptomycin, sulfisoxazole, tertracycline, trimethoprim-sulfamethoxazole	USA (Ohio, Michigan, Pennsylvania)	retail	pre-packaged chicken breasts	total 99 stores, 95 (40) packages	no difference in proportion with increased resistance	not mentioned
Sapkota et al. (2014)	*Salmonella* Kentucky	Amikacin, amoxicillin-clavulanate, ampicillin, cefoxitin, ceftiofur, ceftriaxone, chloramphenicol, cyprofloxacin, gentamicin, kanamycin, nalidixic acid, streptomycin, sulfisoxazole, tetracycline, sulfamethoxazole	USA (Mid-Atlantic)	farm	litter, water, feed	5 (5) farms, 10 (10) houses, 30 (30) litter samples, 20 (20) water samples, 10 (10) feed samples	conventional isolates: amoxicillin-clavulanate (p=0.049), ampicillin (p=0.042), cefoxitin (p=0.042), ceftiofur (p=0.043), ceftriaxone (p=0.042) MDR conventional 44% (6% organic) (p=0.015)	antibiotic selective pressure, multiple and complex factors in environment (e.g. horizontal gene transfer, changed bacterial physiology)
Sapkota et al. (2011)	*Enterococcus faecalis*	Chloramphenicol, ciprofloxacin, daptomycin, erythromycin, flavomycin, gentamicin, kanamycin, lincomycin, linezolid, nitrofurantoin, penicillin, streptomycin, quinupristin/dalfopristin, tetracycline, tigecycline, tylosin, vancomycin	USA (Mid-Atlantic)	farm	litter, water, feed	5 (5) farms, 10 (10) houses, 30 (30) litter samples, 20 (20) water samples, 10 (10) feed samples, 133 (126) isolates	conventional: Erythromycin (p=0.004), tigecycline (p=0.004) MDR conventional 42% (10%) (p=0.02)	use of antimicrobials, hatcheries/parent stocks use antibiotics, antibiotic-resistant bacteria contaminated feed and water
Sapkota et al. (2011)	*Enterococcus faecium*	Chloramphenicol, ciprofloxacin, daptomycin, erythromycin, flavomycin, gentamicin, kanamycin, lincomycin, linezolid, nitrofurantoin, penicillin, streptomycin, quinupristin/dalfopristin, tetracycline, tigecycline, tylosin, vancomycin	USA (Mid-Atlantic)	farm	litter, water, feed	5 (5) farms, 10 (10) houses, 30 (30) litter samples, 20 (20) water samples, 10 (10) feed samples, 133 (126) isolates	conventional: ciprofloxacin (p=0.01), gentamicin (p=0.047), nitrofurantoin (p=0.02), penicillin (p<0.001), tetracycline (p<0.001) MDR conventional 84% (17%) (p<0.001)	use of antimicrobials, hatcheries/parent stocks use antibiotics, antibiotic-resistant bacteria contaminated feed and water

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Laying hens								
Álvarez-Fernández et al. (2012)	*Escherichia coli*	Gentamicin, ampicillin-sulbactam, amoxicillin-clavulanic acid, piperacillin-tazobactam, cefotaxime, sulfamethoxazole-trimethoprim, chloramphenicol, ciprofloxacin, nalidixic acid, tetracycline, nitrofurantoin, phosphomycin	Spain	retail	eggs shell	different supermarkets, total 50 samples of 12 eggs, 20 (20) isolates	conventional: amoxicillin-clavulanic acid 90% (20%) ($p<0.05$), sulfamethoxazole-trimethoprim 85% (15%) ($p<0.05$), tetracycline 95% (0%) ($p<0.05$) organic: phosphomycin 50% (0%) ($p<0.05$) MDR conventional: resistant ≥ 2 antimicrobials 95% (30%) ($p<0.05$)	use of antimicrobials, animal crowding, poor sanitation
Schwaiger et al. (2008)	*Escherichia coli*	Amoxicillin/clavulanic acid, ampicillin, mezlocillin, oxazillin, piperacillin, cefaclor, cefepime, cefotaxime, cefoxitin, ceftazidime, ceftiofur, cefuroxime, imipenem, meropenem, chloramphenicol, florfenicol, ciprofloxacin, enrofloxacin, amikacin, apramycin, gentamicin, netilmicin, streptomycin, tobramycin, sulphamethoxazole/trimethoprim, doxycycline, colistin	Germany	farm	cloacal swap	10 (10) farms, 276 (257) isolates	conventional: resistant to amoxicillin/clavulanic acid 11.2% (3.5%) ($p<0.05$), ampicillin 21.4% (9.3%) ($p<0.05$), cefaclor 19.6% (4.3%) ($p<0.05$), cefuroxime 2.6% (0.0%) ($p<0.05$), mezlocillin 16.7% (7.8%) ($p<0.05$), neomycin 5.8% (0.4%) ($p<0.05$), piperacillin 15.9% (2.7%) ($p<0.05$) organic: gentamicin 8.6% (1.5%) ($p<0.05$) MDR conventional: more double resistant isolates 10.1 (5.1 organic) ($p<0.05$), less susceptible to all agents 44.9% (60.7% organic) $p<0.05$	use of antimicrobials, long duration of resistant population

