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Evaluation of greenhouse gas emissions from three dairy production systems in Iowa--conventional, grazing, and combination conventional/grazing

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Evaluation of greenhouse gas emissions from three dairy production systems in Iowa—conventional, grazing, and combination conventional/grazing

by

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CO_2-eq	carbon dioxide equivalent
Conv	conventional dairy system
ECM	energy corrected milk
GE	gross energy
Graz	grazing dairy system
Graz/Conv	combination grazing/conventional dairy system
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
KWh	kilowatt-hour
LW	live weight
MCF	methane conversion factor
MJ	megajoule
MM	manure management
MMS	manure management system
TMR	total mixed ration

CHAPTER 1 INTRODUCTION AND LITERATURE REVIEW

This thesis project evaluates greenhouse gas emissions from dairy production systems in Iowa and seeks reduction strategies. Does one method of production produce significantly less impact than another? What drives greenhouse gas emissions in each system and to what assumptions are they sensitive? Will mechanisms for reduction of impacts look similar and produce similar results across production systems?

Verifiable comparisons of the environmental impacts of different agricultural production systems either do not exist or are difficult to access for many products. Discussions of the environmental impacts of agricultural systems, therefore, are often charged with more emotional appeal than science. Verifiable scientific analyses of production systems that allow consumers to evaluate products they purchase, and allow regulators to accurately value externalities in policy decisions are needed. Quantification of environmental impacts on agricultural production systems is of social and political importance. Producers, activists, and regulators must communicate in common terms to seek solutions and find common ground. Life cycle assessment is a tool to account for environmental impacts across the entire life cycle of a product, from production of raw materials to use of the product and disposal. Use of life cycle assessment to quantify environmental impacts is one way to find common ground.

Developing a sustainable agriculture system depends upon analyzing the systems in use and improving them in various metrics that contribute to increased resilience. Economics, social impacts, and environmental impacts are commonly discussed as factors important to sustainability of agricultural systems.

Evidence of global warming is mounting and pressure is building to limit greenhouse gas emissions from many human activities, including agricultural production. Agriculture must find ways to reduce resource use and environmental impacts, including global warming potential emissions. Reducing emissions may consist of large shifts in production technology or seemingly minor changes that provide reductions throughout the system. Detailed analysis of agricultural systems is needed to find the variables within systems that can lead to reductions.

This thesis is part of a project funded by the Leopold Center for Sustainable Agriculture titled*: Life Cycle Assessment of Confinement and Pasture-based Dairying in Iowa: Impacts and Options for Mitigation.* This thesis involves the construction of a model and evaluation of predicted global warming potential emissions from three dairy production systems.

The remainder of this chapter consists of a literature review providing background information on dairy production and environmental assessment of agricultural systems. Chapter Two presents the framework and assumptions used in this life cycle assessment process. Chapter Three presents detailed methods relating to the assumptions of the model, as well as results of the analysis. Chapter Four discusses the application of the results of this study and relates these results to existing literature and future research.

Literature Review

The literature review, discusses the environmental impacts of dairy production, the history and present state of dairy production in Iowa and the United States. It also discusses ways in which life cycle assessment is useful for evaluating agricultural systems. The conclusion provides a discussion of uncertainty in environmental assessments.

Environmental impact

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC, 2007) warns that global warming due to human activities may potentially shift climate patterns worldwide; to the benefit of some populations and ecosystems, and to the detriment of others. This global panel of scientists came to a consensus that the changes predicted are more damaging than beneficial, and these changes will likely burden those least able to defend themselves against nature.

The anthropogenic portion of global warming is due to concentrations of carbon dioxide (CO_2) and other “greenhouse gases” in the atmosphere, which cause positive radiative forcing, reducing the amount of heat that the Earth can radiate back into space. This altered energy balance suggests that the Earth may receive more energy than it radiates back to space, leading to a net warming. The United States Environmental Protection

Agency (USEPA) lists agriculture as a significant contributor to emissions of greenhouse gases. The largest emitter of CO_2 in the U.S. is the power generation sector (USEPA, 2006), but potent non-CO_2 greenhouse gases are emitted in from a number of activities. These non-CO_2 gases, such as methane (CH_4) and nitrous oxide (N_2O), cause significantly more positive radiative forcing per unit mass than CO_2 in the short term (IPCC, 2007). According to economic analysis published by the Massachusetts Institute of Technology, “Initial levels of reduction of several of these [non-CO_2] gases can be achieved at low cost relative to CO_2, so they are a natural early target for control efforts” (Paltsev et al., 2007, p18).

Animal agriculture is the source of nearly 40 percent of non-CO_2 greenhouse gas emissions in the U.S., and agriculture in general is responsible for over 70 percent of U.S. N_2O emissions, and approximately 30 percent of CH_4 emissions (USEPA, 2009b). Globally, dairy production accounts for approximately 3 percent of all emissions with global warming potential (GWP) (Sevenster and de Jong, 2008).

Environmental impacts other than greenhouse gas emissions also arise from agricultural activities. The USEPA reports that eutrophication of surface water is an increasing problem that continues to damage aquatic ecosystems and human health. Also, there can be impacts on structures and water bodies from acidifying compounds in the atmosphere, even after point-source control efforts have taken effect (USEPA, 2004; USEPA 2009a). These effects are more local than global. Regional effects are of little consequence for other areas, unless pollution is carried by wind or water to another location. Agriculture is a potentially significant contributor to acidification and eutrophication in the U.S. (USEPA, 2004). Emissions from industry and agriculture that have eutrophication and acidification potential are often subject to direct regulation, such as the Clean Water Act, or more sophisticated forms of market based regulation in the case of sulfur emissions from electricity generators (33 U.S.C.§1251, 2008; USEPA, 2009a). While varying natural and human-induced processes lead to eutrophication and acidification, it is important for any human activity to reduce its contribution to these forms of environmental degradation.

Many studies investigating environmental impacts of dairy production have been conducted during the last decade. Some, such as Casey and Holden (2005a), have simply quantified the global warming potential of the production system, while others have attempted to compare production systems to determine differences in environmental impacts, Arsenault et al. (2009) and Thomassen et al. (2008b). Later studies built on existing literature to test assumptions and sensitivities in methodologies used to evaluate environmental impacts, (Cederberg and Stadig (2003) and Thomassen et al. (2008a). In the literature on environmental burdens of dairy production, GWP is the most frequently analyzed impact. Unlike more localized emissions, GWP emissions are currently unregulated in the United States and in most of the world, but there is debate over creating regulation and markets to lower impacts at a national or global scale. USEPA issued an "advance notice of proposed rulemaking" in July, 2008, that indicated the possibility of taxing methane and other emissions of animal agriculture in the U.S. as part of a larger plan to lower GWP emissions (USEPA, 2008).

Dairy production in Iowa

Iowa has 35.6 million acres of land with twelve percent permanently developed, dedicated to public parks, or forested, or otherwise unsuitable for grazing (NRCS, 2007). Of the 31.2 million acres remaining, 77 percent are devoted to row crops, 4 percent are in CRP programs, and 4.3 percent are in hay and other crops, and 13.6-percent of the state's agricultural acres are potentially available for grazing (NRCS, 2007). There were 4.1 million cattle in IOWA during 2008, 215,000 of which were dedicated to dairy production (NASS, 2009).

The dairy industry in Iowa has changed drastically over the last century. Annual production of milk has ranged from a low of 3.8 million pounds in 1998 to a high of 6.8 billion pounds in 1943. Iowa produced 4.3 billion pounds and ranked 12th in total milk production among U.S. states in 2008 (NASS, 2009). Past herds consisted of a diversity of breeds in small herds fed on pasture. Today, this is considered a low input, low output scenario (Capper et al., 2009). The average herd size in 1965 was 13 cows, and present average herd size is 89 cows in Iowa and 126 cows nationwide (NASS, 2009). In Iowa, the number of cows on farms milking more than 500 cows has grown from less than 5 percent before 1993, when this category was established, to 30 percent in 2008 (NASS, 2009).

Over 85 percent of dairy cattle in the U.S. are of the Holstein breed, and the majority of cows are permanently housed in barns or dry lots, where feed is transported to cows and manure is handled by equipment (USDA, 2007). These cattle are fed diets of hay or ensiled grasses and concentrated energy sources such as grains or ensiled crops.

Using intensified management, scientific feeding, and genetic improvement, production per cow in Iowa has nearly quintupled, from a rolling herd average of 4,132 lb/cow in the 1920s to 20,160 lb/cow in 2008 (USDA, 2007; Capper et al., 2009; NASS, 2009). With increased productivity per cow, fewer producing cows are needed, and the five-year average number of cows in Iowa declined from its peak of 1.5 million in 1934 to a low of 194,000 in 2004 (NASS, 2009).

The increasing size of concentrated animal feeding operations, as labeled by the USEPA (i.e., operations with over 200 lactating cows on one site) raises concerns about pollution, and these large operations are regulated as point source polluters under the Clean Water Act (40 C.F.R, 2008). Operations with fewer animal units are not regulated as point source polluters unless EPA officials determine that the operation is a threat to aquatic systems due to location, history of pollution or a number of other factors. The construction of large confinement dairies is often actively resisted by surrounding communities due to concerns of odor and water pollution.

The trend toward large confinement dairy systems in the U.S. is a trend not seen in other regions of the world. In much of Europe, herds of 20-25 cows represent more than 45 percent of cows (Hospido et al., 2003). New Zealand has large herds, with an average of 351 cows, but a majority of dairy production is from farms using grazing practices (DairyNZ, 2008; Saunders and Barber, 2007).

