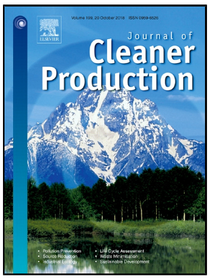

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PII: S0959-6526(18)32542-3

DOI: 10.1016/j.jclepro.2018.08.199

Reference: JCLP 13983

To appear in: *Journal of Cleaner Production*

Received Date: 20 February 2018

Accepted Date: 20 August 2018

Please cite this article as: Sylvia H. Vetter, Daniella Malin, Pete Smith, Jonathan Hillier, The potential to reduce GHG emissions in egg production using a GHG calculator – a Cool Farm Tool case study, *Journal of Cleaner Production* (2018), doi: 10.1016/j.jclepro.2018.08.199

Total words: 7912

The potential to reduce GHG emissions in egg production using a GHG calculator – a Cool Farm Tool case study

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Abstract

Models and tools are used to estimate greenhouse gas (GHG) emissions in agriculture from management processes when measurements are not available. The Cool Farm Tool is widely used by farmers for this purpose. Previously, methods to calculate emissions from crop production have been presented; this paper focuses on the livestock part of the tool. GHG emissions from livestock include enteric methane emissions from ruminants, nitrous oxide and methane emissions from manure management, land use and land-use change, feed production, processing and transport. A case study is presented of 10 large-scale egg producers, who used the Cool Farm Tool over three years to calculate their emissions. The highest GHG emissions were produced through feed, followed by transport and manure management. Through using the tool, the farmers became aware of the sources of emissions in egg production and without targets, took action to reduce emissions. The results show that the averaged GHG emissions decreased over the three years of the study by nearly 25%.

Key words: Cool Farm Tool, greenhouse gases, egg production, mitigation

1. Introduction

Agriculture and forestry produce around a quarter of all anthropogenic greenhouse gas (GHG) emissions (IPCC, 2014). This includes emissions from deforestation and agricultural emissions from livestock, soil and nutrient management. It is crucial to use mitigation practices and explore new possibilities to reduce GHG emissions in order to keep agricultural land productive and sustainable over long periods. Identifying GHG emissions from current practices is the first step in understanding agricultural management and their impact on the environment.

In order to help farmers, consumers and stakeholders to understand the sources of GHG emissions from production and show opportunities of mitigation potential, several models and tools have been created. Several GHG calculators exist for different kinds of users, some of which were reviewed and compared in Colomb et al. (2012) and Whittaker et al. (2013). The models target different aspects of agricultural emissions, use methods ranging from IPCC Tier 1 models (IPCC, 2006) to detailed biogeochemical models (DNDC, Li et al., 2010), and from individual processes such as soil microbial decomposition (RothC, Coleman and Jenkinson, 1999) to the regional scale (Ex-Ante Carbon-balance Tool, EX-ACT 2010), Comet-planner for USA (Comet-planner, 2012), GHGProtocal – Agricultura for Brazil (GHG Protocol, 2003).

This paper presents a case study using the Cool Farm Tool (CFT) (Hillier et al. 2011) which is a GHG emissions calculator developed for use by farmers, and has been widely used and adopted by farmers and other supply chain actors. It consists of a generic set of empirical models to estimate full farm-gate product emissions, constituting a mix of Tier 1, Tier 2, and simple Tier 3 approaches (see IPCC, 1997 for definition of tiers for GHG estimation in national greenhouse gas inventories).

Livestock production is a large contributor to global anthropogenic non-carbon dioxide (CO_2) GHGs through enteric methane (CH_4) emissions from ruminants, and nitrous oxide (N_2O) emissions from pasture fertilization and manure management. The non-CO_2 GHGs, CH_4 and N_2O, have a higher global warming potential (GWP) some 25-34 and 298-310 times more potent than CO_2, respectively, over a 100 year horizon (IPCC, 2007, 2014). Further sources of GHGs from livestock are land use and land-use change, feed production, processing and transport. Land-use change from forest or other natural vegetation to pasture and arable land for feed production can have a large impact on the GHG emissions through carbon release from soils and vegetation (Steinfeld et al., 2006).

GHG emissions from livestock differ widely for different animal types and range from very high emissions for ruminant products like beef (ca. 20 – 60 kg CO_2eq kg^{-1}), sheep and goat meat (ca. 20 – 50 kg CO_2eq kg^{-1}), through pork (ca. 3 – 11 kg CO_2eq kg^{-1}) to much lower emissions for poultry products like poultry meat (ca. 2 – 7 kg CO_2eq kg^{-1}) and eggs (ca. 1 - 5 kg CO_2eq kg^{-1}) (Bellarby et al. 2013, Dudley et al., 2014, Ripple et al. 2014). Reducing GHG emissions intensity in the livestock sector (emissions per unit of product) is mainly linked to an increase in production, but it is often unclear if this really does decrease emissions per animal because of additional feed production and related land use change (Audsley and Wilkinson, 2014, Flysjö et al., 2012). The studies general vary in their life cycle assessment (LCA) boundaries, which makes it difficult to compare the study outcomes.

Egg production is a fast growing industry with an increase globally from 51 million tonne eggs in 2000 to 68 million tonnes in 2013 (FAOSTAT, 2016). Egg and poultry systems generally emit less GHG emissions than ruminants since there is no enteric fermentation (Bellarby et al., 2013, Herrero et al., 2013). There are a few studies analyzing the impact of egg production and these studies vary in terms of LCA boundaries and the production systems. The studies include egg production in Sweden (1.4 kg CO_2eq kg^{-1} egg, Cederberg et al., 2009), Australia (1.3 – 1.6 kg CO_2eq kg^{-1} egg, Wiedemann and McGahan, 2010), the UK (2.92 – 6.18 kg CO_2eq kg^{-1} egg, Leinonen et al., 2012, Williams et al., 2006), the Netherlands (2.2 - 2.7 kg CO_2eq kg^{-1} egg, Dekker et al., 2011) and the USA (5 kg CO_2eq kg^{-1} egg, Pelletier et al., 2013) for intensive and free-range egg production, but less for organic production (2.5 - 3.42 kg CO_2eq kg^{-1} egg, Dekker et al., 2011, Leinonen et al., 2012).

The 10 large-scale egg suppliers presented in this case study collectively produce over 600 million eggs per year. In our study period from 2010-2012, the farmers used the CFT to calculate the overall emissions of their operations and receive a breakdown of emissions by source. The farmers engaged as a group to encourage the processes of learning about carbon footprinting, collecting comprehensive and accurate data, and understanding which practices can reduce emissions - all of which require active participation and engagement. There were no external targets imposed on the farmers to reduce emissions, but through the annual assessments and annual meetings, farmers were able to compare their performance to each other and learn new techniques for reducing their farm's carbon footprint and improving the overall sustainability of their operations.

This paper presents a revision of the livestock module of the CFT and the results of a case study of 10 large-scale egg producers, and how the results were used to identify and implement mitigation options adapted to the specifics of their farm practices and location.

2. Material and Methods

2.1 Cool Farm Tool

The CFT calculates GHG emissions from multiple sources from agriculture including soil management, fertilizer and pesticide use, energy use, residue management, irrigation and livestock management, which produce emissions of CO_2, CH_4 and N_2O (Hillier et al. 2011). The livestock module of the CFT is an integrated package that incorporates several key sources of GHGs to produce a GHG profile for a given product, as a function of location and management practice.