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Schwaiger et al. (2008)	*Campylobacter coli*	Amoxicillin/clavulanic acid, ampicillin, mezlocillin, oxazillin, piperacillin+tazobactam, cefuroxime, imipenem, chloramphenicol, florfenicol, ciprofloxacin, enrofloxacin, moxifloxacin, gentamicin, kanamycin, neomycin, streptomycin high level, erythromycin, tylosin, clindamycin, linezolid, sulphamethoxazole/trimethoprim, doxycycline, fosfomycin, nitrofurantoin	Germany	farm	cloacal swap	10 (10) farms, 18 (25) isolates	no difference MDR no statistical analysis due to low power	natural selection of resistant isolates, cross-contamination with other animals and humans, other selectors as heavy metals
Schwaiger et al. (2008)	*Campylobacter jejuni*	Amoxicillin/clavulanic acid, ampicillin, mezlocillin, oxazillin, piperacillin+tazobactam, cefuroxime, imipenem, chloramphenicol, florfenicol, ciprofloxacin, enrofloxacin, moxifloxacin, gentamicin, kanamycin, neomycin, streptomycin high level, erythromycin, tylosin, clindamycin, linezolid, sulphamethoxazole/ trimethoprim, doxycycline, fosfomycin, nitrofurantoin	Germany	farm	cloacal swap	10 (10) farms, 99 (118) isolates	conventional: resistant to amoxicillin/clavulanic acid 14.1% (4.2%) ($p<0.05$), imipenem 19.2% (8.5%) ($p<0.05$) organic: fosfomycin 22.9% (11.1%) ($p<0.05$) MDR no difference	natural selection of resistant isolates, cross-contamination with other animals and humans, other selectors as heavy metals
Schwaiger et al. (2010)	*Listeria* spp.	Amoxicillin/clavulanic acid, ampicillin, mezlocillin, oxazillin, imipenem, chloramphenicol, florfenicol, ciprofloxacin, enrofloxacin, moxifloxacin, teicoplanin, vancomycin, gentamicin high level, kanamycin, neomycin, streptomycin high level, erythromycin, tylosin, clindamycin, linezolid, quinupristin/dalfopristin, doxycycline, fosfomycin, nitrofurantoin, rifampicin	Germany	farm	cloacal swap	10 (10) farms	no difference	not mentioned

Reference	Bacteria investigated	Antibiotic panel	Study country	Sample point	Sample type	# units/ samples: conventional (organic)	Significantly higher ADR or MDR	Explanation observed differences
Schwaiger et al. (2010)	*Enterococcus* spp.	Amoxicillin/clavulanic acid, ampicillin, mezlocillin, oxazillin, imipenem, chloramphenicol, florfenicol, ciprofloxacin, enrofloxacin, moxifloxacin, teicoplanin, vancomycin, gentamicin high level, kanamycin, neomycin, streptomycin high level, erythromycin, tylosin, clindamycin, linezolid, quinupristin/dalfopristin, doxycycline, fosfomycin, nitrofurantoin, rifampicin	Germany	farm	cloacal swap	10 (10) farms, 99 (118) isolates	conventional: resistance rates higher ($p<0.05$)	use of antimicrobials, coexistence of resistance to antimicrobials and heavy metals on same plasmid, resistance transfer within or between species