The effects of increased production of cows in modern dairies, and fewer cows needed to produce the same volume of milk, have led some researchers to assert that present dairy production has less environmental impact than past production methods (Sevenster and de Jong 2008; Arnot, 2009; Capper et al., 2009). Critics of this view, however, point out that in a multi-function system, all products, co-products, and the inter-relationships between them must be considered in any evaluation of environmental impacts (Martin and Seeland, 1999). Beef production, as a co-product of dairy production systems, is one of these factors that could potentially influence overall environmental impact, but is not often considered in studies on environmental impacts of dairy production. In the U.S., it is estimated that 15 to 30 percent of marketable beef is produced from co-products of dairy systems (Ahola et al., 2009). According to USDA slaughter records, culled dairy cows account for 7.4 percent of animals slaughtered for beef over the last 10 years (USDA, 2009). In addition, dairy calves are an important source of veal, and surplus calves from dairy systems are frequently grown to be slaughtered for beef. In Sweden, 70 percent of beef comes from byproducts of the dairy sector (Cederberg and Stadig, 2003). In the European Union, this figure is approximately 50 percent. In contrast to these European sources of beef, the U.S. derives most of its beef from animals specifically bred for beef production. Beef cattle in the U.S. outnumber dairy cattle of almost 10:1 (NASS, 2009).

Beef cow-calf production systems require keeping cows year-round to give birth to calves, which are then grown in a beef production system. Dairy systems can also produce surplus calves, which can be a close substitute for the output of a beef cow-calf system (Cederberg and Stadig, 2003; Burdine et al., 2004).

Beef cow-calf livestock emit 58 percent of the CH_4 from cattle in the U.S. (USEPA, 2009b). If surplus calves from dairy systems were better utilized in the beef sector, these emissions may be avoidable (Martin and Seeland, 1999). Analyses of beef systems suggest that reduction of beef cow-calf numbers, and fuller use of dairy surplus calves, is a potential strategy to reduce environmental impact of beef production (Casey and Holden, 2006). Optimal management of dairy systems in terms of environmental impacts, therefore, might include optimizing the export of calves that will yield satisfactory meat to offset beef calf production. Thus, minimizing environmental impact of dairy production is not achieved by simply optimizing milk output per cow. A methodical assessment of the entire production chain is necessary to seek improvements in the system, and to ensure that emissions and impacts are not simply transferred to other systems.

Life Cycle Assessment

Life cycle assessment (LCA) is a method used to compile and assess total environmental impacts and emissions from the entire life cycle of a product or service. The life cycle of a product includes acquisition of raw materials, processing, use, and final disposal (ISO 14040, 2006). LCA methodology has gained wide acceptance, and though many assumptions are made in its execution, modern assessments are at least minimally comparable if they follow the pattern laid out by the International Organization for Standardization (ISO 14040, 2006). An ISO 14040 compliant LCA consists of 4 parts: goal and scope definition, life cycle inventory, impact assessment, and interpretation. Best practices for important assumptions that must be made in LCA analysis are also included in the ISO standards, such as methods to allocate environmental impacts between products resulting from the same production system.

LCA methodology is well-adapted to evaluate agricultural systems because it provides an objective method of defining the production system and quantifying impacts in terms of the outputs of a production system (Casey and Holden 2005b; Thomassen et al., 2008a). Availability of the farm-produced commodity to be consumed by humans or to enter another production process is generally the extent of modeling in agricultural LCA. This means use and end-of-life scenarios are not considered for agricultural production systems. Typical LCA of a manufactured product is termed a “cradle to grave” analysis because all impacts on the environment from the life of that product have been included. Without a use phase or end-of-life scenario, agricultural LCA is generally termed a “cradle to gate” analysis. This name denotes an analysis that quantifies all environmental impacts of raw materials and processing to deliver the farm product to the farm gate, where another entity is assumed to pick up the commodity (Kim and Dale, 2005; ISO 14040, 2006; Saunders and Barber, 2007).

Use of LCA in agriculture has been expanded to evaluate non-environmental impacts as well. For example, Haas et al. (2001) evaluated rural aesthetics alongside environmental impacts using the LCA framework. The premier software for LCA, SimaPro (PRé Consultants, Amersfoot, The Netherlands), has incorporated the ability to evaluate economics and social impacts (PRé Consultants, 2008b). Evaluations of impacts of an environmental or non-environmental nature can benefit from the strengths of life cycle assessment, the ability to evaluate impacts across the entire lifecycle of a product.

Functional unit in life cycle assessment

In LCA, it is critical to establish a functional unit during the goal and scope phase of the project. If products are to be compared by LCA, it is important that products perform a similar function; this standard exceeds that which considers two end products equivalent simply based on similar volume or size. In multi-function systems such as milk production, co-products as well as inputs to the system are scaled to the production of the functional unit.

Milk produced by dairy cows serves as food for humans and animals and as the basis for processed foods and other products. Important indicators of the ability of milk to perform these functions are its mass, fat content, and protein content. These attributes of milk vary by breed of animal, production intensity, and quality of feed (Dale Thoreson, Iowa State University, Extension Dairy Specialist, pers. comm. 6/5/09). Two equal volumes of milk having different levels of these components are not able to perform these functions equally. As found in LCA literature, raw milk fat content varies from 3.69 percent in the U.S. to 4.45 percent in the Netherlands, and protein varies from 3.05 percent to 3.5 percent (Capper et al, 2008; Thomassen et al., 2008b). These disparities can lead to significant differences in calculations of the resources required to produce a unit of milk if only mass or volume of milk is considered. To aid in comparing dairy systems globally, Sjaunja et al. (1990) developed a formula for correcting the mass of milk to account for the energy it contains. The result of the formula is an “energy corrected milk” (ECM) unit that has become the standard functional unit in dairy LCA (Cederberg and Mattson, 2000; Casey and Holden, 2005a). Some recent LCAs, however, have been published without the ECM factor. The systems compared within such a study may be adequately analyzed using this approach, but results are generally less comparable with the majority of studies (Arsenault et al., 2009; Capper et al., 2009).

Sjaunja et al. (1990) defines the functional unit of a milk production system to be one kg ECM, as shown in Equation 1.1.

Equation 1.1 Energy corrected milk (ECM) calculation (Sjaunja, 1990)

$$\mathbf{ECM = .25W + 12.5F + 7.7P}$$

where W is the weight of the milk (kg), F is fat content (kg), and P is protein content (kg). Other methods of equalizing milk have been used in LCA, such as fat and protein corrected milk, as used by Thomassen and de Boer (2005), Thomassen et al. (2008a), and Thomassen et al. (2008b). However, the methodology for this milk correction factor has been published only in the Dutch language, and it has not been as widely adopted. Additional energy corrected milk equations exist as well, and the equations differ depending on the standard milk analysis to which the analyzed milk is being adjusted (DRMS, 2009). The ECM equation was chosen for use in this analysis to allow direct comparison with other LCA literature on this topic.

Multifunctionality and allocation

Unit processes often produce more than one useful product or material. Such unit processes are referred to as multifunctional. When only a subset of the co-products enters the system being analyzed, a method must be used to disaggregate the inputs and outputs of the multifunctional process so that the inputs and outputs are "allocated" between all of the useful products of the process. This process is called co-product allocation and is a critical consideration in LCA. According to ISO 14041 (1998), allocation should “approximate as much as possible such fundamental input-output relationships and characteristics” of the system in order to prevent distorting results. In dairy production analyses, fluid milk output from the farm is typically the reference flow around which all other flows are scaled. Co-products include meat from cull cows and surplus calves. Hide and offal are also natural co-products of dairy production, as they are constituent parts of a cull cow. These outputs of a dairy system, however, are of insignificant value in all of the allocation methods explored to date, and are generally excluded from analysis in an LCA framework. Several studies have analyzed and discussed the insignificance of hide and offal in LCA (Eide, 2002; Hospido et al., 2003), and many later studies have followed precedent, assigning no value to, and giving no mention of, these co-products (Casey and Holden, 2005a; Thomassen et al., 2008b).

Many different allocation methods have been used to analyze dairy systems, and the sensitivity of LCA results to the allocation method has been tested in European studies (Cederberg and Stadig, 2003; Thomassen et al., 2008b). Cederberg and Stadig (2003) found that environmental burden allocated to the milk product from a dairy system may vary from 63 percent to 100 percent depending upon the allocation system used. Thus, it is important to follow best practices and ISO standards to ensure accuracy and comparability between studies.

The allocation methods found in literature for dairy systems are: no allocation, mass allocation, economic allocation, cause and effect or biological allocation, and allocation avoidance through system expansion. These methods will be discussed in detail in the following pages.

No allocation

This method assigns the entire environmental burden of the production system to the functional unit. No credit is given for co-products produced. This method is used in Phetteplace et al. (2001) and Capper et al. (2009), and it is compared to other allocation methods in Cederberg and Stadig (2003) and Casey and Holden, (2005a). The no allocation method overstates the environmental burden of dairy production relative to analyses that give credit for co-products produced (Cederberg and Stadig, 2003, Casey and Holden, 2005a). This method does not require as much data gathering as other allocation methods, but it also does not accurately represent the flows of energy and emissions within a multi-function system.

Mass

In this method, environmental impacts are allocated based upon the physical weight of the end-products of the system--the functional unit and the co-products. Casey and

Holden (2005a) analyzed this method for a milk production system, and allocated 97 percent of impacts to milk and 3 percent to co-products. Mass-based allocation is important in other industrial sectors, and it is important to understand as a point on the continuum of methodological complexity. Agricultural products and co-products, however, often differ in energy content and density, and therefore the mass allocation method has limited ability to accurately account for environmental impacts of agricultural production.

As with no allocation, this method overstates the environmental burden of milk production because the milk product consists of 87 percent water, giving it much greater weight per unit of energy or protein than the other co-products. If compared on a protein mass basis, the results can be much different. For example, Martin and Seeland (1999) used a protein mass allocation method and allocated 78 percent of the environmental burden to milk and 22 percent to co-products.

