Multi-criteria decision analysis of feed formulation for laying hens

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ABSTRACT
Increase awareness of environmentally sustainable food products and sustainability reporting in the food industry led to assessment of environmental performance of agri-food products using life cycle assessment (LCA). Feed production is mainly responsible for the overall environmental impact of egg and broiler production. In addition, feed cost accounts for a significant portion of the total cost of egg production. Feed formulation is a complex process of quantifying the amount of feed ingredients to satisfy nutritional requirement of layers. Traditional linear programming models can find least cost combination of feed ingredients that meet nutritional requirements. However, it has limitations of rigidity that cannot solve several conflicting objectives simultaneously. Alternatively, multi-criteria decision analysis (MCDA) can be used to find the optimal combination of feed ingredients that meet nutritional requirements at the lowest possible cost with the minimum carbon footprint. The results suggest that the carbon footprint of feed formulation could be reduced with a modest increase in cost.

Keywords: life cycle assessment (LCA), multi-criteria decision analysis (MCDA), carbon footprint, cost, feed formulation

1. Introduction

Consumer awareness of environmentally sustainable food products and sustainability reporting are responsible for a growing trend in sustainability of the food supply chain. Consumers are more conscious about how foods are produced and their consequential impacts on the environment. Many stakeholders in the food supply chain including producers, processors and retailers are adopting sustainable practices to address consumer demand for environmental friendly products and communicate the environmental profile of their products. Increasingly food retailers are integrating sustainable considerations into their supply chain to reduce cost, to enhance corporate reputation and to differentiate their products from competitors. In response to the demand and need for sustainability reporting, a life cycle assessment has been recently completed to assess the environmental performance of egg production in Alberta.

Key findings of LCA results identified feed production as the main contributor to greenhouse gas emissions (carbon footprint) (70%) of egg production in Alberta. The results were consistent with other LCA studies of egg and broiler production that identified feed production as a major contributor of greenhouse gas emissions (46-80%) from egg and broiler chicken production (Pelletier 2008; Sonesson et al. 2009; Wiedemann and McGahan 2011; Wiedemann et al. 2012). In addition, feed cost accounts for a significant portion (46-54%) of total cost of egg production (Martin et al. 1998). Improvement in the feed formulation can help to optimize feed efficiency.

Feed formulation is a complex process of assembling a blend of feed ingredients that meet the nutritional requirements of layers. Inadequate nutrition may lead to a reduction in egg size and production. Energy, protein and amino acid levels are major factors in feed formulation to achieve the best performance of egg production (Elliot 2012). Traditional linear programming has been used to formulate the least cost combination of feed ingredients that satisfies a specific level of nutritional requirements of layers. However, it has limitations of rigid assumptions that cannot solve several conflicting objectives such as cost minimization and reduction of environmental impact (Castrodeza et al. 2005; Rehman and Romero 1984). Compared to the linear programming, multi-criteria decision analysis (MCDA) is a more flexible method to solve several conflicting objectives simultaneously. Using MCDA, this study builds on the LCA study results to find the best compromise solution to the optimal combination of feed ingredients that satisfies economic, nutritional and environmental criteria.

2. Methods

2.1. LCA of feed ingredients

Carbon footprints of feed ingredients were assessed using ISO standards 14040/14044 (2006). This study included crop production on the farm, the subsequent drying, processing and the transport of feed grain to the farm. The functional unit used was 1 kg of feed ingredient at the gate of the feed mill. Background processes associated with input production (manufactured fertilizers, pesticides, agricultural machinery, and diesel), field operations and the transport of feed grains to the feed mill were adapted from the ecoinvent database (Nemecek and Kagi 2007). The electricity grid mix value was modified using Alberta data for energy sources and electricity importation from other provinces.

Life cycle inventory data for wheat, barley, peas and canola were developed using Alberta crop production data. Two farming systems (conventional and no tillage systems) were modeled for the four crops. Crop yield (2009-2011) and the proportion of each tillage system were used from the Alberta Agriculture Financial Service Corporation (AFSC – crop insurance). Corn, corn dry distiller grains (DDGS), soybean and soymeal were adopted from ecoinvent database using U.S Midwest data. Attributional LCA modelling was applied to the study because the main purpose of the study was to measure the total greenhouse gas emissions of feed ingredients based on average production data and the effects of any changes in level of output were beyond the scope of the study.