Table 5.3

Reviewed studies comparing chemical hazards (residues, toxins, heavy metals) in organic and conventional livestock production

Reference	Hazard investigated	Study country	Sample point	Sample type	# units/samples: conventional (organic)	System with lower value (other system value)	Explanation observed differences
Dairy cattle							
Almeida-González et al. (2012)	organochlorine pesticides (OC)	Spain (Canary Islands)	retail	cheese	54 (7) brands	organic: lower levels	conventional: previous use of pesticides (lindane, cyclodienes)
Gabryszuk et al. (2008)	aluminium, lead, arsenic, mercury, cadmium	Poland	farm	milk, hair	2 (2) farms, 30 (20) cows	no consistent difference	amount of grazing (contaminated soil intake, concentration in plants)
Luzardo et al. (2012)	organochlorine pesticides (OC)	Spain (Canary Islands)	retail	milk	16 (10) brands, 96 (60) samples	organic: total OC 14.49 ng/g fat (27.43) (p=0.003)	conventional: previous use of pesticides (lindane, endosulfane)
Olsson et al. (2001)	cadmium	Sweden	slaught er plant	liver, kidney, muscle, mammary tissue	1 research station farm, 38 (29) cows	organic: kidney 330 µg/kg (410) (p<0.05), liver 33 (44) (p<0.05), mammary tissue 0.38 (0.59) (p<0.05) no differences in muscle	organic: no phosphate fertiliser on field resulted in decreased levels of Cd in roughage; age of cow (Cd accumulates in time); month in milk production (higher metabolic activity during milking results in faster Cd uptake)
Pattono et al. (2011)	Ochratoxin A	? Italy	retail	milk	20 (63, of which 15 goat and 9 sheep) samples	conventional: 0.0% positive samples (4.8%) (p value not provided)	organic: higher risk of toxin-producing fungi in feed; lower total energy level in feed results in lower protozoa density, which impairs the degradation of ochratoxin A to less toxic ochratoxin α
Rey-Crespo et al. (2013)	arsenic, mercury, cadmium, lead,	Spain	farm	milk tank	10 (22) farms	no difference	degree of soil ingestion during grazing
Skaug (1999)	Ochratoxin A	Norway	retail	milk	40 (47) samples	no difference	organic: restricted use fungicides increases risk of fungal infection and ochratoxin A in feed stuffs, longer outdoor period decrease risk of inhaling dust and fungal spores; general: direct contamination of milk under poor hygiene conditions
Tomza-Marciniak et al. (2011)	cadmium, lead, arsenic	Poland	farm	blood	21 (20) farms, 21 (20) samples	organic: lead 0.007 µg/ml (0.017) (p=0.0017), arsenic 0.002 µg/ml (0.005) (p=0.0026); no difference in cadmium (p=0.0580)	organic: less exposed