Economic Allocation

In this method, impacts are allocated based upon the economic motivation for producing the product and co-products, as determined by prices and volumes produced rather than the physical flow of energy and impacts. For dairy production, this method has allocated 85-92 percent of impacts to milk, and 8-15 percent of impacts to co-products (Cederberg and Stadig, 2003; Hospido et al., 2003; Casey and Holden, 2005a). In the Cederberg and Stadig (2003) analysis, co-products are further broken down into meat and surplus calves, with an allocation of 6 percent and 2 percent of the total impact, respectively. The reasoning behind this method is important to understand because economic profit is generally the motivating force that causes production to happen. There are weaknesses to this method, however, as the prices of the goods are subject to volatility and regional differences that do not correspond to a difference in environmental impact or volume of production. Economic allocation is also subject to market distortions due to agricultural subsidies. Economic allocation is particularly relevant for industrial processes utilizing inputs with multiple uses and producing outputs with multiple substitutes.

Cause and effect/Biological/Energy Allocation

Impacts associated with inputs to a system may be allocated according to how the input is used, and processing steps required for particular products may be allocated to associated final products. In dairy production, some portion of the nutrients and energy consumed in the feed will go to maintaining bodily functions of the animal, known as maintenance energy. Additional energy will be required for growth of the animal's frame and carcass, lactation, and for growth of the calf in a pregnant cow. Software models of cow nutrition, such as the Nutrient Requirements for Dairy Cattle: Seventh Revised Edition (National Research Council, Washington, D.C.), and the Cornell Net Carbohydrate and Protein System (Cornell University, Ithaca, NY), predict how certain feeds provide energy and protein for these different functions. Using these tools, environmental impacts from feed production, enteric fermentation, and manure emissions can be allocated according to the metabolic needs of the animal to produce the product and co-products. This type of analysis performed with cattle in Sweden placed 85 percent of the burden of environmental impact on milk and 15 percent on co-products (Cederberg and Mattson, 2000; Cederberg and Stadig, 2003). Eide (2002) found that only 38-60 percent of various crop and forage inputs to dairy systems are biologically associated with milk production. This study suggests a lower percentage of impacts associated with the milk product than other studies have found, but comparison of these findings with other studies is difficult because key emissions such as enteric fermentation are not considered. Arsenault et al., (2009) also uses the biological allocation method and allocated 32 percent of environmental impacts to co-products. If allocation must be used, this method most closely fulfills the requirement of the ISO standards because it matches impacts to biophysical flows.

System expansion

Standards for LCA published in ISO 14041 (1998) recommend, when possible, integrating the production of co-products into the production of the functional unit to form a larger production system that includes all relevant processes. A substitute for each co-product of the system is then evaluated using LCA methodology in the same way as the functional unit. The environmental impact of the functional unit is reduced by the avoided environmental burden of producing the substitute (Guinée, 2001). System expansion assumes that market demand for the co-products of a system are constant, and that if the co-product was not produced as part of the studied system, the same function would have to be delivered by the substitute product, giving rise to emissions calculated in that system.

System expansion requires greater amounts of data collection than other allocation methods, making it prohibitive in some smaller and older studies (Weidema and Meeusen, 1999; Cederberg and Stadig, 2003). Use of this method is limited when co-products have no close substitutes, or when production processes of substitutes are not well documented. System expansion is well suited for evaluating dairy systems because each co-product has an alternative system of production that can be evaluated using LCA.

System expansion and avoided production

Cederberg and Stadig (2003) laid the foundation for system expansion in dairy, establishing assumptions that surplus calves in the dairy system avoid the production of calves produced in a beef cow-calf system, and that meat from cull cows displaces meat produced in a beef production system. These assumptions are subject to some uncertainty because calves from different breeds are grown using different practices and feeds, and cull cows generally produce meat that cannot displace many of the high-value cuts from feedlot animals.

True equivalency of calves going into feedlot systems would mean that they are able to produce identical products using identical inputs. For an LCA analysis of dairy systems focusing on global warming potential, equivalence would mean the calves produce similar quality and quantity of meat with similar GWP emissions. Equivalence is highly dependent upon the system in which the calf is placed. Research on Holstein steers finds that they produce quality beef, but the systems in which they are grown differ from beef-bred animals (Burdine et al., 2004). Holsteins have genetic potential to be larger animals than most beef breeds, and are generally put directly onto feed after weaning, whereas beef systems may feed the weaned calves on pasture or low-quality feeds for a time. For the Holsteins, moving directly to feedlot allows them to attain marketable meat quality before they become excessively heavy (Burdine et al., 2004). If Holsteins are grown too large, the high-value meat cuts are outside the acceptable range for most purchasers, and thus the carcass value declines. When Holstein steers are grown for meat and slaughtered at an optimal weight, the resulting marketable cuts are indistinguishable from those of beef-type animals (Schaefer, 2005).

Holstein steers can achieve carcass weight to live weight ratios similar to beef-type animals, but their genetics give them high metabolic activity, and thus Holsteins require approximately 20 percent higher maintenance energy, energy which cannot be used for growth (Schaefer, 2005). This difference in the energy required to grow Holstein steers does make the equivalence assumption somewhat uncertain, and analyses using it will need to determine the importance of this assumption and recommend methods to improve it.

Cull cows from dairy and beef systems generally produce meat of a lower quality than animals bred for beef production and slaughtered at an optimal time (Burdine et al., 2004). This is due to the fact that the animals are older and have not been fed to gain the intramuscular fat necessary for tenderness. However, cull cows do supply a significant amount of meat that, if quantity demanded remains unchanged, would otherwise have to be provided by a beef production system. Various characteristics of the meat, such as intramuscular fat and prevalence of injection site lesions, affect the ability of cull cow meat to replace beef from feedlot production systems (Thrift, 2000). Cederberg and Stadig (2003) is currently the only study found in the literature that discusses equivalency of cull cow beef to meat produced in a beef system. Cederberg and Stadig calculate greenhouse gas emissions from Swedish dairy emissions with culled cow meat directly offsetting meat from a beef production system. Because a majority of beef produced in Sweden is derived from by-products of the dairy industry, the equivalency of beef from culled dairy cows and beef cows may not accurately represent the situation in the U.S. Thus, direct offsetting of meat produced in a beef system by cull cow meat is the only precedent set by previous literature, but uncertainty exists, and studies using this assumption should carefully examine the sensitivity of results to this assumption.

Allocation of determinant products

Co-products of grain processing are important feed ingredients in dairy rations, but accounting for the emissions generated by their production is difficult in the system expansion framework. While it is possible to simply use the same process data and switching the functional unit for a by-product does not generally return accurate results (Weidema, 1999). Ethanol, for example generates by-product feed ingredients. As is discussed Weidema (1999), an increase in ethanol demand will increase production of the by-product feed ingredient. The reverse, however is not generally true. An increase in animal feed demand will increase production of the lowest cost appropriate animal feed source. In this case, ethanol is the determinant product flowing from the production process, and to analyze the system with one of the non-determinant co-products as a function unit would lead to inaccuracies.

To determine the environmental impact of the production of a by-product feed, Weidema recommends an economic analysis to establish a substitute for the by-product feed. This substitution, however can be complicated if the substitute product is produced in a multi-function process as well. This can generally be resolved through multiple iterations to determine a reasonable substitution to allow avoidance of allocation by system expansion, though economics of the market as a whole must be known (Weidema, 1999).

Use of LCA in agriculture

Life Cycle Assessment is well-suited for evaluating agricultural systems in part because it is able to avoid “problem shifting,” where processes that cause environmental impacts may be moved out of one system only to cause similar impacts as part of another system, with no change in causality (Guinée, 2001). An example of this strategy is neglecting consideration of environmental impacts of crop production as an aspect of dairy production. In this example, impacts recorded in the dairy system are reduced, but, in reality, the environmental impacts still occur and are attributable to milk production. LCA focuses on the causal links of environmental impacts. Therefore, if a production system demands an input, the full burden of producing that input is added to the impact for the downstream production system (Guinée, 2001).

To perform LCA on an agricultural system, it is critical to define the boundaries of that system, outside of which impacts will not be considered. This is important because an agricultural system interacts with an ecosystem and industrial processes together. To enhance the analysis of the functional unit at hand and limit uncertainty, analyses must define a boundary and exclude some processes that are not well understood or are beyond the scope of the immediate functional unit. Several components of agricultural practice are generally outside the boundary of analysis: interaction between crops in crop rotation, capital goods (machinery, buildings), and land use and soil quality changes. Although several recent analyses have broken with this precedent and have included capital goods and infrastructure in their analysis, this is still uncommon in the literature (Saunders and Barber, 2007).

Soil and the ecosystem surrounding the agricultural production system are important to distinguish as either inside or outside the production system. In LCA methodology, emissions are not considered harmful to the environment until they leave the production system into air, water, or soil. Some impact assessment methods consider soil as part of the technosphere, thus not considering it a natural input to the system (PRé Consultants, 2008a). In these assessments, nutrients and pollutants are allowed to accumulate in the soil, and only actual emissions to air and water from this pool in the soil are quantified in the LCA.

However, most assessment methods consider soil to be an input from nature, and a common assumption in agricultural LCA is that the soil is in equilibrium, with constant pools of nutrients, carbon, and pollutants. According to the University of Leiden (CML) 1992 impact assessment method, “It may be assumed that emissions that initially enter the soil will ultimately appear in the groundwater and hence can be dealt with as emissions to water” (PRé Consultants, 2008a, p. 6). Some of the life cycle inventory databases embedded in SimaPro internalize this assumption by calculating emissions as directly to air and water, as in the United States Life Cycle Inventory database (National Renewable Energy Laboratory, Golden, CO). Under this assumption, additions of fertilizer, pesticides or other pollutants to soil are assumed to move out of the soil into plants, air or water within the time scale of the analysis.