Economic allocation was used to allocate environmental impact of the by-products of feed ingredients such as soymeal, canola meal and corn DDGS because physical relationships of feed materials differed significantly from one feed type to another depending on nutritional contents such as energy, protein and essential amino acid (FAO 2014). Moreover, the prices of feed ingredients reflected their nutritional value. In this case, economic allocation was the best possible option to allocate environmental impacts of feed ingredients and their by-products in a consistent manner and on the basis of meaningful relationship between nutritional values and prices (FAO 2014). Limestone, dicalcium phosphate and salt were used from the ecoinvent database. Vitamin premix was used from Nguyen et al. (2012).

Global warming potential was considered as a single environmental impact indicator to analyze in the model because global warming potential was widely used as a standalone impact indicator using internationally recognized greenhouse gas quantification protocols such as ISO/TS 14067 and PAS 2050 to communicate the results to the public through carbon labelling schemes. For life cycle impact assessment method, IPCC 2007 GWP 100a was selected from SimaPro 7.3.3 to evaluate the global warming potential of feed ingredients (Goedkoop et al. 2008; Goedkoop et al. 2010).

2.2. Multi-criteria decision analysis (MCDA) for feed formulation

Multi-criteria decision analysis can be used to find the best comprise solution among several conflicting objectives. In order to model multiple objective programming, it needs to find target values for each of objectives (Tozer and Stokes 2001). This study focuses on two objectives – cost minimization and reduction of carbon footprint. Cost target (C*) and impact target (I*) are solved using traditional linear programming. C* is determined by a LP model of cost minimization as follow:

$$\min C = \sum_{i=1}^{I} \pi_i X_i \tag{1}$$

Subject to:

$$\sum_{i=1}^{I} a_{ij} X_i \geq b_{ij} \ \forall \ j = 1,2,..., J-1 \tag{2}$$

$$\sum_{i=1}^{I} a_{ij} X_i \leq b_j \tag{3}$$

The objective function specified by equation 1 describes the summation of the prices of the i feed ingredients (π_i) multiplied by its amount (X_i) used in the optimal feed formulation. Equation 2 and 3 are recommended nutritional lower and upper bound constraints. The coefficients a_{ij} measure the amount of the jth nutrient in the ith feed ingredients and b_j limit the allowable minimum or maximum amount of the jth nutrient in the feed formulation depending on the sign of inequality. Crude protein (%), metabolizable energy (kcal/kg), available phosphorus (%), calcium (%) and essential amino acids such as methionine (%), methionine + cystine (%), lysine (%), threonine (%), tryptophan (%) and isoleucine (%), are considered as the jth nutrient according to diet specification from commercial poultry nutrition (Leeson et al. 2008). Wheat, barley, corn, corn DDGS, soymeal, canola meal and peas were included as major feed grain crops. Other feed ingredients such as limestone, canola oil, dicalcium phosphate, salt and vitamin premix were also included in the feed formulation based on recommended diet specifications (Leeson et al. 2008).

Diet specifications for layers (60-70 weeks) were used based on guidelines for nutritional requirements of layers from commercial poultry nutrition (Leeson et al. 2008). Nutritional values of feed ingredients were collected from commercial poultry nutrition by Leeson et al. (2008). Price data (2013) for wheat, barley, corn, corn DDGS, soymeal and canola meal were collected from the Alberta Pulse Growers Association. Price of canola oil was used from the Canola Council of Canada. Prices of other minerals and feed supplements were from Masterfeeds - retail bulk price list of July 22, 2013. Nutritional values and prices of feed ingredients are presented in Table 1.

Table 1. Nutritional values and prices of major feed ingredients

Feed	ME (kcal)	C.P (%)	Ca (%)	P (%)	Methionine (%)	Lysine (%)	Threonine (%)	Methionine +Cystine (%)	Isoleucine (%)	Tryptop han (%)	$/tonne
Wheat	3150	13	0.05	0.2	0.2	0.49	0.42	0.41	0.3	0.21	258
Barley	2780	11.5	0.1	0.2	0.21	0.31	0.4	0.42	0.5	0.19	240
Soymeal	2550	48	0.2	0.37	0.72	3.22	1.96	1.51	2.6	0.71	569
Canola meal	2000	37.5	0.65	0.45	0.69	2.21	1.72	1.3	1.4	0.5	338
Corn	3330	8.5	0.01	0.13	0.2	0.2	0.41	0.31	0.29	0.1	290
Corn DDGS	2770	36.5	0.07	0.77	0.5	0.73	0.96	1.04	0.96	0.2	305
Peas	2550	23.5	0.1	0.3	0.3	1.6	0.9	0.5	1.1	0.23	287
Minimum requirement	2800	16	4.6	0.33	0.34	0.73	0.55	0.6	0.53	0.15	

Similar to the finding the minimum cost target, the impact target is solved using the following LP model:

$$\min I = \sum_{i=1}^{I} \pi_i X_i \qquad 4$$

Subject to:

$$\sum_{i=1}^{I} a_{ij} X_i \geq b_{ij} \;\forall\; j = 1,2,\ldots, J-1 \qquad 5$$

$$\sum_{i=1}^{I} a_{ij} X_i \leq b_j \qquad 6$$

The objective function in equation 4 describes the summation of the carbon footprint of the i feed ingredients (π_i) multiplied by its amount (X_i) used in the optimal feed formulation. Equation 5 and 6 are specified by similar procedures to equation 2 and 3.