Reference	Hazard investigated	Study country	Sample point	Sample type	# units/samples: conventional (organic)	System with lower value (other system value)	Explanation observed differences
Tsakiris et al. (2015)	DDT	Greece	retail	milk	154 (42) samples	No differences in detected or summed residue (p>0.05) concentrations, with few exceptions	persistence in environment, packaging in plastic showed higher amounts than Tetrapack® bottles, milk processing procedures
Beef cattle							
Blanco-Penedo et al. (2009a)	arsenic, cadmium, mercury, lead	Spain	slaughter plant	liver, kidney	total 9 farms, 120 calves	no consistent difference in concentrations	risk higher at low proportion of concentrate in ration and high levels of grazing (soil ingestion)
Pigs							
Linden et al. (2001)	cadmium	Sweden	farm, slaughter plant	liver, kidney, manure	1 experimental farm, conventional 40 pigs, organic 37/38 (kidney/liver), manure 10 both, soil 10 both	conventional: kidney 84.0 µg/kg wet weight (96.1) (p<0.005), manure 223 µg/kg dry weight (266) (p<0.02) no difference in liver	contaminated soil ingestion, contaminated feed intake (Cadmium concentration in organic feed was lower than in conventional feed), availability in food stuffs
Pozzo et al. (2010)	Ochratoxin A	Italy	farm	feed, blood	11 (4) farms, 22 (8) feed samples, 205 (80) blood samples	conventional: in blood 0.16 ng/ml (1.32) (p<0.001); in feed 0.61 µg/kg (2.68) (p<0.05)	organic: only higher because higher concentration in feed due to higher concentration in feed stuffs
Broilers							
Nachman et al. (2013)	arsenic	USA	retail	chicken breast	69 (37) breasts	organic: inorganic arsenic concentrations 0.6 µg/kg (1.8) (p<0.05), roxarsone detected in 0% of samples (50%) (p<0.05); no difference in total arsenic	use of drug roxarsone, drinking water
Schiavone et al. (2008)	Ochratoxin A	Italy	farm	blood, feed	broiler: 3 (2) farms, 6 (2) feed samples, 30 (13) blood samples	no difference between systems and animal type	organic: higher risk of toxin-producing fungi in feed
Laying hens							
Luzardo et al. (2013)	organochlorine pesticides (OC)	Spain (Canary Islands)	retail	eggs	12 (12) packages with 6 eggs	no difference	organic: outdoor access (eating soil and soil's creatures)
Luzardo et al. (2013)	polycyclic aromatic hydrocarbons (PAH)	Spain (Canary Islands)	retail	eggs	12 (12) packages with 6 eggs	Organic: 31.29 ng/g (65.95) (p=0.0007)	Contamination in feed
Schiavone et al. (2008)	Ochratoxin A	Italy	farm	blood, feed	laying hen: 3 (2) farms, 6 (6) feed samples, 25 (26) blood samples	no difference between systems and animal type	organic: higher risk of toxin-producing fungi in feed

Table 5.4

Reviewed studies comparing product quality aspects related to public health (essential elements, fatty acids, vitamins and cholesterol) in organic and conventional livestock production

Reference	Hazard investigated	Study country	Sample point	Sample type	# units/samples: conventional (organic)	Significantly lower	Explanation observed differences
Dairy cattle							
Adler et al. (2013)	selenium	Norway	farm	bulk milk tank	14 (14) paired farms, 84 (84) samples	conventional: Se concentration ($p=0.009$)	concentration in concentrate feed
Adler et al. (2013)	fat-soluble vitamins (α-Tocophreol, β-Carotene, Retinol)	Norway	farm	bulk milk tank	14 (14) paired farms, 84 (84) samples	no difference ($p>0.081$)	-
Adler et al. (2013)	fatty acids	Norway	farm	bulk milk tank	14 (14) paired farms, 84 (84) samples	conventional: proportion health-beneficial n-3 fatty acids ($p<0.001$), proportion unhealthy total saturated fatty acids ($p=0.001$)	n-3 FA: higher intake fish meal; saturated fatty acids: lower energy status of cows
Bloksma et al. (2008)	omega-3 fatty acids	Netherlands	farm	bulk milk tank	5 (5) neighbouring farms, 10 (10) samples	conventional: 4.9 mg/g fat (10.6) ($p<0.001$)	organic: more grass and red clover silage, hay and less concentrate and maize silage
Bloksma et al. (2008)	CLA	Netherlands	farm	bulk milk tank	5 (5) neighbouring farms, 10 (10) samples	no difference	organic: more grass and red clover silage, hay and less concentrate and maize silage
Butler et al. (2011)	CLA, alpha linoleic acid, alpha tocopherol, carotenoids	Italy, Sweden, Denmark, UK	farm	milk	conventional ≤3 farms, organic ≤2 farms per country	conventional: up to 2.5 fold lower	amount of fresh forage, breed
Butler et al. (2009)	CLA	Wales	farm	bulk milk tank	5 (5) farms, 16 (20) samples	conventional: total CLA 7.46 mg/g fat (13.33) ($p<0.001$) +seven isomers lower than organic ($p<0.01$)	fresh forage intake
Gabryszuk et al. (2008)	Essential elements Ca, K, Mg, Na, P, S, B, Ba, Co, Cr, Cu, Fe, Ge, I, Li, Mn, Mo, Ni, Se, Si, Sn, Sr, V, Zn	Poland	farm	milk, hair	2 (2) farms, 30 (20) cows	highest concentrations I, Mn, Sr, V, Zn in milk on conventional intensively producing farm, those of Li, Si, Sn, Ba, Ge on both organic farms. Highest concentrations B, Ba, Co, Fe, Ge, Li in cow hair on organic farm, those of Cr, I, Mo, Se, So, Sr, V, Zn on conventional farm with extensive production.	amount of grazing (control of uptake of sufficient mineral elements)