Drawing the boundary on the finished good side is also of particular importance for dairy products. Fluid milk, the least processed dairy product purchased by consumers, is generally processed by pasteurization, cream separation, and bottling. Additional processing steps are needed to create value-added products such as cheese, butter, and yogurt, all adding environmental impacts beyond the farm gate. Even with high levels of post-production processing, studies have found that on-farm production of raw milk accounts for approximately 80 percent of global warming potential emitted in the entire supply chain of dairy products, and on-farm activities are also the largest contributor to other impacts (Capper et al., 2009; Hospido et al., 2003). For this reason, processing steps that take place after milk leaves the farm are generally excluded from the assessment of the dairy production phase.

Hotspots in dairy production

Many LCA analyses of dairy production focus on finding hotspots, which are described as factors in the production system with particularly high emissions, or factors that have large impact relative to the physical flow, that may most easily be reduced. Some studies investigating the broader dairy industry simply conclude that, as the largest emitter of pollution, the agricultural production stage as a whole is the hotspot (Eide, 2002). In studies more focused on the milk production system, a common recommendation is to reduce total concentrated feeds in favor of feeds that require less energy and machinery. A slightly different recommendation is to reduce concentrated feed intake per unit of milk produced, which could come about by increasing the production of the animal or by substituting feeds (Phetteplace et al., 2001; Thomassen et al., 2008b). Concentrated sources of energy and protein, such as corn silage and soybean meal, are a major component of feed rations for modern high-production dairy cattle in the U.S. The inclusion of these feeds has increased dramatically as the U.S. dairy industry has moved away from low-intensity grazing systems. Although they enable the animals to consume sufficient feed to maintain high levels of production, concentrated feeds, as compared to grazing systems, generally require more tractor-hours, fuel, and processing to grow and prepare them for consumption by animals (Arsenault et al., 2009). While it may be a relatively simple, and perhaps even a "costless," activity, to swap specific feed components that create significant emissions, major changes to the dairy system will be required to dramatically shift feed consumption back to low-impact feeds (Hospido et al, 2003). With a significant change in production system to reduce GWP emissions, other environmental impacts are likely to gain importance, such as elevated nitrogen leaching in New Zealand, where studies have demonstrated low greenhouse gas emissions (Saunders and Barber, 2007; Sevenster and de Jong, 2008). Contributing to this particular effect is the fact that changing the feeding system to a less controlled diet based on low-intensity feeds increases the probability that cattle will consume an excess of some nutrients, which, when later emitted as manure, can have environmental impacts. Grass-legume forages, for example, are high in nitrogen, and cows will excrete more nitrogen in manure per calorie consumed than if some of their energy is primarily derived from concentrated energy feeds that are lower in nitrogen, such as corn silage (Velthof et al., 1998; Luo et al., 2008).

Similarly, enteric fermentation is a primary cause of GWP emissions in ruminant livestock systems, but reducing it can create negative feedbacks. Feedstuffs composed of cellulose, such as hay and pasture of grasses and legumes, requires microbial fermentation in the rumen to release usable energy. While making energy available to the animal, this fermentation also allows microbes to release CH_4 into the atmosphere, contributing to GWP emissions. Concentrated energy feeds generally require less fermentation and pass through the gut more quickly, and thus lower emissions are released per calorie consumed. There are tradeoffs to be made, as concentrated feeds may cause more emissions in their production, as discussed previously. Gibbons et al. (2006) found that dairy systems may reduce enteric fermentation emissions by shifting away from grass-based dairying, but other environmental problems may be exacerbated.

Animals require a base level of energy intake to maintain bodily functions, which is termed maintenance energy. Reducing feed intake per unit of milk due to improved genetics or a management practice such as milking three times per day is generally referred to as a "dilution of maintenance." The energy needed for maintaining an animal's mobility and digestive and nervous systems varies little by how much milk is produced by the animal. Under the dilution of maintenance theory, increasing milk production from each animal leads to fewer animals needed to produce the same level of output. Recent papers cite this dilution of maintenance as the driving force in dairy sustainability (Capper et al., 2008; Arnot, 2009; Capper et al., 2009). If higher production does lead to fewer animals needed, this unequivocally reduces environmental impact if the dairy system is viewed narrowly and without consideration of co-production, as Capper and Arnot have done. The ISO standards, however, suggest full accounting for co-products. According to Martin and Seeland (1999), increased milk production and using fewer producing dairy cows have implications for co-product production. This analysis found that increasing milk output of dairy cows did in fact result in fewer cows needed to supply the same milk product, which reduced environmental impact from the dairy system. However, if co-products of beef and calves from the dairy system are considered, and no change in beef demand is assumed, additional beef cows are needed to supply beef calves that are no longer supplied by the dairy system. While beef-bred animals have a higher yield of meat per animal, the additional cows needed to produce calves resulted in greater overall emissions of greenhouse gases (Martin and Seeland, 1999). The 2008 Sustainable Dairy Sector report (Sevenster and de Jong, 2008) compared global emissions of dairy production and found that countries that produce lower GWP emissions from enteric fermentation per unit milk generally have higher total GWP emissions. The primary tools cited by this report for directly reducing enteric fermentation are increased production per cow, and substantial supplementation of the diet with concentrated energy and protein sources. Reducing enteric fermentation using these methods, however, may increase emissions from food production or decrease co-product credits in one way or another. Full system analyses, accounting for co-products, are needed to find paths to reduce emissions from the entire system.

Uncertainty

LCA and other analyses of biological production systems are subject to compounded uncertainties of natural and human origin. Many processes within biological systems are not fully understood by science, and even when much is known, variability in weather and differences in soil and surrounding ecosystems are factors that are difficult to capture in LCA of agricultural systems (Weidema and Meeusen, 1999; Gibbons et al., 2006). For example, Gibbons et al. (2006) found that "N_2O emissions can vary substantially over a [spatial] scale [of land surface] of less than 9 cm. This variation makes scaling-up of emissions, to the farm or even the field scale, potentially difficult." This differs from analyses of highly controlled systems such as power generation, where known and easily measurable quantities of gases are emitted from combustion of fossil fuels. The IPCC default emission factors assume a single N_2O conversion factor for all scales of analysis, which may not take into account considerable differences in emissions on a local scale due to climate, soil conditions, or a number of other factors.

The composition and nutrient content of manure is also source of significant uncertainty in animal agriculture systems. Nutrients contained in manure may volatilize or leach during transport and storage. This possible loss of nutrients can be a source of pollution in air and water, and as the nutrient value of manure may displace synthetic fertilizer, the avoided burden of synthetic fertilizer production is less certain (Weidema and Meeusen, 1999).

In addition to natural variation in many aspects of dairying, variation in practices between dairy producers within the same production system can be just as great as differences between production systems (Dr. Leo Timms, Iowa State University professor of Animal Science, pers. comm., 4/20/2009). These challenges may not present the same degree of difficulty for other systems modeled by LCA, such as industrial processes, which are generally performed in a more controlled environment (Gibbons et al., 2006).

Hospido et al. (2003) studied regional milk production using two operating farms in Spain, and concluded that overall uncertainty in the quantified GWP emissions is 13-17 percent. Gibbons et al. (2006) echoed this conclusion, finding a low confidence level in quantifying absolute emissions at the farm level. In agricultural systems, however, Gibbons found that once a baseline emission is established, modeling improvements on that system can be done with much higher confidence.

Some emissions from biological systems are very sensitive to assumptions made about uncertain factors, such as feed and manure analysis. Accurate estimation of the digestible energy (DE%) in a diet is singularly important in the estimation of feed intake, and thus emissions, as previously emphasized. “A 10% error in [estimating] the average diet DE% will result in CH_4 errors ranging from 12 to 20% depending on circumstance” (IPCC, 2006a, p. 32).

Agriculture LCA deals with particularly dynamic systems with interacting effects not controlled by human intervention. Uncertainty must be recognized and minimized in order to generate the most usable results. Uncertainty can be reduced by using data and prediction models that are most appropriate for the systems being evaluated, and at the highest resolution possible (Weidema and Meeusen, 1999; Gibbons et al., 2006).

Conclusion

In conclusion, literature regarding environmental impacts of dairy systems is plentiful, with many different angles explored. The consensus found in literature is that the production system generates the most impact in the supply chain of dairy products to consumers, that co-products are a critical component to consider in calculating environmental impact of the production system, and that there are trade-offs that must be made to reduce overall impacts. Prior studies have sought to differentiate emissions between dairy systems, but new methods exist to calculate key emissions such as enteric fermentation, and new data on U.S. dairy production enables a more detailed analysis of dairy systems than has been performed in the past. The USDA 2007 Dairy report (USDA, 2007) contains data separated by type of production system, including grazing, combination grazing/conventional, and conventional production systems. These systems differ in some key categories that may lead to different levels of emissions and emissions reduction strategies may look quite different for these different systems. Analysis of these three different dairy systems utilizing best practices from literature and this new data could further the discussion of how to reduce emissions from dairy systems by analyzing more closely the internal factors that influence emissions.

CHAPTER 2 INTRODUCTION TO PROJECT AND ASSUMPTIONS

This chapter presents the first phase of the life cycle assessment process as recommended by ISO standards: goal and scope of the project. This phase of life cycle assessment (LCA) defines the system to be modeled, the functional unit, and boundaries of the analysis.

Goal and scope

This analysis is carried out to estimate global warming potential emissions from three dairy production systems in Iowa: grazing, combination grazing/conventional, and conventional. A cradle to farmgate LCA is performed for these three systems with milk production as the reference flow. The functional unit is defined as one kg of energy corrected milk (ECM), as developed by Sjaunja et al., (1990).

An ISO 14040 (2006) compliant framework is used, and best practices from literature are implemented, to ensure the most rigorous results possible from the available data. Public databases are used whenever appropriate to supplement direct emissions estimates.