When the target values (C* and I*) are solved, a multiple objective programming model is solved using the following MINIMAX formulation:

$$Min\ \lambda \quad (7)$$

Subject to:

$$\sum_{i=1}^{I} a_{ij} X_i \geq b_{ij}\ \forall\ j = 1,2,...,J-1 \quad (8)$$

$$\sum_{i=1}^{I} a_{ij} X_i \leq b_j \quad (9)$$

$$\sum_{i=1}^{I} \pi_i X_i = C \quad (10)$$

$$\sum_{i=1}^{I} \pi_i X_i = I \quad (11)$$

$$w_C (C - C^*)/C^* \leq \lambda \quad (12)$$

$$w_I (I - I^*)/I^* \leq \lambda \quad (13)$$

The objective function of the multiple objective model minimizes λ ,which is the weighted percentage deviations from the target values for each of the two objectives. The constraints specified by equation 12 and 13 measure percentage deviations from the target values when the weights for the goals $(W_C \text{ and } W_I)$ are equal to one. However, the model is flexible to adjust the weights that reflect a decision maker's priority over each objective.

3. Results

3.1. Carbon footprint of feed ingredients

Results of global warming potential (GWP 100a) ranged from 0.012 to 1.799 kg CO_2e/kg of feed ingredient (Table 2). Canola oil had the highest GWP while limestone had the lowest GWP. Among major feed crops, corn DDGS had the highest GWP, followed by wheat and corn which had greater GWP than barley, canola meal, peas and soymeal. For major protein feed ingredient, GWP of soymeal was higher than that of canola meal. Fertilizer production and its emissions from field application was a major contributor to GWP of feed crops. Transportation was mainly responsible for GWP of imported feed grains such as corn, corn DDGS and soymeal which accounted for 41, 33 and 19 % of total impact of GWP.

3.2. Least cost feed formulation

Least cost feed formulation had the lowest cost of $282/tonne and 562 kg CO_2e/tonne. The feed formulation contained wheat (18%), barley (25%), canola meal (8.7%), peas (19.7%), corn DDGS (17%), limestone (11%) and others[1] (1.3%). As energy and protein are essential for layer feed, unit cost/crude protein (%) and energy (1000 kcal) are calculated and presented in Figure 1. Wheat, barley and corn had the lower level of cost per unit energy while soymeal, canola meal, peas and corn DDGS had the lower cost per unit protein. Corn had the highest cost per protein content and soymeal had the highest cost per energy content. Both corn and soymeal had a huge gap of trade-off between energy and protein content. In terms of cost minimization, corn DDGS was more competitive than corn.

[1] Others included canola oil, dicalcium phosphate, salt and vitamin premix.

Table 2. Carbon footprint of feed ingredients (kg CO_2e/tonne)

Feed	kg CO_2e/tonne
Wheat	662
Barley	425
Soymeal	541
Canola meal	406
Corn	656
Corn DDGS	1153
Peas	435
Limestone	12
Canola oil	1799
Dicalcium phosphate	970
Salt	226
Vitamin premix	680