Reference	Hazard investigated	Study country	Sample point	Sample type	# units/samples: conventional (organic)	Significantly lower	Explanation observed differences
O'Donnell et al. (2010)	fatty acids	USA (48 states)	retail	milk	111 (99) samples, rbST-free 82	differences minor, not of physiological importance conventional: saturated fatty acids 62.8% (65.9%) ($p<0.001$), CLA 0.57% (0.70%) ($p<0.001$); organic: monounsaturated fatty acids 26.8% (29.7%) ($p<0.001$), polyunsaturated fatty acids 4.3% (4.8%) ($p<0.001$), trans 18:1 fatty acids 2.8% (3.1%) ($p<0.001$)	dietary components and formulations, rather than management practices
Olsson et al. (2001)	zinc	Sweden	slaughter plant	liver, kidney, muscle, mammary tissue	1 research station farm, 38 (29) cows	organic: kidney 19 mg/kg (20) ($p<0.05$) conventional: muscle 57 (67) ($p<0.05$) no difference liver, mammary tissue	production related
Popović-Vranješ et al. (2011)	vitamins A, C and α-tocopherol	Serbia	farm	milk	60 (30) samples	no difference	amount of grazing and fresh grass
Popović-Vranješ et al. (2011)	fatty acids	Serbia	farm	milk	60 (30) samples	conventional: polyunsaturated fatty acids 3.13% (3.57% ($p<0.01$), omega-3 fatty acids 0.53% (0.91%) ($p<0.01$); organic: monounsaturated fatty acids 29.25% (30.76%) ($p<0.05$); saturated fatty acids, omega-6 fatty acids no difference	amount of grazing and fresh grass
Rey-Crespo et al. (2013)	Essential elements Co, Cr, Cu, Fe, I, Mn, Mo, Ni, Se, Zn	Spain	farm	milk tank	10 (22) farms	organic: Cu 41.0 µg/l (51.3) (significant), Zn 3326 (3639) (significant), Se 9.4 (15.3) (significant)	conventional: Cu, Zn, Se supplemented in feed; organic: for I depend more on grazing and more nitrogen fixing crops in field, that lower milk-I concentration through inhibition of the sodium-iodine symporter of the mammary gland; organic: Fe with more soil ingestion

Reference	Hazard investigated	Study country	Sample point	Sample type	# units/samples: conventional (organic)	Significantly lower	Explanation observed differences
Laying hens							
Matt et al. (2009)	vitamins	? Estonia	farm	egg yolks	1 (1) farm, 20 (20) eggs	negligible differences. conventional: vitamin E β 0.25 mg/100 g yolk (0.36) ($p<0.002$); organic: vitamin A 0.46 mg/100g yolk (0.57) ($p<0.00006$), vitamin D3 0.008 (0.014) ($p=0.0006$), vitamin E α 6.20 (14.90) ($p<0.00001$), vitamin E γ 0.22 (0.62) ($p=0.0002$)	genetics, egg production rate, diet composition
Matt et al. (2009)	fatty acids	? Estonia	farm	egg yolks	1 (1) farm, 20 (20) eggs	no differences	diet composition
Matt et al. (2009)	cholesterol	? Estonia	farm	egg yolks	1 (1) farm, 20 (20) eggs	conventional: 341 mg/100 g (489) (p not provided)	breed, age of hen, management, nutrition

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