The ISO 14041 (1998) best practice of avoiding allocation is achieved by using system expansion to assign emissions to the primary products of the dairy system: milk, surplus calves, and meat from cull cows. System expansion is used for all processes except for by-product feed ingredients. System expansion analysis for by-product feeds from grain processing, requires analysis of feed production markets and lowest-cost substitutable feeds. That level of analysis is beyond the scope of this study, and therefore economic allocation between the products from the grain processing systems is used. Variables and assumptions in each system are analyzed to determine the sensitivity of net emissions. Emissions reduction strategies are then developed based upon the system variables which provide the most potential for emissions reductions.

Boundaries

The boundaries for this analysis are consistent with practices used in literature. These include emissions from the dairy system and production and transportation of consumable inputs to the dairy system. These inputs include energy use in the dairy and the crops fed to the cattle and their inputs of fuel and fertilizer, as well as other upstream inputs (Figure 2.1). Emissions directly from the dairy system include enteric fermentation and manure management system emissions. Emissions from soil due to manure deposition and agricultural inputs are also included. Input of capital goods such as tractors, barns, tanks, and other infrastructure may differ between the modeled systems, but common practice in LCA is to exclude infrastructure, and these are not included in this analysis. The downstream boundary in this analysis is defined as the farm gate. Milk is assumed to be cooled on the farm using energy included in the model, and picked up by an external entity whose transportation and processing are not included.

Boundaries of the beef system are also cradle to farmgate (Figure 2.1). Upstream inputs are accounted for, excluding infrastructure. Direct emissions from enteric fermentation and manure management are included in the analysis. An outline of the modeled systems and a detailed description of underlying assumptions follow.

Carbon Balance

Carbon uptake of plants and respiration of CO_2 by animals is excluded from analysis. Carbon in plants is readily released upon digestion, burning, or decomposition of the crop, and respiration by animals is the release of carbon captured by the plants eaten by the animal. This relatively rapid flux of carbon in and out of plant materials leaves no persistent change in carbon stocks, and thus CO_2 uptake by plants is generally disregarded by LCA (Kim and Dale, 2004; Nathan Pelletier, Dalhousie University, pers. comm., 2009).

The effects of land-use change, effects of cropping rotations, and changes in overall dairy and beef supply are also omitted from this analysis. Carbon in agricultural soils depends on many local geologic and climactic conditions, and this carbon may be released upon a change in crop or change in land use that is beyond the scope of this analysis. Similarly, carbon sequestered in root systems of deep-rooted perennials is generally disregarded from LCA analysis (Kim and Dale, 2004).

Dairy Systems and Assumptions

For this analysis, statistics for the three dairy systems are derived from producer responses in the USDA (2007) report titled "Dairy 2007: Reference of Dairy Cattle Health and Management Practices in the United States." In this survey, producers were asked to identify their operation as conventional, grazing, combination grazing/conventional, organic or other. Organic and other systems were excluded from further analysis. Specific data has been cross-tabulated according to the three remaining categories, and are detailed in the descriptions below. Specifics of each system not detailed in the USDA (2007) report were developed with the aid of dairy specialists and in agreement with literature. Rations for the lactating, dry, and heifer animals have been assembled by a dairy nutritionist to represent typical feeding conditions in Iowa for the projected milk production (Table 2.1).

For the described systems, a model herd based on 100 total cows (milking and dry) is detailed in Table 2.2, rounded to the nearest whole animal. Bulls are not considered in this analysis due to lack of data and widely varying practices on the use of artificial insemination. In addition, data is lacking on the differences in environmental impact between artificial insemination and natural service bulls.

Dairy cows

All three dairy systems analyzed here are assumed to be comprised of Holstein cows. While over 85 percent of dairy cattle in the U.S. are Holsteins, there is greater use of other breeds in the grazing systems (USDA, 2007). The assumption of Holsteins was made to eliminate any effects of animal breed. The Holstein cows in all three dairy systems are assumed to be producing milk with the average analysis for Holsteins in Iowa, 3.7 percent fat and 3.0 percent protein (Dairy Records Management System: Dairy Metrics, Ames, IA, http://www.drms.org). The result of this conversion is that 1 kg of average Iowa milk with this analysis is equivalent to 0.944 kg of energy corrected milk.

It is assumed that Holstein heifers are freshened at 1300 lbs and that mature cows weigh 1500 lbs when culled. Over the milking lifetime of the cow, weight gained by the cow is assumed to be 0.2 lb/day. This gain is taken into account when calculating the nutrient content of manure excretions. At slaughter, the culled cows are assumed to have a dressed weight equaling 55 percent of live weight, or 825lbs (Rob Petersohn, Iowa State University Meat Lab, pers. comm. 5/28/09).

Conventional dairy herd

This management system seeks high milk production by closely controlling the environment of the cows, and by precisely controlled rations. Cows are housed year-round in tie-stall or freestall barns and are fed a total mixed ration (TMR) throughout the year. The modeled conventional herd consists of Holstein cows producing a rolling herd average (RHA) of 22,000 lbs of milk (USDA, 2007; Table 2.3). The average milking lifetime of a cow in this herd is 3.2 years, with calving on average every 13.4 months (USDA, 2007; Table 2.3). Culling and mortality rates, along with interval between calving, age at first calving, and heifer death loss are used to compute the number of replacement heifers needed to maintain the herd (Table 2.3). After replacement heifers are retained, this herd produces 50 calves for sale into other production systems (Table 2.2).

Combination grazing/conventional dairy herd

This management system seeks some of the benefits of pasture-based systems by putting cows on pasture during the growing season, but maintains a high level of production by providing the majority of gross energy intake through concentrated feeds. Manure deposited to pasture conforms to the IPCC definition, which states that manure deposited to pasture is to “lie as deposited, and is not managed” (IPCC 2006a).

This herd consists of cows producing a RHA of 18,330 lb of milk per year (USDA, 2007; Table 2.3). Lactating and dry cows are turned out to graze on permanent pasture during 170 days of each year. Pasture forages contribute 36.5 percent of their daily feed requirements over the grazing season. During the grazing season, cows are housed on pasture and supplemental feed is provided through a mixed ration, and during the winter, cows are housed in a free-stall or tie-stall barn, and a TMR is fed. During the grazing season, animals are assumed to be on pasture continually, except for 2 hours per day when they are in the milking parlor and holding areas. The average milking lifetime of a cow in this herd is

3.8 years, and the cows calve on average every 13.0 months (USDA, 2007). After replacement heifers are retained, this herd produces 57 calves for sale into other production systems (Table 2.2).

Grazing dairy herd

This management system is focused on utilizing fresh forages for the majority of feed intake during the growing season, and dried forages during the winter, with minimal supplementary feed during both seasons. Yield per cow is considerably lower than other systems, but variable costs to feed the cows are generally lower. This herd produces a RHA of 16,530 lbs of milk per cow (USDA, 2007; Table 2.3). Lactating and dry cows are intensively grazed on grass-legume pastures for 170 days per year, with supplementation of grain at 17 percent of gross energy intake. All other assumptions related to grazing time and manure management are the same as the combination grazing/conventional herd. The average milking lifetime of a cow in this herd is 4.8 years, and the cows calve on average every 12.9 months (USDA, 2007; Table 2.3). After replacement heifers are retained, this herd produces 64 calves for sale into other production systems (Table 2.2).

Heifers and calves

For this analysis, it is assumed that heifers are raised in a similar manner regardless of overall dairy system. The heifers are weaned at eight weeks of age and fed pasture and a ration until freshening at 1300 lbs for Holsteins (USDA, 2007). Calf mortality is 6.5 percent within the first 48 hours (USDA, 2007). Surplus calves are assumed to be sold after this 48-hour period; therefore, the calculation of surplus calves takes mortality into account. Mortality of pre-wean heifers (after 48-hours loss) is 7.9 percent and 1.6 percent for post-wean heifers, and is assumed to be equal between systems (USDA, 2007). Transportation is assumed to be insignificant, as 89.4 percent of operations transport heifers less than 50 miles (USDA, 2007). This value was not reported on a per cow basis, and was not able to be tabulated separately for the three different dairy systems analyzed here. While this statistic leads us to believe that the uncertainty would exceed any precision gained, some bias may exist in the size of dairies, as 17.7 percent of large operations (>500 cows) transported heifers more than 50 miles (USDA, 2007). The age at first calving for each system is assumed to be equal to numbers reported by USDA (2007); these are included in Table 2.3.

Excess calves are bull and heifer calves not needed to replace dairy cows in the current production herd. The number of heifers retained in the dairy system is calculated by taking into account culling rates, mortality of cows and calves, interval between calving, and age at first calving.

Farm energy

No research was found that allows direct comparison of the energy consumption in grazing, combination, and conventional dairy systems. Electricity, diesel, and natural gas are the sources of energy discussed and estimated in university extension documents and in the energy audit of Iowa dairy production performed in 2008 by Ensave, Inc. (Ozkan, 1985; University of Wisconsin; Ensave, 2008). Computations of electrical usage were made using published formulas, leading to a range of estimates from 0.0474 to 0.0955 kWh/kg milk (University of Wisconsin, 2009). Most electrical usage estimation methods found in literature use milk production as the primary variable in dairy energy usage on the farm; therefore, this analysis uses an energy estimate per unit of milk production. Wide variation in electrical energy use estimates and lack of data on differences in energy use between the systems prevents precise differentiation of electrical energy use across systems. Equal electrical energy use per kilogram of milk produced in each system is assumed. The Ensave audit reports electrical usage of 0.0686 kWh/kg milk. This value will be used for each dairy production system (Table 2.4).