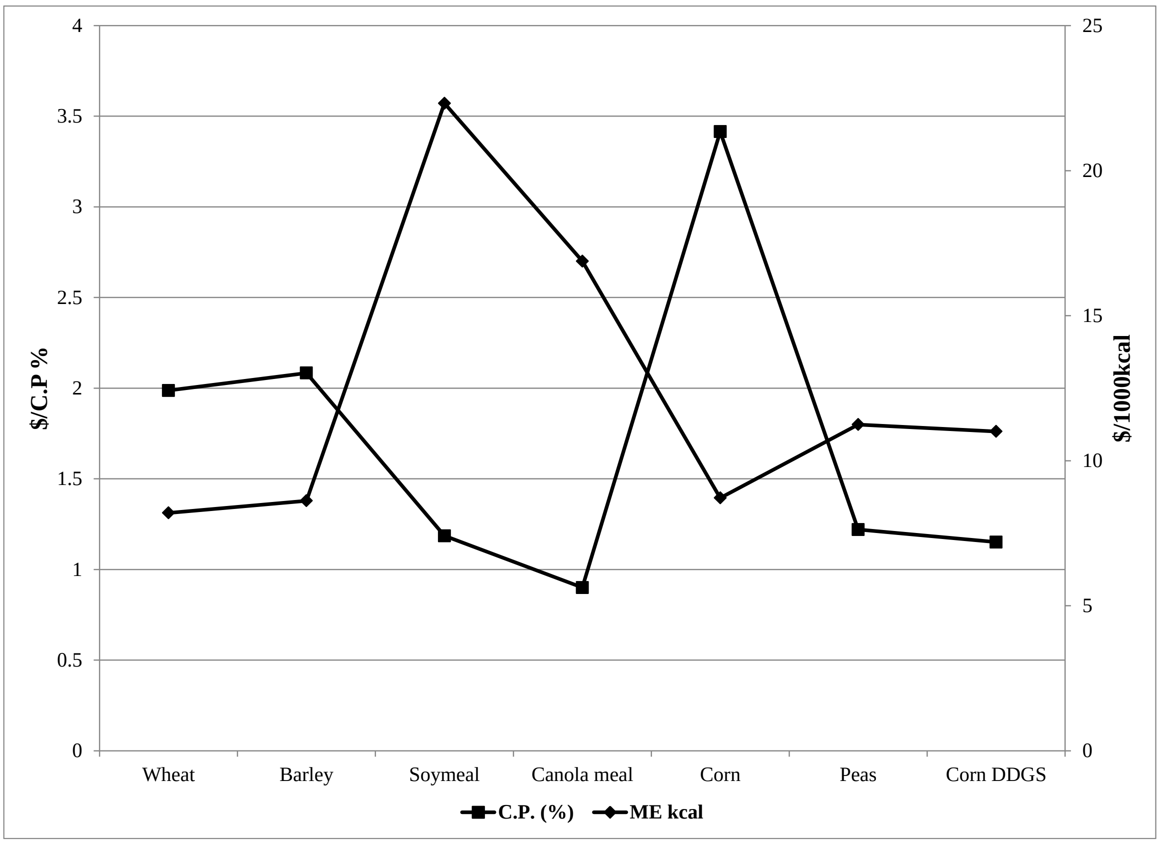

Figure 1. Unit cost per crude protein (%) and energy (1000 kcal) of major feed ingredients

3.3. Low-impact feed formulation

Low-impact feed formulation had the minimum level of 403 CO_2e/tonne and feed cost of $296/tonne. Low-impact feed reduced the carbon coefficient by 159 kg CO_2e/tonne (28%) at an increase cost of $13/tonne (4.5%). The feed formulation contained barley (59%), soymeal (9.5%), canola meal (8.5%), peas (12%), limestone (11%) and others (1.3%). Carbon footprint per crude protein (%) and energy (1000 kcal) are presented in Figure 2. Soymeal and canola meal were more competitive than peas and corn DDGS for crude protein. Wheat, corn and corn DDGS had a higher carbon footprint per unit crude protein and energy content. Barley, soymeal, canola meal and peas had the lower level of carbon footprint per both nutritional values.