2.2 Cool Farm Tool livestock module

The model integrates several established "off-the-shelf" empirical models for GHG emissions with data input broken down into several sections. In the following section the module for livestock and farm management is explained.

2.2.1 Livestock

The CFT module is derived in large part from the IPCC Tier 1 and 2 methods. The Tier 1 inventory method for emissions from livestock is a function of animal numbers (IPCC, 2006), but for beef and dairy cattle and other ruminant species, the IPCC also offers Tier 2 methods to estimate feed requirements as a function of management and production, through which emission factors for enteric fermentation can be refined. The CFT implementation allows options for the user depending on the level of data available and detail required for their assessment. For dairy cows, the tool allows dry matter intake to be estimated as a function of milk production, and the option to correct for fat and protein content.

Manure

Emission factors for manure management (Table 1) of the different animal types are based on IPCC (2006, Table 10.18) with the exception of composting, for which non-forced aeration composting is substituted for passive windrows, and relative figures for forced-aeration composting were determined according to Brown et al. (2009). The figures for methane and direct nitrous oxide emissions for composting are given in Table 2.

Feed

Emissions from feed depend on the feed mix, and the specifics of cultivation of the feed constituents. For specific assessments where there is good knowledge of the suppliers' practices, the tool can be used to determine embedded emissions in feed components. Failing this, a model derived from Lal (2004), Hillier et al. (2009) and IFA (IFA, 2016) management statistics is used for a range of crops commonly used in livestock feed:

$$EE\ kgCO_2eq/t\ d.m. = \left(160.4 + 20.5 \times C_p + 4.95 \times N + 0.73 \times P + 0.545 \times K\right)/Y$$

where EE is the embedded emissions in each feed constituent, Cp is the number of doses of pesticide (herbicide, insecticide, fungicide, nematicide, etc.), N is the applied nitrogen, P is the applied phosphorous, and K is the applied potassium, all in kg ha^{-1}, and Y is the yield in tonnes per ha. The value of 160.4 kg ha^{-1} is an estimate of emissions per ha from the fuel used for common agricultural machinery operations such as tillage, cultivation, and harvesting according to Hillier et al. (2009), derived from the average across the 54 farms in that study. The value of 20.5 is an emissions factor estimated for pesticide or herbicide use, per application/ha, as noted above, following Audsley (1997). The values: 4.95, 0.73, and 0.545 are the averages of low and high emissions factors for the production of elemental N, P, and K respectively in fertilizer from Lal (2004).

For the default values embedded in the tool given in Table 3, we obtained fertilizer use statistics from the IFA (IFA, 2016), and assumed 2.5 doses of pesticide/herbicide per growing season as an average across crops. These assumptions and coefficients are explicit in the CFT and can be modified by the user to produce a more regionally accurate list of crop emission estimates, even if no specific field level management practice information is available. There is currently no dataset of GHG emissions from feed publically available for North America or organic feed. When available, it will be included in the tool. The results therefore provide an estimate of total absolute feed emissions, but the changes are over the three years are robust, as they reflect the changes in management by the farmers, irrespective of the absolute values.

2.2.2 Direct energy use

Emissions from on-site machinery and other direct energy use are described in Hillier et al. (2011). This includes a model for fuel use from farm machinery operations (mostly derived from ASABE, 2006). For other energy use, most figures come from GHG Protocol (2003), or from Ecoinvent (2007) for renewable electricity emissions. Electricity emissions are country specific for 133 countries and 50 US states plus the District of Columbia. Data for emissions from electricity production are from the IEA (2011) and the USEPA (2007).

2.2.3 Transport

Transport of feed, produce, or other materials off the farm is also incorporated. The options of road, rail, air or ship are provided using the formula:

$$\text{Emissions (kg } CO_2 \text{ eq)} = c_{VEH} \times c_{VW} \times \text{distance (KM)} \times \text{mass transported (t)}$$

with c_{VEH} (GHG Protocol, 2003) and c_{VW} a coefficient accounting for truck weight set to 4/3 for single journeys and 5/3 if the vehicle is returning empty, assuming that an empty truck weighs 1/3 of a fully laden truck.

2.3 Egg production – case study

Data was collected from 10 organic egg farms across the USA in September from 2010-2012. Farmers were asked to provide specific information on all aspects of hen and egg production to estimate their GHG emissions associated with: (1) the production of feed components, such as maize and soy, for both pullets and adult hens; (2) transportation of feed components from the field to the mill, and from the mill to the poultry farms; (3) energy used by the mill for processing grains and other components into feed; (4) energy used in the brooder building for care of new chicks, including electricity and heating fuel; (5) transportation of pullets to the layer houses, and transport of eggs to processing for those farms that did not use conveyor belts to transport eggs to processing (washing, grading, packing). In 2011, the project added transport of eggs from the farm or processing facility to the final retail outlet; (6) energy used for lighting, ventilation, heating and other in-house machinery on the farm; (7) manure management for all life phases of the hens; (8) energy used for processing (washing and packing eggs); and (9) composting or incineration of spent hens.

In 2010, 8 farms participated in the study and from 2011, 10 farms calculated their annual emissions from egg production. One of the 8 farms underwent changes in their management in 2010 to increase production, which resulted in variable emissions over the years. In order to apply a consistent baseline, the results are therefore given totals for 7 farms over the 3 years, and for all farms only in the years 2011 and 2012. In 2011 data from one of the two new farms was extrapolated for the year from 3 months of actual data.

3. Results and Discussion

GHG emissions of egg management were calculated with the CFT for the different sections of management and are presented in the following in kg CO_2eq per kg of product (in this case egg). For this conversion the weight of an average egg is assumed to be 60 g.

3.1 GHG emissions by source

3.1.1 Manure

Emissions from manure management were highly variable between farms with rates from close to 0 kg CO_2eq kg^{-1} egg (when the farmer exports manure off farm immediately) up to around 0.24 kg CO_2eq kg^{-1} egg (Table 4, Figure 1). In this case study, emissions from manure management essentially depend on the duration for which the manure is held with nearly all farms storing manure with litter as is typically the case for poultry breeder flocks (IPCC, 2006). Some farms also employed uncovered anaerobic lagoons, characterizing flush systems that use water to transport manure to the lagoons, or a daily spread of the manure, where it is collected in solid form and applied to fields regularly (IPCC, 2006).

A small reduction in emissions from manure management was registered over the 3 observed years (Table 4, Figure 1). One farm reduced emissions from poultry manure by over 30% by storing less manure in an anaerobic lagoon. Another achieved a reduction in poultry manure emissions by having neighboring organic farms pick up the manure earlier in the season although it is worth noting that if the same storage facility is used on the neighboring farm this only represents displaced emissions rather than a net reduction.