Energy usage for water heating is discussed but not quantified in the Ensave audit. Natural gas usage for water heating is calculated using the United States Department of Agriculture Energy Consumption Awareness Tool (http://ahat.sc.egov.usda.gov/Dairy.aspx). The fuel is assumed to be natural gas, and the usage is calculated in the tool to be 0.0865 ft^3/kg milk, and is assumed to be equal between systems per kg of milk production (Table 2.4).

Diesel use on-farm for manure management and handling of feed is estimated by Ozkan (1985), and diesel use for non-cropping operations on the dairy is reported in the Ensave (2008) energy audit. Both sources estimate diesel usage of 0.0023 gallons per kg of milk production. Substantial differences exist in the weight and volume of manure that must be handled by the dairy systems, as much manure in the grazing and combination systems is deposited directly to pasture. However, no literature was found to establish causal relationships between diesel usage and volume of manure handled, and the contribution of this energy use to total system emissions is quite small. Therefore, the uncertainty in attempting to estimate different diesel usage between dairy systems exceeds the possible precision gained in the model from consideration of differences in fuel use. The reported value of 0.0023 gallons of diesel per kg milk will be used for all three dairy systems (Table 2.4).

Feed and fodder production

Crops represented in the United States Life Cycle Inventory (USLCI) (National Renewable Energy Laboratory, Golden, CO) are modeled with substantial updates to conform to the boundaries defined for this study. The changes made to processes derived from the USLCI database are detailed on paged 38 under the heading “Databases.” Crops and forage that are not present in the USLCI database are assumed to be grown in Iowa, and are modeled using data from literature. Data from the United States Department of Agriculture: National Agricultural Statistics Service, university extension documents, expert and producer input, and peer-reviewed literature will be used to model these production systems. Specific data used for each feed ingredient is included with results in Table 3.5. Grass hay is assumed to be fertilized with nitrogen (N), phosphorus (P) and potassium (K) macronutrients at average rates prescribed by Iowa State University Extension publications. Legume hay is assumed to be fertilized with P and K at recommended levels. Pasture is assumed to be a mix of legume and grass species, and assumed to be fertilized with P and K.

The trampling rate for forages is assumed to equal harvesting losses from haying, approximately 25-30 percent, and therefore yields of forages are assumed to equal hay yields on a dry matter basis; therefore, nutrient needs are assumed to be the same (Larry Tranel, Iowa State University, Extension Dairy Field Specialist, pers. comm.).

Analysis of crop processing uses data from peer-reviewed studies using U.S. average electrical and fuel mixes, as discussed in the section on databases on page 38. Emissions from the production of by-product feeds are associated with outputs using economic allocation. Commodity price data for this allocation is either the five-year average Chicago Mercantile Exchange prices, or historic price analysis from Iowa State University documents.

Energy inputs to crop production are derived from USLCI data and Iowa State University Extension publications. Fertilizer production is assumed to have environmental impacts as calculated in the USLCI database. Field-level emissions from nutrient application will be calculated using IPCC (2006a) Tier II methods using default emission factors for North America and system-specific activity data.

Transportation

Transportation of feeds produced on-farm is included in the fuel and energy use estimates in the energy audit of Iowa dairy production (Ensave, 2008). Therefore, in this analysis, all feeds that could be produced on-farm are assumed to be transported using fuel accounted for in the energy audit, which is allocated to the functional unit directly, and no additional accounting of transportation is attempted. Feed ingredients that require substantial processing and by-products of processing systems are assumed to be transported to the processor according to findings in the 1996 Iowa Grain Flow Survey. The by-product used by the dairy farm is assumed to be returned the same distance, as presented in Table 2.5 (Gervais and Baumel, 1996). Assumptions for transportation of fertilizers are taken from examples in the USLCI database.

Nutrient and manure management

Manure management systems (MMS) have been shown to be a significant source of emissions on dairy farms (Massé et al., 2008). All manure captured by the MMS is assumed to be handled according to the usage statistics published for North America in IPCC methodology reports (IPCC, 2006a; Table 2.6). All manure produced during the non-grazing season for the grazing and combination system, and year-round for the conventional system, is assumed to be collected and managed by the MMS. Manure captured by a MMS is assumed to be used in lieu of commercial fertilizers with the same N, P, K analysis, with losses of fertilizer value accounted for using a weighted average IPCC default nutrient loss factor for each MMS, according to its usage in U.S. dairying (IPCC, 2006a). This weighted average loss of N is calculated to be 42 percent. P and K are assumed to suffer no loss. Manure deposited directly to pasture is assumed to contribute nutrients to soil at the same loss factor as daily application of manure: 22 percent loss of N, with no loss of P or K. Manure deposited or spread on crops or pasture is assumed to emit gases according to IPCC Tier II methodology using default emission factors and system-specific manure data.

During the grazing period, cows are assumed to be in the holding area or in the milking parlor for two hours per day, and all manure excreted during this time is handled using the MMS assumptions outlined here. This assumes even distribution of manure excretion over a 24 hour period (Dou et al., 1996).

Emissions

Emissions of compounds with global warming potential (GWP) are calculated using relevant IPCC (2006a) Tier I and Tier II methods using system-specific activity data and IPCC default or calculated emissions factors. All emissions with GWP are characterized according to the IPCC 100-year time horizon.

Allocation and interaction with the beef supply chain

Impacts of the dairy production system are highly integrated with the impacts of beef production because co-products of dairy are assumed to displace products that would otherwise be produced in a system focused on meat production. Dressed weight of dairy cull cows is assumed to directly offset dressed weight of beef from a feedlot production system, and surplus bull and heifer calves from the dairy system offset calves produced in a beef cow-calf system (Cederberg and Stadig, 2003). Due to differing energy needs, feedlot practices, and carcass yields between Holsteins and beef-bred animals, these assumptions are not without uncertainty. Therefore, the sensitivity of overall emissions to this assumption is analyzed and discussed.

Beef herd

Emissions produced from the beef system will be quantified using assumptions from Pelletier et al. (in press) and IPCC Tier I and Tier II default emission factors and values. Beef cows have an assumed calving rate of 90 percent, and a culling rate of 15 percent (Pelletier et al, in press). No additional death loss of heifers or cattle is accounted for. An example herd of 100 beef cows is presented in Table 2.2. The annual diet for beef cows and heifers, as analyzed in Pelletier at al. (in press), is presented in Table 2.7. Culled beef cows yield a 440-lb carcass, assuming 55 percent yield from live weight (Pelletier et al., in press; Rob Petersohn, pers. comm.).

In this system, spring-born calves are sent to a feedlot finishing system at approximately 6 months of age. These cattle are fed in the feedlot system for 303 days until slaughter, at a live weight of 637 kg. Carcass weight at slaughter from cattle in this system is 394.9 kg, assuming 62 percent yield (Iowa State University, 2005). The diet to bring feedlot steers to market weight is presented in Table 2.8.

Nitrogen emissions from the beef herd are calculated using the IPCC default emission factor (IPCC 2006a). Emissions of N_2O from nitrogen in manure handled in a dry lot are computed using IPCC default conversion factors for the time period that the cattle are in the feedlot. N_2O emissions from N deposited to pasture are computed for the time that calves spend on pasture using IPCC default emission factors and system-specific animal weight.

Figure 2.1 Boundary of analysis for dairy and beef production systems for life cycle assessment

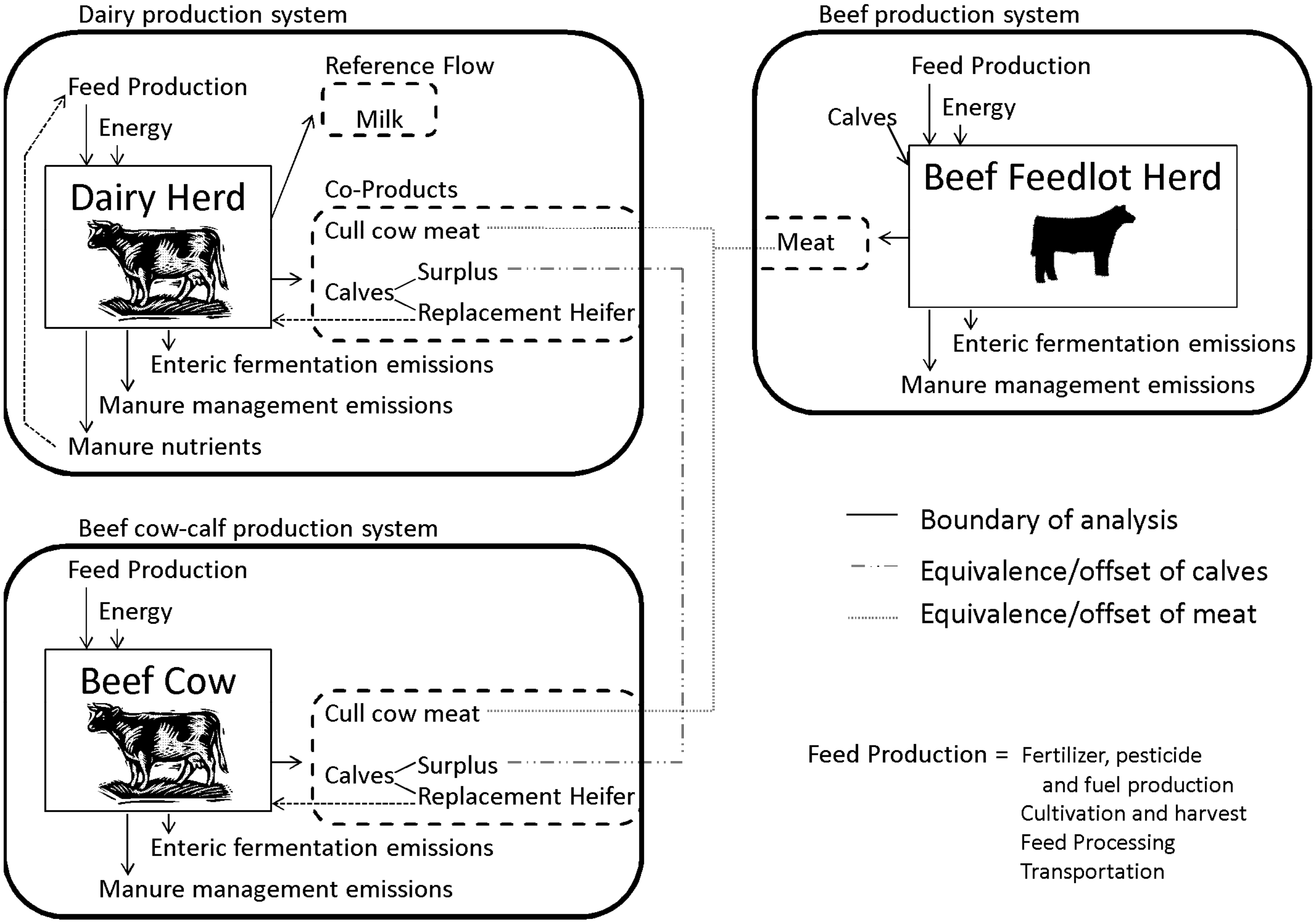

Table 2.1 Daily diet consumed by dairy animals in this study. All values are on a dry matter basis, measured in pounds