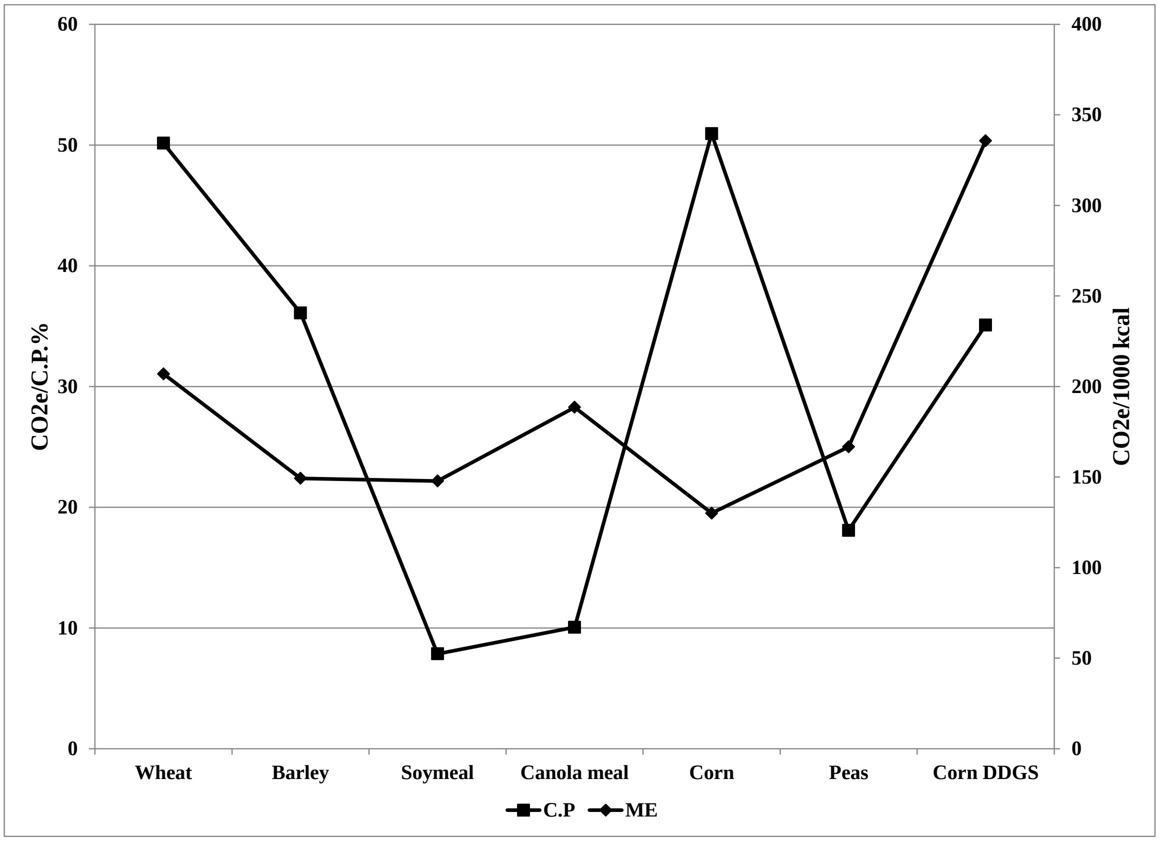

Figure 2. Carbon footprint per unit of crude protein (%) and metabolizable energy (1000 kcal) for seven major feed ingredients

3.4. Multiple objective solutions

The lowest cost ($282/tonne) from the least cost feed formulation and the minimum level of carbon footprint (403 CO_2e/tonne) from the low-impact feed formulation were used as the target levels of the two objectives – least-cost and low-impact. Multiple objective programming was solved under three different weighting scenarios for the two targets – equally weighted scenario ($W_{LC} = W_{LI} = 1$), cost heavily weighted scenario ($W_{LC} = 2$, $W_{LI} = 1$) and carbon footprint heavily weighted scenario ($W_{LC} = 1$, $W_{LI} = 2$).

The results of least cost, low-impact and three multiple objective solutions are presented in Figures 3 and 4. For the solution of equally weighted scenario (W_cW_i), the cost of feed formulation was $291/tonne, an increase over the least cost formulation of $9/tonne or 3% and, the carbon footprint was 411 kg CO_2e/tonne with a marginal decrease of 151kg CO_2e/tonne or 27% compared to the least cost formulation (LC). For the solution of the carbon footprint heavily weighted scenario ($1W_c2W_i$), the cost and carbon footprint of feed formulation were $296/tonne and 403 kg CO_2e/tonne that increased the cost by $14/tonne or 5% and decreased the footprint by 159 kg CO_2e/tonne or 28% compared to the least cost formulation. The results were almost the same as those of the low-impact (LI) feed formulation ($295/tonne and 403 kg CO_2e/tonne). Compared to the results of the equally weighted solution (a 3% cost increase and a 27% CO_2e reduction), the low-impact and the carbon footprint heavily weighted scenarios cost more (a 5% cost increase) but reduced relatively similar amount of the carbon footprint (a 28% CO_2e reduction). Therefore, both solutions are not optimal in terms of the marginal changes in cost and carbon footprint.

For the solution of the cost heavily weighted scenario ($2W_c1W_i$), the cost of feed formulation increased by only $1/tonne or 0.35% compared to the least cost formulation but the carbon footprint decreased by 105 kg CO_2e/tonne or 19%. The solution of the cost heavily weighted scenario was more feasible than that of the equally weighted scenario in terms of the marginal changes in cost and carbon footprint. Compared to the least cost formulation, a major change in these formulations was the substitution of wheat and corn DDGS by barley, peas and soymeal. The results indicated that wheat and corn DDGS had relatively higher carbon footprints with respect to crude protein and energy content in the diet than did other feed ingredients.