Manure management practices account for 8 to 10% of total emissions on average, and avoiding prolonged manure build-up can help decrease emissions. The emissions accounted for in this study are from CH_4 and direct and indirect N_2O, with methods based on the IPCC (2006) guidelines for manure management, which have uncertainty ranges of around ±10% to ±50% (IPCC, 2006). This includes direct emissions N_2O of between 0.1% and 1% depending on the manure management system. Recent studies (Chadwick et al., 2011) show evidence that between 0.2 and 0.8% of total N is lost as N_2O from stored poultry manure heaps – so in the same range as assumed in the CFT. In addition, Meda et al. (2011) also identified poultry as a major producer of ammonia (NH_3) compared to other livestock systems, whilst relatively less important for other GHGs. In our method indirect emissions of volatilized N of between 40% and 55% which supports this finding.

The effect of manure management in egg or poultry production differs for production systems and depends on handling (Leinonen et al., 2012, Xin et al., 2011). Covering of heaps can lower NH_3 emissions but has no observable effect on N_2O emissions (Chadwick et al., 2011).

The frequency of manure removal can also affect NH_3 emissions, and emissions from manure storage are largely affected by storage conditions (including ventilation rate, manure moisture, air temperature, stacking profile) (Xin et al., 2011). However, these factors, although not included in the CFT, have the greatest influence in caged and housing systems, but do not apply to the farms examined here. Production of manure and its handling on the farm can be used to reduce emissions by selling poultry manure raw as fertilizer or as a feedstock for anaerobic digestion, and the production of renewable electricity (Taylor et al., 2014).

3.1.2 Feed

The most important source of GHG emissions in the footprint of eggs according to our study was for feed production. Emissions from feed were between 0.4 kg CO_2eq kg^{-1} egg and 1 kg CO_2eq kg^{-1} egg (Table 4, Figure 1). Emissions from feed production include full crop production including fertilizer use, machinery, emissions from soil and further processing. The dry matter intake (DMI) ranged from 40 to 72 g day^{-1} for pullets and 100 to 190 g day^{-1} for adults.

Over the 3 years there was, on average, a decrease in emissions from feed production (Table 4). This reduction was as a result of changes in the components of the feed mix during this period, usually with a reduction in maize.

The main feed source is maize with around 50% for adult hens and 55% for pullets (Figure 2). Other feed sources are soybean and wheat and - in smaller amounts - calcium supplement, fodder legume and oilseed rape. In this study, the range of standard feed types was limited to that used in the CFT – which provides emission factors for different feed types based on average yield and fertilizer use. These generic data are for global averages of inputs across a broad range of crops and therefore do not consider regional or management based variations in embedded emissions. As embedded emissions in feed are in reality likely to be quite variable in relation to the above, a more regionally disaggregated estimate of inputs for main feed components would be beneficial.

We therefore repeated our calculations using more recent and regionally disaggregated data (Animalchange: Mogensen, 2013). In general, emissions in this database are slightly higher than those in the CFT (Table 4, Figures 1 and 3). For our comparison, the values for Europe were used (Table 3) since no data were available for North America, and we considered that this provided the most comparable set of conditions. There is no dataset of GHG emissions from feed available for North America or organic feed; as soon as it exists, it will be included in the tool to give a more specific estimates in such cases. In spite of an observable difference in the values (Figure 1), both calculation methods show a substantial reduction in GHG emissions from feed over the observed years, providing evidence the estimates of changes in emissions are robust, irrespective of the absolute starting emissions estimates.

Studies (Meier et al. 2015, Tuomisto et al. 2012) concentrating on the differences between conventional and organic agriculture showed that the impact on a per area bases organic systems show lower impacts but higher impacts on a per product bases than conventional agriculture. Tuomisto et al. (2012) found that organic farms tend to have higher SOC and lower nutrient loss per unit area. The organic systems have generally lower energy requirements but a higher land use than conventional agriculture. Considering models which calculate nitrogen fluxes, Meier et al. (2015) found that they are not well adapted to organic fertilizer and build on assumptions of conventional agriculture; improvements in this area is needed.

Over the three years in our study, several farms made relatively simple adjustments to feed components. For instance, some suppliers decreased the amount of maize and increased the amount of wheat used in their feed. In North America, wheat is generally grown with lower inputs of nitrogen fertilizer than maize, resulting in a lower emissions intensity (141 kg CO_2eq per tonne of wheat compared to 271 kg CO_2eq per tonne of maize). N.B. we do not state that this difference between maize and wheat will always be the case, but this effect highlights the importance of identifying mitigation options which are adapted to farming practices and location. This substitution reduced livestock feed emissions for one farmer by 32% and enabled them to achieve overall emissions reductions of 30% since 2010. Similarly, another supplier achieved a 28% reduction in feed-related emissions within the first year by adopting a higher portion of alfalfa, with an emissions intensity of 20 kg CO_2eq per tonne. The transportation of feed from the field to the mill and from the mill to the poultry farm represents the second most significant source of emissions, after feed production. While some farmers were located in regions amenable to growing feed crops and with organic feed mills nearby, others were reliant on having to transport organic feed long distances by road and rail – sometimes more than 1,600 km. With generally improving trends in vehicle fuel use efficiency it is to be expected that emissions from these sources, although largely beyond the influence of the farmer, will decrease over time.

Finally, Figure 4 indicates a possible relation between the size of the farm (number of animals) and the emissions from production and sourcing of feed. It is not possible to conclude that such an effect – indicative of an economy of scale – is robust, however, given the logistical overhead of sourcing large volumes of feed it would not be surprising.

3.1.3 Field energy use and primary processing

Field energy included electricity for housing and feed mill energy as well as field fuel energy (diesel and propane). The emissions for field energy use per kg egg showed a clear relation to the number of pullets (Figure 5) with emissions decreasing with number of pullets. This ratio between pullets and adults reflected whether the farm was growing in size or holding steady. If the farm was growing, the number of pullets was higher relative to the adults. The energy on the farms, needed mainly to provide additional heat in the juvenile phase, was less intense with a larger number of pullets.

Energy for primary processing included electricity, gas, diesel and propane with energy sources for both field energy use and primary processing, and differed across farms contributing to a range of emissions. Emissions for field energy use ranged from around 0 to 0.5 kg CO_2eq kg^{-1} egg, and emissions for primary processing were between 0.01 and 0.16 kg CO_2eq kg^{-1} egg. There was, on average, a decreasing trend over the three years. Only one farm was able to show a dramatic 48% decrease in primary processing and a 12% reduction in housing energy. Nevertheless the ranking of the farms was preserved and farms with relatively high emissions for primary processing in the first year were still so in year 3. The same result can be seen for the field energy use, and is indicative, that in spite of the efforts of the farmers, some farms had intrinsically higher emissions than others due to exogenous variables, or else were dependent on agricultural and processing machinery that would be costly to replace, meaning that barriers to reduction were high.

Energy provision is known to be a major source of GHG emissions in egg production (Leinonen et al. 2012, Xin et al. 2011). Energy sources differ between processes and can influence the GHGs produced. For example, Cederberg et al. (2009) reported that oil for heating is mostly used in slaughter chicken production; in chicken stables mostly bio-fuel is used and heating in the first weeks after hatching is provided mostly by electricity. The farms in the case study use different sources, or a combination between fuel (diesel or petrol) and electricity sources. The correlation between electricity use and pullets suggests that there is a minimum scale required to make it more economically viable to use electricity. For example those farms that use conveyor belt to transport the eggs from hen houses to processing are locked into a higher level of electricity use.