	Lactating Cows					**Dry Cows**				**Heifers**
	Graz (Summer)	Graz (Winter)	Graz/Conv (Summer)	Graz/Conv (Winter)	Conv	Graz (Summer)	Graz (Winter)	Graz/Conv (Summer)	Conv[a]	All Systems
Grass-Legume Pasture	35.25		16.43			23.80		20.47		
Corn Silage			8.17	12.25	17.99	3.21	3.21	8.75	10.50	2.98
Corn	3.83	3.83	10.27	8.09	5.22	1.19	1.19			
Grass Hay		17.63					11.90		6.43	
Alf Hay		17.63	2.55	3.40			11.90			
Alf Haylage				7.02	7.74				5.40	5.49
Corn Gluten Pellets				7.12	8.90				1.60	4.45
Dist Grain			3.15	4.50	4.05				0.90	
Wheat Straw			0.35	0.35	0.21				3.60	4.77
Soybean Meal	0.58	0.58	3.40	1.48	1.31	0.42	0.42		0.87	
Mineral Mix	0.47	0.47	1.23	1.12	1.76	0.65	0.65	0.71	0.68	0.30
Soy Hulls	1.72	1.72								
Corn Syrup										2.04
Roasted Soybeans					1.84					
Vegetable Oil	0.04	0.04				0.18	0.18			
Total Dry Matter Intake (lb day^{-1})	41.89	41.89	45.55	45.33	49.02	29.45	29.45	29.93	29.98	20.03

[a] The conventional dry cow diet is also used for the grazing/conventional combination herd during the winter.

Table 2.2 Dairy and beef herds modeled in this analysis, assuming 100 cows, as calculated using cross-tabulated data from the USDA Dairy 2007 report, East region (USDA, 2007)

	Graz	Graz/Conv	Conv	Beef[a]
Total cows	**100**	**100**	**100**	**100**
Lactating cows	86	85	86	-
Dry cows	14	15	14	-
Total heifers	**43**	**56**	**64**	**15**
Unweaned heifers	3	4	5	-
Weaned heifers	18	22	26	-
Yearling heifers	22	30	33	-
Total animals	**143**	**156**	**164**	**115**
Cows culled (yr^{-1})	21	26	31	15
Calves born (yr^{-1})	87[b]	86[b]	84[b]	90[c]
Heifer calves retained (yr^{-1})	23	29	34	15
Calves exported (yr^{-1})	64	57	50	75

[a] Beef herd data compiled using assumptions from Pelletier et al. (in press)

[b] Counted after 48 hours, as reduced by the calf death loss percentage of 6.5 percent (USDA, 2007)

Table 2.3 Cross-tablulated data from the USDA Dairy 2007 report, East region (USDA, 2007)

	Graz	Graz/Conv	Conv
RHA milk (lb yr^{-1})	16,530	18,330	22,000
Total cow replacement rate	20.8%	26.2%	30.9%
Cow removal rate (culling)	17.6%	21.6%	25.1%
Cow mortality	3.2%	4.6%	5.8%
Average milking lifetime (years)[a]	4.8	3.8	3.2
Calving interval (months)	12.9	13.0	13.4
Age at first calving (months)	24.6	25.5	24.7
Average days dry (per lactation)	56.3	59.1	56.1

[a] Calculated as the inverse of the total cow replacement rate

Table 2.4 Energy use per kg energy corrected milk

	Iowa Dairy Systems
Electricity use (kWh)[a]	0.0686
Natural Gas (ft^3)[b]	0.0865
Diesel (gal)[c]	0.0023

[a] Assumed to be equal per unit of milk between systems (Ensave, 2008)
[b] Assumed to be equal per unit of milk between systems (USDA:NRCS Energy Consumption Awareness Tool http://ahat.sc.egov.usda.gov/Dairy.aspx)
[c] Assumed to be equal per unit of milk (Ensave, 2008; Ozkan, 1985)

Table 2.5 Transportation distance assumptions used in the calculation of environmental impacts of processed and by-product feed ingredients*

Feed ingredient	Distance traveled
Corn, to processor[a]	80 km
By-products of corn processing, to farm[a]	80 km
Soybeans, to processor[a]	51 km
By-products of soybean processing, to farm[a]	51 km
Fertilizer, to farm [b]	200km
Fertilizer, to farm (train)[b]	400km

[*] Transportation is via truck unless otherwise noted
[a] Gervais and Baumel, 1996
[b] USLCI database (NREL, Golden, CO)

Table 2.6 Manure management system usage in North American dairies (IPCC, 2006a)

Manure Management System	Percent usage[a]
Lagoon	16.8%
Liquid/slurry	30.3%
Solid storage	29.5%
Daily spread	20.6%
Other (pit storage)	2.9%

[a] After factoring out "Pasture/Range/Paddock" (PRP) as a manure management system. Manure deposited to PRP will be assessed separately in the grazing/conventional combination and grazing dairy systems.

Table 2.7 Annual feed intake for cows and heifers in the beef cow-calf system, measured in tons, as fed (Pelletier et al., in press)

	Beef Cow	Beef Heifer
Pasture	21.61	7.90
Hay	3.26	1.33
Wheat Grain	0.10	0.11

Table 2.8 Feed intake to grow a steer in the beef feedlot production system to market weight, measured in tons, as fed (Pelletier et al., in press)

	Beef Steer
Alfalfa hay – mature	0.33
Corn Silage	0.81
Corn Grain	2.01
Corn Gluten Feed	0.70
Soybean Meal	0.07

CHAPTER 3 METHODS AND RESULTS

This chapter describes the methods used to evaluate the previously described data and assumptions using life cycle assessment. The term "total" emissions will be used to denote total emissions from the production system, not accounting for co-products. "Net" emissions will denote emissions associated with the functional unit net of the "avoided burden" of producing co-products in an alternate system.

Software

SimaPro 7.1 (PRé Consultants, Amersfoot, The Netherlands) is used to compile data for each dairy system and to calculate environmental impacts. This software package aids the researcher by streamlining data entry and unit conversions. Using a professional software package helps prevent errors in time- and labor-intensive LCA, and SimaPro has become a standard and well-accepted tool for LCA. SimaPro also facilitates direct integration of public and private databases, allowing access to a broad spectrum of background data that enhances the accuracy of the current study.

The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), version 3.01, is used, as embedded in SimaPro 7.1, to classify and characterize the environmental impacts in this LCA (Bare et al., 2003). This methodology uses IPCC global warming potential (GWP) emission equivalencies over a 100-year time horizon, which is the only time horizon cited in agricultural LCA literature reviewed for this study. The 100-year time horizon relates only to the lifetime and potency of the emitted gasses in the atmosphere for the purpose of computing an equivalency of all gasses to CO_2. TRACI has the capability to classify and characterize a broad range of impacts relevant to North American environmental risks and sensitivities, which will be useful for future expansion of this project.

Databases

The United States Life Cycle Inventory (USLCI) database (National Renewable Energy Laboratory, Golden, CO) is integrated into SimaPro and used to provide background data for this study. Energy, material, and transportation processes from this database are used as published. The agricultural production processes in this database, however, contain flows that are inaccurate for use in this study. The USLCI agricultural production processes were modified to exclude carbon dioxide ($CO_{2)}$ uptake by plants, as previously outlined in carbon balance section on page 23. The USLCI agricultural production processes, as published, also included several sections that were incorrect or incomplete. The product used to for lime soils was changed from quicklime to limestone. The incomplete sections often contained "dummy" processes which contained quantity data of the input or emission, but no resource use or environmental impacts are associated with the processes. Therefore, these dummy processes are replaced with appropriate processes and inputs from other databases. The U.S. energy mix and transportation assumptions from the USLCI are substituted into processes imported from databases applicable to other countries. The LCA Food DK database (www.lcafood.dk), as embedded in SimaPro 7.1, is the source of data behind potassium (K) fertilizer production and several crop processing procedures.