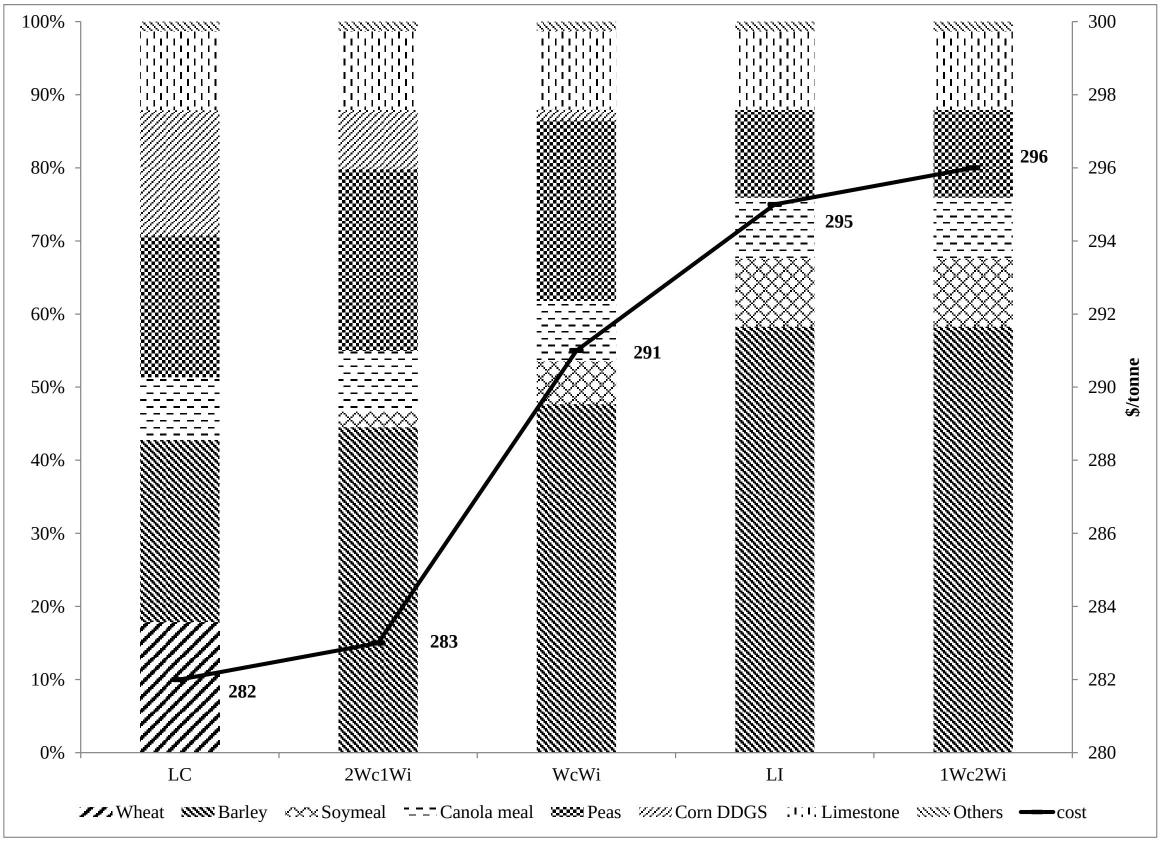

Figure 3 Optimal feed formulations and costs for five different scenarios

Note: LC, LI, W_cW_i, $2W_c1W_i$ and $1W_c2W_i$ stand for least cost scenario, low-impact scenario, equally weighted multiple objective scenario, cost heavily weighted multiple objective scenario and carbon footprint heavily weighted multiple objective scenario respectively.