3.1.4 Transport

We included both transport of the animals and feed in our analysis. Since emissions are proportional to fuel use, and fuel use is primarily a function of distance travelled, emissions from transport reflected the distance to the mills or the shops. There is little scope, therefore, for a farmer to change them unilaterally. Lack of availability of local organic feed was a major challenge for some farmers and caused one farm in particular to have more than twice the average transport-related emissions of the others. However, other farms were able to achieve transportation-related emission reductions, with one farm reducing transport emissions by 30% as a result of sourcing a higher percentage of feed more locally. These effects illustrate that the consequences of adhering to ideologies of “organic” and “locally-sourced” as proxies for “environmentally friendly” are not always evident, and may indeed lead to contradictory effects. One very significant observation from our case study which perhaps demonstrates the effectiveness of the peer group approach to mitigation, *via* the use of decision support tools, is that at least two of the farms are now planning to build their own onsite feed mills. Such a measure, although requiring significant investment and up-front carbon cost, would be projected to cut their transport related emissions by nearly a third.

3.2 Total GHG emissions

Total GHG emissions of egg production ranged from around 0.7 to 1.8 kg CO_2eq kg^{-1} egg including manure management, feed, energy use, primary processing and off-farm transport (Figure 1 and 3, Table 4). The highest emissions came from feed, field energy use and transport. Using the Animalchange data (Mogensen, 2013) for feed resulted in an increase of ~20% in estimated total GHG emissions. The highest emissions are recorded in the first year for most farms and the biggest differences from farm to farm resulted from field energy use and transport. The biggest reduction in GHG emissions came *via* reduced emissions from feed production and transport. Emissions from "spent hen management" (disposal of carcasses) were reported only for a few farms and therefore, not included in the totals. The GHG emissions from this process were very low on average, around 0.001 kg CO_2eq kg^{-1} egg.

In general, there are limited studies which focus on GHG emissions from egg production with which to compare our findings. These studies vary in terms of the life cycle assessment LCA boundaries, and the production systems: In 2009 a Swedish study calculated 1.4 kg CO_2eq kg^{-1} egg to the farm gate (Cederberg et al., 2009), which is within the range of the calculated GHG emissions of this study. A summary of GHG emissions from livestock (Bellarby et al., 2013) show generally higher emissions compared to this study from 4.4 – 6.18 kg CO_2eq kg^{-1} egg for UK (Williams et al., 2006), 3.9 – 4.9 kg CO_2eq kg^{-1} egg for European countries (De Vries and De Boer, 2010) and 1.6 – 2.9 kg CO_2eq kg^{-1} egg for EU27 (Lesschen et al., 2011, Weiss and Leip, 2012). One study estimated a global average for poultry meat and egg of 3.7

kg CO_2eq kg^{-1} edible protein, equating to 0.411 kg CO_2eq kg^{-1} (Herrero et al., 2013) which gives therefore, a much lower estimate for egg production. A report on Australian egg production made the distinction between caged housing and free range egg production, resulting in 1.3 kg CO_2eq kg^{-1} egg and 1.6 kg CO_2eq kg^{-1} egg, respectively (Wiedemann and McGahan, 2010). There are two studies comparing the total GHG emissions from different egg production systems including organic egg production, which have slightly different outcomes. Leinonen et al. (2012) found the lowest GHG emissions for caged production in the UK (2.92 kg CO_2eq kg^{-1} egg), followed by free range (3.38 kg CO_2eq kg^{-1} egg) and highest emissions for organic (3.42 kg CO_2eq kg^{-1} egg) and barn (3.45 kg CO_2eq kg^{-1} egg) eggs. Dekker et al. (2011) in a Netherlands-based study, also found the lowest emissions for caged production (2.2 kg CO_2eq kg^{-1} egg), but highest emissions for barn (2.6 kg CO_2eq kg^{-1} egg) and free range (2.7 kg CO_2eq kg^{-1} egg) production; organic egg production (2.5 kg CO_2eq kg^{-1} egg) is in-between. Both studies included transport, and embedded emissions in feed had the highest impact on the results. Organic production showed higher GHG emissions than caged production due to higher use of feed resources. As a consequence, each egg production system has different impacts on the environment and need to be investigated separately to focus on different economic aspects or sustainability, and therefore potentially requires a different set of mitigation options (Xin et al., 2011).

The above studies differ not only in terms of the egg production systems and the different LCA approaches, but also in terms of the geographic regions studied. Notably, emissions were much smaller for Australia than for European countries. Results from the Australian study should mainly be compared with the findings for other organic egg production systems, however, the results for the UK and the Netherlands also differ by around 1 kg CO_2eq kg^{-1} egg, so such comparison is not straightforward. As a consequence of similar constraints due to EU restrictions, the latter studies result in substantially higher emissions than in the Australian example. A comparable study to ours is one from the U.S., where 5 kg CO_2eq kg^{-1} egg is estimated for intensive egg production for the Midwest (Pelletier et al., 2013). These high emissions result from feed concentrate including ruminant by-product meal and ruminant fat. The same study concludes that by changing the protein source to non-animal by-products, total GHG emissions could be reduced to 1.5 kg CO_2eq kg^{-1} egg, which is in the range of this study (0.9 – 1.5 kg CO_2eq kg^{-1} egg on average).

In all studies, feed is the most influential factor. Feed not only produces the highest GHG emissions in the LCA of egg production, but the opportunities for reducing the emissions from feed are numerous. One of the biggest factors is the feed source. As shown above, GHG emissions from animal by-products are much higher than from other plant sources. This is especially true for ruminants where emissions are some 19-48 times higher than other high protein foods. Total emissions from non-ruminants average between 3-10 times higher than high-protein plant food plans (Ripple et al., 2014). This consideration includes both direct and indirect environmental effects for enteric fermentation, manure, feed, fertilizer, processing, transportation and land-use change. So changing the feed source to non-animal by-products has a large impact on the total GHG emissions. Other protein sources for poultry include worms produced by organic waste and algae produced in biological CO_2-absorption systems (Taylor et al., 2014). Such systems perhaps offer significant potential to dramatically reduce total GHG emissions from poultry, if such practices can achieve sufficient scale.

The feed sources in this study and the majority of the above studies are plant based and include maize, wheat, soy and other crop products. There are opportunities in the production process of these feed sources to reduce GHGs, for example through fertilizer management to reduce N_2O emissions, or change of soil management to increase soil carbon (Smith et al., 2008). Also, the transport for feed production can be minimized if the feed can be sourced locally.

Additional improvements to production processes can bring about significant emissions reductions. For example, that farm that decreased emissions from energy used in its processing facilities by 48% did so by consolidating two buildings and introducing more efficient technology, including simple fixes such as installing skylights for increased heat.

Emissions were estimated using production practices on surveyed working farms, and a widely employed GHG calculator which has been designed to be usable by farmers. The main findings of the case studies were that (1) there is substantial variability across the farms due to differences in various aspects of management, and (2), a consistent decrease in emissions occurred between Year 1 and Year 3 of the study.

Overall, our study showed no relation between the GHG emissions per unit product and the farm size (number of animals/ production of eggs). There has been a study by Yue et al. (2017) that showed the effect of the farm scale on GHG emissions with higher emissions for small-scaled farms (< 1000 head) and lower emissions for medium- and large-scaled (> 10000 head) farms in China. Such a trend could not be found in this study beside the relation between energy use and number of pullets.

The totals per product showed, for nearly all farms, a large to modest reduction of GHG emissions. On average, the total emissions decreased for the 7 farms from 2010 to 2011 by 23% (13% with feed update) and from 2011 to 2012 by 2% (10% with feed update). Overall, the GHG emissions decreased by nearly 25% over the 3 observed years. Considering all 8 farms, which were involved in the study from 2010, the average reduction in GHG emissions was 14.6% over the 3 years. For the single farms the reduction in GHG emissions range between 4% and 33% over the time of the study. For all 10 farms, the GHG emissions decreased from 2011 to 2012 by 2% (7% with feed update). The smaller reduction on average between the second and third years resulted since more essential management changes were implemented between years 1 and 2. This occurs without the explicit setting of emission reduction targets, but simply through use of a practical decision support tool quantifying emission sources and allowing efficiency gains to be identified and then realized. The fact that some farmers attitudes shifted during the 3 years as far as having the intention to adopt measures requiring significant upfront cost, such as the development of on-site feed mills, is evidence that the process adopted in the case study is effective in overcoming one of the main barriers to adoption of behavioral change.

4. Conclusion

The main source of GHG emissions in egg production is feed, followed by transport, energy use and manure management. All of these processes are accounted for in the CFT. Since livestock feed is the most significant contributing factor to emissions on most poultry farms, it should be a priority for further investigation as a mitigation option as well as a priority to continue to develop regional databases for feed emissions to include in and improve such tools as the CFT. The use of the CFT for egg farmers to calculate the GHG emissions helped farmers identify effective mitigation options and the process by which the tool was trialed, and learnings shared among the peer group appears effective at enabling behavior change. The detail provided by the CFT about emission sources, along with training from the

Sustainable Food Lab and demand signal from the buyer for environmentally improved product, inspired the supplier interest and encouraged the farmers to reduce GHGs.

Acknowledgments

The case study in this paper includes 10 large-scale organic egg suppliers of Costco, who engaged its entire supply base to measure the GHG emissions associated with the production of organic eggs. Working in collaboration with the Sustainable Food Lab and using the CFT, the project seeks to spur reductions in emissions and introduce more sustainable production practices – from farm to shelf. We thank Costco and the 10 farmers for participating and for providing the data used in this study.

References

ASABE, 2006. Agricultural machinery management data. American Society of Agricultural and Biological Engineers Standard ASAE EP496.3 ASABE, St Joseph, MI, USA (2006) pp. 385–390.

Audsley, E., 1997. Harmonisation of environmental life cycle assessment for agriculture. Final Report, Concerted Action AIR3-CT94-2028. European Commission, DG VI Agriculture, 139 p.

Audsley, E., Wilkinson, M., 2014. What is the potential for reducing national greenhouse gas emissions from crop and livestock production systems? J. Clean. Prod. 73, 263-268.

Bellarby, J., Tirado, R., Leip, A., Weiss, F., Lesschen, J.P., Smith, P., 2013. Livestock greenhouse gas emissions and mitigation potential in Europe. Global Change Biol. 19, 3-18.

Brown, S., Cotton, M., Messner, S., Berry, F., Norem, D., 2009. Methane avoidance from composting. Issue paper for the Climate Action Reserve.

Cederberg, C., Sonesson, U., Henriksson, M., Sund, V., Davis, J., 2009. Greenhouse gas emissions from Swedish production of meat, milk and eggs 1990 and 2005. SIK Report No 793, SIK-Institutet för livsmedel och bioteknik.

Chadwick, D., Sommer, S., Thorman, R., Fangueiro, D., Cardenas, L., Amon, B., Misselbrook, T., 2011. Manure management: Implications for greenhouse gas emissions. Anim. Feed Sci. Technol. 166-167, 514-531.

CFT, 2016. http://www.coolfarmtool.org [accessed 20/09/2016].

Coleman, K., Jenkinson, D., 1999. ROTHC-26.3. A Model for the Turnover of Carbon in Soil. Model Description and Windows Users Guide. Harpenden.

Colomb, V., Bernoux, M., Bockel, L., Chotte, J., Martin, S., Martin-Phipps, C., Mousset, J., Tinlot, M., Touchemoulin, O., 2012. Review of GHG calculators in agriculture and forestry sectors. A guideline for appropriate choice and use of landscape based tools. ADEME, IRD, FAO

Comet-planner 2012. http://www.comet-planner.com/ [accessed 20/09/2016].

De Vries, M., De Boer, I., 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock science. 128, 1-11.

Dekker, S.E.M., de Boer, I.J.M., Vermeij, I., Aarnink, A.J.A., Koerkamp, P.W.G.G., 2011. Ecological and economic evaluation of Dutch egg production systems. Livestock Science. 139, 109-121.

Dudley, Q.M., Liska, A.J., Watson, A.K., Erickson, G.E., 2014. Uncertainties in life cycle greenhouse gas emissions from U.S. beef cattle. J. Clean. Prod. 75, 31-39.

Ecoinvent, 2007. Ecoinvent data v2.0. Ecoinvent reports No. 1e25, Swiss Centre for Life Cycle Inventories, Dübendorf, 2007. http://www. ecoinvent.org [accessed 09/09/2016].

EX-ACT 2010. http://www.fao.org/tc/exact/ex-act-home/jp/ [accessed 20/09/2016].

FAOSTAT, 2016. http://faostat3.fao.org/ [accessed 20/09/2016].

Flysjö, A., Cederberg, C., Henriksson, M., Ledgard, S., 2012. The interaction between milk and beef production and emissions from land use change – critical considerations in life cycle assessment and carbon footprint studies of milk. J. Clean. Prod. 28, 134-142.

GHG Protocol, 2003. Emissions Factors from Cross-Sector Tools. December 2010. http://www.ghgprotocol.org [accessed 20/09/2016].

Herrero, M., Havlík, P., Valin, H., Notenbaert, A., Rufino, M.C., Thornton, P.K., Blümmel, M., Weiss, F., Grace, D., Obersteiner, M., 2013. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proceedings of the National Academy of Sciences. 110, 20888-20893.

Hillier, J., Hawes, C., Squire, G., Hilton, A., Wale, S., Smith, P., 2009. The carbon footprints of food crop production. International Journal of Agricultural Sustainability. 7, 107-118.

Hillier, J., Walter, C., Malin, D., Garcia-Suarez, T., Mila-i-Canals, L., Smith, P., 2011. A farm-focused calculator for emissions from crop and livestock production. Environmental Modelling & Software. 26, 1070-1078.

IEA, 2011. CO_2 Emissions from Fuel Combustion. International Energy Agency, Paris, available at www.iea.org/media/statistics/co2highlights.pdf [last accessed 09/09/2016].

IFA, 2016. http://www.fertilizer.org/ifa/Home-Page/LIBRARY/Our-selection2/World-Fertilizer-Use-Manual/by-type-of-crops [accessed 20/09/2016].

IPCC, 1997. An Introduction to Simple Climate Models, in: Houghton, J. T., Filho, L. G. M., Griggs, D. J., Maskell, K. (Eds.) IPCC Second Assessment Report. Intergovernmental Panel on Climate Change.

IPCC, 2006. IPCC 2006 Revised Good Practice Guidelines for Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change (IPCC), Institute for Global Environmental Strategies, Tokyo, Japan.