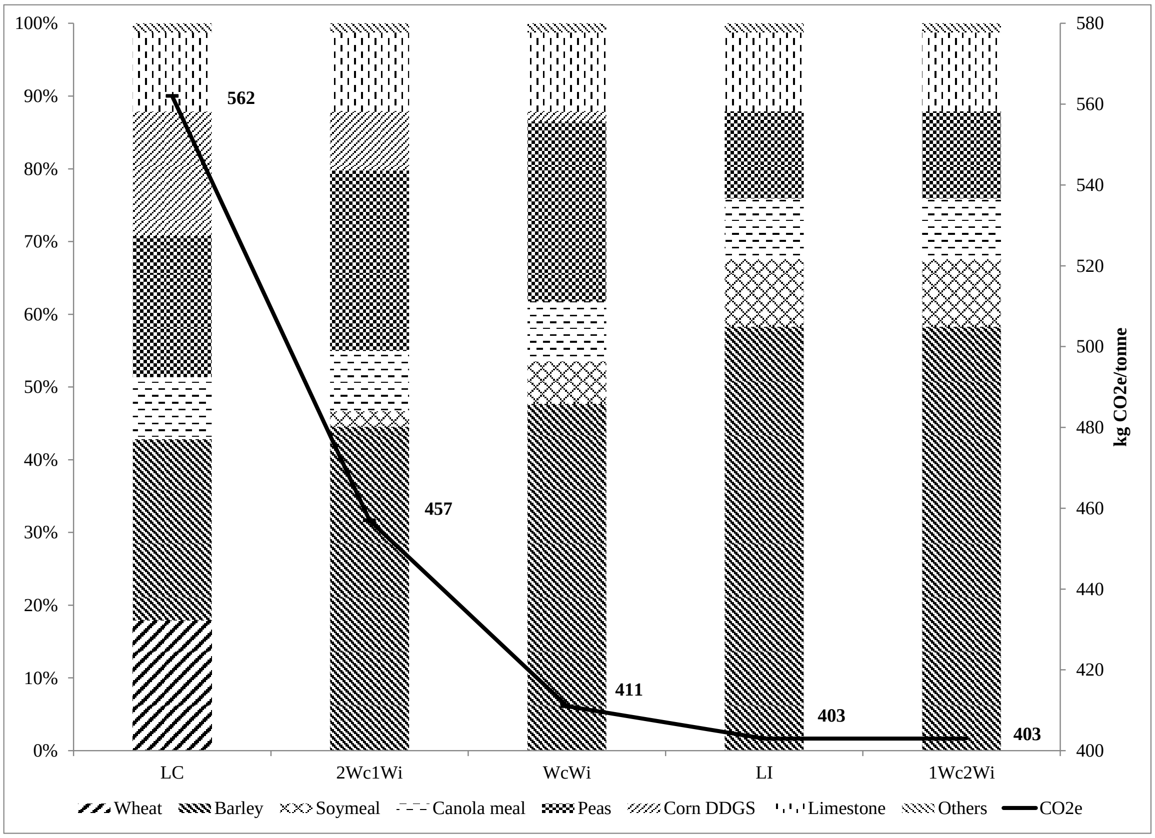

Figure 4 Optimal feed formulations and carbon footprints for five different scenarios

Note: LC, LI, W_cW_i, $2W_c1W_i$ and $1W_c2W_i$ stand for least cost scenario, low-impact scenario, equally weighted multiple objective scenario, cost heavily weighted multiple objective scenario and carbon footprint heavily weighted multiple objective scenario respectively.

4. Discussion

As feed production contributes to a large environmental impact of livestock production, feed has become a targeted environmental hotspot of attention in livestock production systems. The environmental impact of feed production could be reduced by supplementation with synthetic amino acids and inclusion of locally grown and low impact feed ingredients in feed formulations (Eriksson et al. 2005; Mosnier et al. 2011; Nguyen et al. 2012). Mosnier et al. (2011) found that the incorporation of synthetic amino acids in pig and broiler feeds could reduce the use of high impact Brazilian soymeal, resulting in a lower carbon footprint of feed formulations. Eriksson et al. (2005) investigated the impact of feed choice of pig production using three alternative scenarios of protein supply. The results indicated that feed formulation based on peas and rapeseed meal supplemented with synthetic amino acid was environmentally preferable because of the exclusion of high impact soymeal from the feed. Nguyen et al. (2012) confirmed that carbon footprint and eutrophication potential of poultry feeds could be reduced by the substitution of soymeal and cereals by rapeseed meal, grain legumes and co-products (wheat bran, gluten) with about a 2-8% increased cost.

Similar to the study of Nguyen et al. (2012), the results of this study suggest that carbon footprint of feed formulation could be reduced with a modest increase in the feed cost. Each feed ingredient has the strength and weakness in terms of cost and carbon footprint with respect to protein and energy content. Corn DDGS is more competitive than corn because corn DDGS contains a relatively high level of energy and protein compared to corn which contains more energy and less protein. Wheat is also a competitive feed ingredient because the unit cost per protein and energy is similar to that of barley. However, the low-impact formulation does not include wheat and corn DDGS because both feed crops have a higher carbon footprint. Barley, peas and canola meal have become major feed ingredients in terms of both cost minimization and reduction of carbon footprint. However, the inclusion of large proportion of barley in feed formulation requires adding non-starch polysaccharide (NSP) enzymes to layer feeds to enhance energy digestibility (Geraert and Dalibard 2003). Peas and canola have limitations of inclusion in formulations so that the amount of peas cannot exceed more than 30% and the amount of canola meal cannot exceed more than 10% (Hickling 2003; Newkirk 2009). Therefore, it is important to consult with poultry nutritionists about any suggested changes in feed formulations so that nutritional requirements and ingredient limitations are not compromised.