IPCC, 2007. Climate Change 2007: The Physical Science Basis. Contribution of the Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, USA.

IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T.,Minx, J.C. (eds.)].

Lal, R., 2004. Carbon emission from farm operations. Environ. Int. 7, 981-990.

Leinonen, I., Williams, A.G., Wiseman, J., Guy, J., Kyriazakis, I., 2012. Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: Egg production systems. Poultry Science. 91, 26-40.

Lesschen, J.P., van den Berg, M., Westhoek, H.J., Witzke, H.P., Oenema, O., 2011. Greenhouse gas emission profiles of European livestock sectors. Anim. Feed Sci. Technol. 166-167, 16-28.

Li, H., Qiu, J., Wang, L., Tang, H., Li, C., Van Ranst, E., 2010. Modelling impacts of alternative farming management practices on greenhouse gas emissions from a winter wheat-maize rotation system in China. Agric. Ecosyst. Environ. 135, 24-33.

Meda, B., Hassouna, M., Aubert, C., Robin, P., Dourmad, J.Y., 2011. Influence of rearing conditions and manure management practices on ammonia and greenhouse gas emissions from poultry houses. Worlds Poult. Sci. J. 67, 441-456.

Meier, M.S., Stoessel, F., Jungbluth, N., Juraske, R., Schader, C., Stolze, M., 2015. Environmental impacts of organic and conventional agricultural products – Are the differences captured by life cycle assessment? J. Environ. Manage. 149, 193-208.

Mogensen, L., Lesschen, J. P., Klumpp, K., Hutchings, N., Stienezen, M., Eory, V., Lecomte, P., Olesen, J., 2013. Compiled database on LCA (Life Cycle Assessment) coefficients for including pre-chain emissions in LCA of animal products. Deliverable 10.2. Animal Change project. Theme 2: Food, Agriculture and Fisheries, and Biotechnologies. Seventh Framework Programme. Available at: www.animalchange.eu/Content/deliverables.html [accessed 09/09/2016].

Pelletier, N., Ibarburu, M., Xin, H., 2013. A carbon footprint analysis of egg production and processing supply chains in the Midwestern United States. J. Clean. Prod. 54, 108-114.

Ripple, W.J., Smith, P., Haberl, H., Montzka, S.A., McAlpine, C., Boucher, D.H., 2014. Ruminants, climate change and climate policy. Nature Clim. Change. 4, 2-5.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M., Smith, J., 2008. Greenhouse gas mitigation in agriculture. Philosophical Transactions of the Royal Society B: Biological Sciences 363, 789-813.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C., 2006. Livestock's long shadow – Environmental issues and options, FAO, Rome.

Taylor, R.C., Omed, H., Edwards-Jones, G., 2014. The greenhouse emissions footprint of free-range eggs. Poultry Science 93, 231-237.

Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012. Does organic farming reduce environmental impacts? – A meta-analysis of European research. J. Environ. Manage. 112, 309-320.

USEPA, 2007. http://www.epa.gov/energy/egrid [accessed 09/09/2016].

Weiss, F., Leip, A., 2012. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. Agric. Ecosyst. Environ. 149, 124-134.

Whittaker, C., McManus, M.C., Smith, P., 2013. A comparison of carbon accounting tools for arable crops in the United Kingdom. Environmental Modelling & Software 46, 228-239.

Wiedemann, S.G., McGahan, E.J., 2010. Environmental Assessment of an Egg Production Supply Chain using Life Cycle Assessment. A report for the Australian Egg Corporation Limited, Sydney, Australia.

Williams, A.G., Audsley, E., Sandars, D.L., 2006. Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities, Bedford, UK.

Xin, H., Gates, R.S., Green, A.R., Mitloehner, F.M., Moore, P.A., Wathes, C.M., 2011. Environmental impacts and sustainability of egg production systems. Poultry Science. 90, 263-277.

Yue, Q., Xu, X., Hillier, J., Cheng K., Pan, G., 2017. Mitigating greenhouse gas emissions in agriculture: From farm production to food consumption. J. Clean. Prod. 149, 1011 – 1019.

Figures

Figure 1: Comparison of average GHG emissions of organic egg production shown for different sources for CFT feed calculation and feed calculation updated. Error bars show variation over all 7 farms for total GHG emissions per kg egg.

Figure 2: Averaged feed rations over all farms and years for adults and pullets

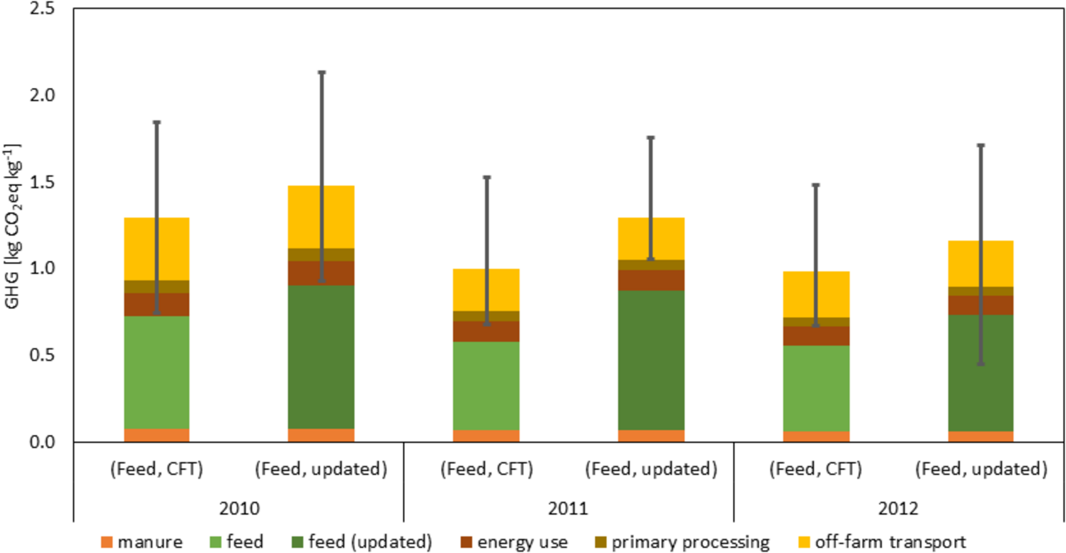
Figure 3: Average GHG emissions of organic egg production shown for different sources for CFT feed calculation and feed calculation updated. Error bars show variation over all 10 farms for total GHG emissions per kg egg.

Figure 4: Relation between farm size (number of animals) and GHG emissions from feed.