5. Conclusion

Carbon footprints of feed formulations could be reduced using low impact feed ingredients while satisfying nutritional requirement of laying hens. The feed cost will be higher in order to reduce carbon footprint of feed formulation. However, it is possible to find a lower carbon footprint of formulated feed at a reasonable cost. Barley, peas and canola meal play a major role to reduce the carbon footprint of feed formulation. Multi-criteria decision analysis could be used as a tool to achieve the best possible combination of feed ingredients at the lowest possible cost using multiple objective programming. This tool will help Alberta egg producers develop eco-efficient feed formulations that demonstrates industry's commitment to environmental sustainability.

6. References

Castrodeza C, Lara P, Pena T, (1984) Multiple-criteria fractional model for feed formulation: economic, nutritional and environmental criteria. Agricultural Systems 86:76-86

Elliot MA, (2012) New concepts in layer nutrition. Proceedings of the 23nd Annual Australian Poultry Science Symposium, Sydney, New South Wales

Eriksson IS, Elmquist H, Stern S, Nybrant T, (2005) Environmental systems analysis of pig production. International Journal of Life Cycle Assessment 10(2):143-154

Food and Agriculture Organization (FAO) (2014) Environmental performance of animal feeds supply chains: Guidelines for quantification. Draft for public review. Available at: http://www.fao.org/fileadmin/user_upload/benchmarking/docs/LEAP_Anima_feeds_DRAFT.pdf

Geraert PA, Dalibard P, (2003) Enzymes in layer diets: an opportunity. World Poultry 19 (4):12-13

Goedkoop M, Oele M, Schryver AD, Vieira M, (2008) SimaPro Database Manual: Method library. PRe Consultants, Netherland

Goedkoop M, Schryver AD, Oele M, Durksz S, de Roest D, (2010) Introduction to LCA with SimaPro 7. PRe Consultants, Netherland

Hickling D, (2003) Canadian feed peas industry guide. Pulse Canada, Winnipeg, Manitoba, Canada. Available at: http://www.pulsecanada.com/uploads/31/1b/311beeea01659c37ca27e91d669c2a87/Feed-Peas-English.pdf

ISO 14040:2006 (2006) Environmental Management – Life Cycle Assessment – Principles and framework, the International Organization for Standardization, Geneva

ISO 14044:2006 (2006) Environmental Management – Life Cycle Assessment – Requirements and guidelines, the International Organization for Standardization, Geneva

ISO/TS 14047:2013 (2013) Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification and communication, the International Organization for Standardization, Geneva

Leeson S, Summers JD, (2008) Commercial Poultry Nutrition. Thrumpton, Nottingham: Nottingham University Press

Martin L, Kruja Z, Alexiou J, (1998) Prospect of expanded egg production in Western Canada. George Morris Centre, Guelph, Ontario, Canada

Mosnier E, van der Werf HMG, Boissy J, Dourmad J-Y, (2011) Evaluation of the environmental implications of the incorporation of feed-use amino acids in the manufacturing of pig and broiler feeds using life cycle assessment. Animal 5:1972-1983

Nemecek T, Kagi T, (2007) Life cycle inventories of Swiss and European agricultural production systems. Final Report Ecoinvent No.15. Agroscope Reckenholz-Taenikon Research Station ART, Swiss Centre for life cycle inventories, Zurick and Dubendorf, Switzerland

Newkirk R, (2009) Canola meal feed industry guide. Canola Council of Canada, Winnipeg, Canada. Available at: http://www.canolacouncil.org/media/516716/canola_meal_feed_guide_english.pdf

Nguyen TTH, Bouvarel I, Ponchant P, van der Werf HMG, (2012) Using environmental constraints to formulate low-impact poultry feeds. Journal of Cleaner Production 28:215-224

PAS 2050:2008 (2008) Specification for assessment of the life cycle greenhouse gas emissions of goods and services. British Standards, London

Pelletier N, (2008) Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. Agricultural Systems 98: 67-73

Rehman T, Romero C, (1984) Multiple-criteria decision-making techniques and their role in livestock ration formulation. Agricultural Systems 15:23–49

Sonesson U, Cederberg C, Berglund M, (2009) Greenhouse gas emissions in egg production: decision support for climate certification. Report 2009:7, KLIMATMARKNING FOR MAT. (Climate Certification for Food), Stockholm, Sweden

Tozer PR, Stokes JR, (2001) A multi-objective programming approach to feed ratio balancing and nutrient management. Agricultural Systems 67:201-215

Weidemann SG, McGahan EJ, (2011) Environmental assessment of an egg production supply chain using life cycle assessment. A final report. Publication No 1FS091A, Australian Egg Corporation Limited, North Sydney, Australia

Weidemann SG, McGahan EJ, Poad G, (2012) Using life cycle assessment to quantify the environmental impact of chicken meat production. A final report. RIRDC Publication No 12/029, Rural Industries Research and Development Corporation (RIRDC), Barton, Australia

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