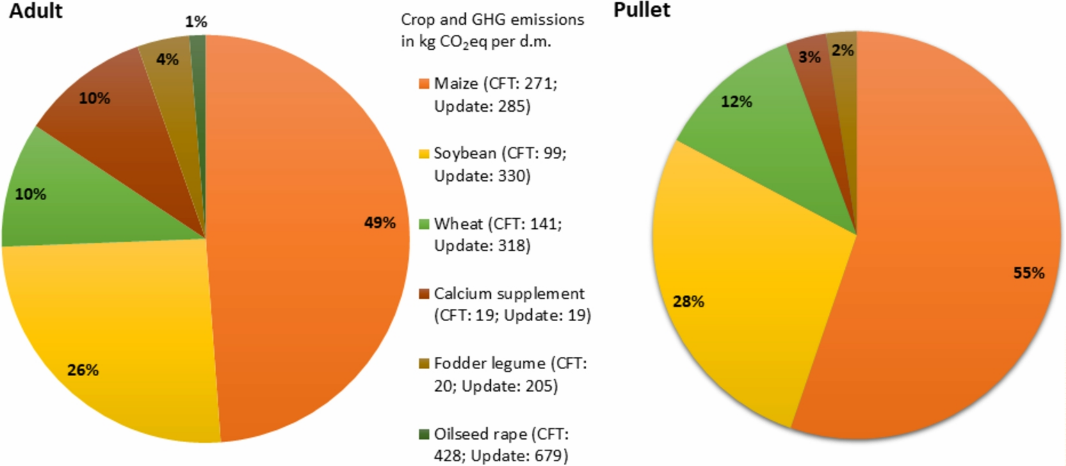
Figure 5: Relation between number of pullets and GHG emissions from field energy.

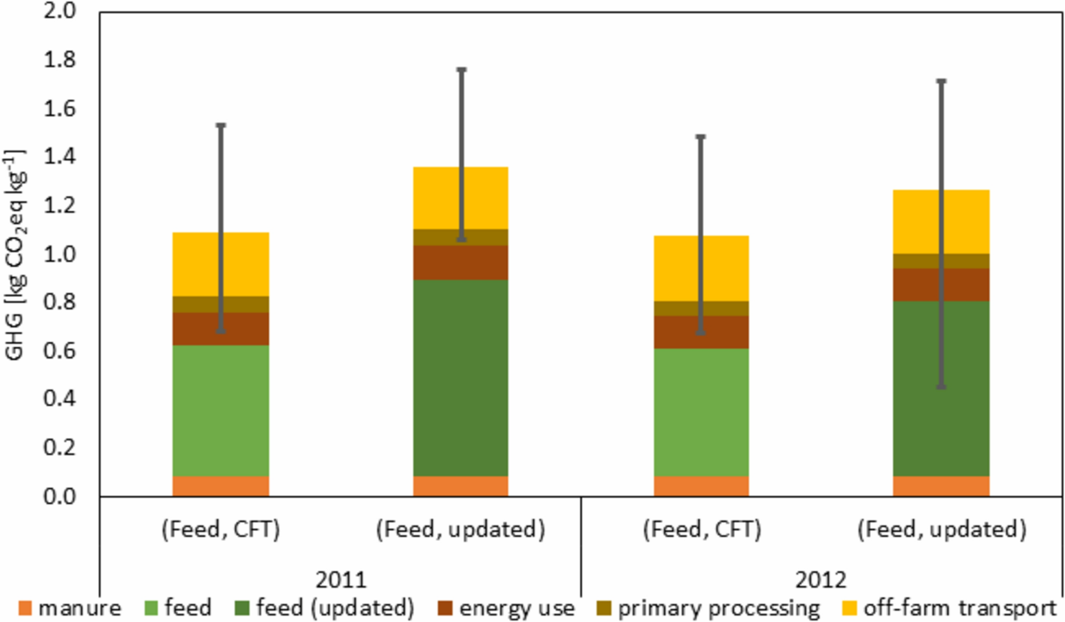
Highlights

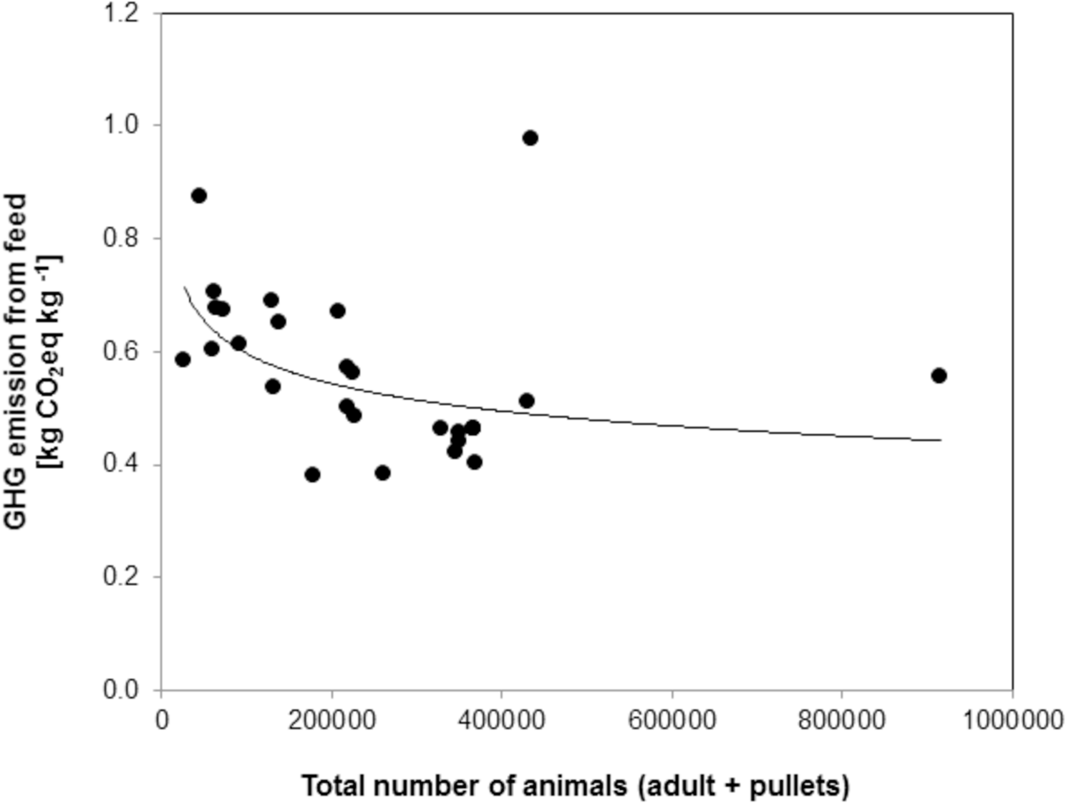
- Cool Farm Tool can be used to calculate greenhouse gas emissions from farm products
- Farmers get informed by the Cool Farm Tool about sources of emissions
- Farmers can explore the options to reduce greenhouse gas emissions
- A case study of organic egg farms showed a reductions in emissions by 25%

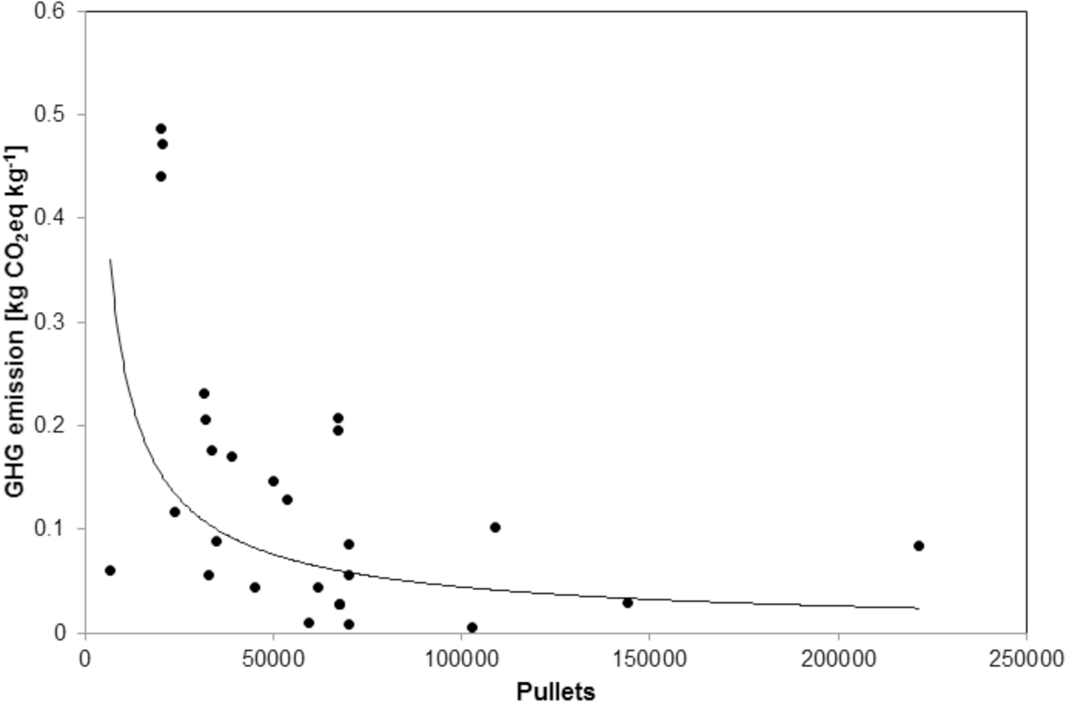


2.5
2.0
1.5
1.0
0.5
0.0
GHG [kg CO_2eq kg^{-1}]
(Feed, CFT)
(Feed, updated)
(Feed, CFT)
(Feed, updated)
(Feed, CFT)
(Feed, updated)
2010
2011
2012
manure
feed
feed (updated)
energy use
primary processing
off-farm transport


Adult
1%
4%
10%
10%
49%
26%
Crop and GHG emissions in kg CO_2eq per d.m.
Maize (CFT: 271; Update: 285)
Soybean (CFT: 99; Update: 330)
Wheat (CFT: 141; Update: 318)
Calcium supplement (CFT: 19; Update: 19)
Fodder legume (CFT: 20; Update: 205)
Oilseed rape (CFT: 428; Update: 679)
Pullet
3%
2%
12%
55%
28%


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
GHG [kg CO_2eq kg^{-1}]
(Feed, CFT)
(Feed, updated)
(Feed, CFT)
(Feed, updated)
2011
2012
manure
feed
feed (updated)
energy use
primary processing
off-farm transport


1.2
1.0
0.8
0.6
0.4
0.2
0.0
GHG emission from feed
[kg CO_2eq kg $^{-1}$]
0
200000
400000
600000
800000
1000000
Total number of animals (adult + pullets)


0.6
0.5
0.4
0.3
0.2
0.1
0
GHG emission [kg CO_2eq kg^{-1}]
0
50000
100000
150000
200000
250000
Pullets

Tables

Table 1: Manure management options in CFT

Manure management options
Daily spread
Solid storage
Dry lot
Liquid slurry with natural crust cover
Liquid slurry without natural crust cover
Uncovered anaerobic lagoon
Pit storage below animal confinements
Deep bedding - no mixing
Deep bedding - active mixing
Composting in vessel
Composting - static pile
Composting - forced aeration
Composting - non-forced aeration
Poultry manure with litter
Poultry manure without litter
Aerobic treatment - natural aeration
Aerobic treatment - forced aeration
Grazing

Table 2: Emissions from composting.

	Composting - forced aeration	Composting - non-forced aeration
methane conversion factor (10-14 ºC)	0.33	0.5
methane conversion factor (15-25 ºC)	0.67	1
methane conversion factor (> 25 ºC)	1.00	1.5
nitrous oxide (kg N2O-N/kg N excreted)	0.01	0.0067

Table 3: Default GHG emissions from a range of crops as a function of fertilizer usage (d.m. refers to dry matter) as used in the CFT and from the Animalchange project (Mogensen, 2013).

kg CO_2eq per t d.m.				
Feed crop	**numbers in CFT**	**Animalchange**		
		Europe	**Africa**	**Latin America**
Bananas			83	204

Barley		307	281	283
Cassava			72	256
Chickpea	189			
Cotton	387			
Field Bean [Broad Bean, Faba Bean]	42	227	108	321
Field Pea	35			
Fodder Legumes	20			
Fodderbeet	142			
Groundnut [Peanut]	89			
Lentil	177			
Maize	271	285	274	268
Millet	305	536	144	322
Oats	208	462	221	402
Oilseed Rape	428	679	779	473
Pigeon pea/cowpea/mungbean	226			
Potato	91	254	200	780
Rice	183	1272	2064	1515
Rye	274	434	344	306
Safflower	432			
Sorghum	151	367	190	293
Soybean	99	330	106	174
Spring barley	335			
Sugarbeet	10	261	429	358
Sugarcane		74	46	52
Sunflower	287	600	637	376
Sweet Potato	98	388	103	315
Temperate Grassland: Grass/Legume Swards	31	266	223	579
Temperate Grassland: Permanent Grass and Sown Grass or Leys	432			
Tropical Grasses	45			
Vegetables		417	535	1054
Wheat	141	318		330
Winter barley	271			
Yams and Cocoyams	38			
Other Cereals		446	115	462
Other Pulses		205	143	259
Other Root Crops		166	32	178

Table 4: GHG emissions of organic egg farms for single sources and in total. Totals are given without spent hen management and retail transport. Emissions from feed were calculated with the old version in the CFT and with updated data from Animalchange (2013)

			spent hen management	**livestock manure management**	Feed (CFT now)	**feed updated**	**field energy use**	**primary processing**	**off-farm transport**	retail transport	total GHG emissions (with feed, CFT now)	**total GHG emissions (feed updated)**
			kg CO_2eq kg $^{-1}$ egg									
7 Farms	**2010**	**Average**	0.008	0.081	0.644	0.826	0.135	0.073	0.364		1.300	**1.479**
		std dev	0.005	0.077	0.210	0.223	0.165	0.067	0.363		0.432	**0.495**
	2011	**Average**	0.007	0.069	0.511	0.804	0.120	0.058	0.240	0.103	1.001	**1.292**
		std dev	0.003	0.069	0.111	0.126	0.161	0.050	0.192	0.107	0.319	**0.291**
	2012	**Average**	0.010	0.066	0.492	0.668	0.109	0.055	0.266	0.057	0.989	**1.164**
		std dev		0.066	0.099	0.263	0.152	0.057	0.184	0.048	0.311	**0.419**
10 Farms	**2011**	**Average**	0.007	0.084	0.537	0.812	0.139	0.068	0.258	0.097	1.087	**1.361**
		std dev	0.003	0.080	0.113	0.116	0.138	0.047	0.182	0.091	0.310	**0.271**
	2012	**Average**		0.080	0.531	0.724	0.135	0.062	0.266	0.069	1.075	**1.268**
		std dev		0.073	0.107	0.238	0.131	0.051	0.176	0.050	0.296	**0.384**