Enteric fermentation

To estimate methane (CH_4) emissions from dairy cattle due to enteric fermentation, the COWPOLL model is used, as developed by Kebreab et al. (2004). COWPOLL is a mechanistic tool that models nutrient and microbial pools in digestive systems of ruminants and predicts methanogenesis from the entire bovine digestive system (Kebreab et al., 2004). There are many such models, and this one was investigated for use in this study at the recommendation of Dr. Dan Loy, Professor of Animal Science, Iowa State University. Prior LCA studies of dairy production have used the IPCC default CH_4 conversion factor (MCF) to estimate enteric fermentation emissions. The IPCC default MCF is an empirical method of estimation that does not take into account digestibility of feedstuffs, predicting that 6.5 percent of gross energy intake by a dairy cow will be converted to CH_4. When tested against observed data, COWPOLL has been shown to more accurately predict enteric fermentation emissions than empirical methods such as the IPCC default MCF (COWPOLL estimated r=0.75, IPCC estimated r=0.5) (Kebreab et al., 2008). COWPOLL has also been shown to simulate differences in diet more accurately than some other enteric fermentation estimation models that are able to take into account digestibility of feedstuffs (Kebreab at al., 2008). Accurately simulating enteric fermentation emissions across differing diet compositions and gross energy intakes between systems is critical in this study, and therefore COWPOLL was selected.

COWPOLL, in general, predicts lower enteric fermentation emissions than the IPCC default MCF. COWPOLL finds the average CH_4 yield in dairy cattle to be 5.63 percent of gross energy (GE) intake, whereas the IPCC empirical approach estimates CH_4 conversion at 6.5 percent (Kebreab et al., 2008; IPCC, 2006a).

Each daily diet was compiled in the COWPOLL for this project by Dr. Ermias Kebreab (University of Manitoba). Emissions were reported from the COWPOLL model as MJ CH_4, day^{-1} and are converted to kg CH_4 day^{-1} using the IPCC default conversion factor of 55.65 MJ (kg CH_4)$^{-1}$ (IPCC, 2006a). The GE content of the diets was also calculated by Dr. Kebreab. This value for each diet was used as an input to calculating enteric fermentation using the IPCC default CH_4 conversion factor, and the difference between the prediction models is compared and discussed. Enteric fermentation emissions are attributed directly to the daily diets associated with cows and heifers in this study, facilitating tests of different parameters that would change the diet consumed during a year. Emissions from beef cows and beef heifers are computed using IPCC Tier I default CH_4 emissions factors.

Feed production

Diets for each dairy animal are compiled in SimaPro on a daily basis so that changes in parameters, such as number of days on pasture, days dry, and other variables, can be changed to test sensitivity of net emissions to these assumptions. Agricultural commodities modeled in the USLCI database are used with the modifications described previously. Plant production and feeds that are included in the animal rations but not modeled in the USLCI database are compiled using peer-reviewed literature, extension documents, and expert input. Specific sources for each feed ingredient are included with the results in Table 3.5.

Several by-products of grain processing were identified by the nutritionists as imperative for dairying in Iowa. Dry distillers grains, soybean meal, and corn gluten pellets were identified as important by-product feed ingredients for dairy production in Iowa. These feeds are included in the diets in this study, and are modeled according to assumptions in literature, listed with the results in Table 3.5. Allocation of impacts of processing and agriculture to by-product feed ingredients was modeled with economic allocation. Price data for economic allocation are 5 year average prices from Chicago Board of Trade data, with no basis assumed, and Iowa State University extension documents discussing prices. By-product feed ingredients are modeled using agricultural production processes as described earlier, and background processes of energy and transportation from the USLCI database. There are various ways to allocate impacts to products and co-products of processing. Many by-product feed ingredients have been modeled as co-product when another functional unit was being evaluated, such as distillers grain for ethanol production. Simply reversing these analysis, using the by-product feed as the functional unit is possible, but this practice highlights some debate in the LCA community about whether a product should be evaluated to find environmental impacts independent on the system in which it's analyzed, or whether impacts should always be relative to the context in which the product is being evaluated. These by-product feed ingredients are modeled as well using system expansion, with the by-product feed as the functional unit. This difference in allocation method is tested to determine net emissions sensitivity to this assumption, and is discussed later.

Lime is the most significant feed ingredient in the diets that is not derived from a biomass source. It is modeled using the USLCI “limestone, at mine“ system process, following the example of other feed rations modeled in the USLCI database.

Manure management

An IPCC Tier II approach to emissions from manure management systems (MMS) is used, incorporating both IPCC default emission factors for the average Iowa climate and system-specific activity data. Emissions from MMS vary widely by the local climate (IPCC, 2006a). Some IPCC default emissions factors account for temperature, and for these Iowa's annual mean temperature of 9.2°C is used (USNWS, 2009; IPCC, 2006a). This average temperature fits into the lowest category estimated by IPCC default emissions factors, <10°C average annual temperature.

The emission factor for various GWP gas emissions from MMS is assumed to be a weighted average emission factor of the individual MMS, as reported for North American dairies, as presented in the assumptions. Lacking more specific data, this MMS is assumed to be used for all manure deposited to MMS in all three dairy systems. Manure deposited to pasture does not enter a manure management system, and therefore are considered separately using IPCC default emissions factors.

Rations for each animal are compiled in the Cornell Net Carbohydrate and Protein System (CNCPS) (Cornell University, Ithaca, NY), and excretions of nitrogen (N) and phosphorus (P) are calculated on a daily basis. Nitrogen excretion estimates are inputs to the equations for emissions from MMS. Diets are also compiled in the software package that accompanies Nutrient Requirements for Dairy Cattle: Seventh Revised Edition (National Research Council, Washington, D.C.) to corroborate results with the CNCPS model and compute excretion of potassium (K).

Methane (CH_4)

Volatile solids (VS) deposited to the manure management system from each daily ration are calculated according to IPCC formulas, and potential conversion of VS to CH_4 (B_o), is assumed to be 0.24 m^3 CH_4 $(kg\ VS)^{-1}$ for dairy cattle, according to IPCC default values (IPCC, 2006a). The calculated weighted average methane conversion factor (MCF) for manure systems in all three dairy systems is 17.4 percent (Table 3.1). Volatile solids deposited to pasture are assumed to convert to CH_4 at 1 percent of their potential (B_o) (IPCC, 2006a).

Nitrous Oxide (N_2O)

Direct N_2O emissions from MMS are calculated using nitrogen excretion rates predicted by CNCPS, and a weighted average N to N_2O-N conversion factor of 0.003 kg N_2O-N $(kg\ N)^{-1}$. Pasture emissions are calculated at the default conversion factor of 0.02 kg N_2O-N $(kg\ N)^{-1}$ (IPCC, 2006b). Nitrogen excretion from beef animals is calculated using the assumed animal weights from Pelletier et al. (in press) and the Tier I nitrogen excretion formula for North American "other" cattle: 0.31 kg N (1000 kg animal mass)$^{-1}$(day^{-1}) (IPCC, 2006a). Conversion of this N to N_2O uses the same assumptions as dairy cow manure deposits to pasture.

Indirect N_2O emissions from leaching and volatilization of N from manure are calculated using IPCC default N_2O-N conversion factors for N volatilized and leached from manure management systems. The N loss factors from each manure system are combined in the weighted average manure management system assumed in this analysis. These N losses are calculated to be 29.1 percent of N loss to volatilization and 13.1 percent loss to leaching (Table 3.1).

Fertilizer value

Fertilizer derived from MMS, after losses, is assumed to directly replace commercial fertilizers. The IPCC default emission factor for N_2O emitted from N deposited to managed soil is the same for manure application as for commercial fertilizer, so manure directly offset production emissions of fertilizer production, and no difference is modeled in the cropping system (IPCC, 2006b). Nitrogen loss from manure deposited to MMS is the sum of losses due to leaching and volatilization, using the weighted average losses of MMS usage in North America, 42.2 percent (IPCC, 2006a; Table 3.1). Manure deposited to pasture directly offsets the fertilizer needs of the pasture. The grass-legume pasture, as assumed in this model, requires no N fertilizer. Therefore the N fertilizer value in the manure deposited directly to the grass-legume pasture does not displace the production of any fertilizer. The remaining nutrients needed are supplied by commercial fertilizer.

Alternate manure management system

Each dairy system was modeled with an anaerobic digester system substituted for the weighted average manure management system outlined earlier. Only manure captured in the manure management system is assumed to be handled in the digester system. Default IPCC emissions factors and nitrogen loss factors are used with system-specific activity data. All methane produced in the digester is assumed to be captured, and 35 percent of the energetic value is assumed to be used within the digester system to maintain temperature (Barker, 2001; IPCC, 2006a). The remaining captured methane is then assumed to offset natural gas on an energetic equivalent basis (Barker, 2001). The process modeled for the offset is “Natural gas, processed, at plant/US,” from the USLCI database. This process, as published in the USLCI, does not include pipeline transportation or leakages, which could add significantly to the emissions of natural gas production.

Co-products

Co-products of the dairy system, surplus calves and cull cow meat, are assumed to displace products of equivalent function. As outlined by Cederberg and Stadig (2003) the avoided burden of producing the equivalent products are subtracted from the milk functional unit. Cull cow meat quantities vary according to assumptions made in the dairy system concerning culling rate. Cows lost to mortality are assumed to be not usable as meat, and therefore account for no avoided burden of production. The formula to determine export calves uses this culling and mortality data along with statistics on calf death loss and interval between calving as reported in the USDA Dairy 2007 report.

Meat from cull cows is assumed to displace beef from a feedlot system on a dressed carcass weight basis, and surplus calves are assumed to be equivalent to a calf produced in a beef cow-calf system (Cederberg and Stadig, 2003). These assumptions are somewhat uncertain, and could have an impact on the dairy system. Thus, the sensitivity of net emissions to this assumption is tested.

The beef herd modeled is based on assumptions in Pelletier et al. (in press) using IPCC Tier I and Tier II default emission factors for enteric fermentation and manure management. Meat from culled beef cows is also assumed to offset beef from a feedlot production system on a dressed carcass weight basis.

Sensitivity Analysis

Sensitivity tests are performed in this model to determine which variables and assumptions have significant impacts on net emissions. This analysis is important, not only to find which variables are most likely to bring about the desired result of reducing emissions, but also to indicate which assumptions and variables are most important in determining emissions, so that these highly sensitive factors can be more closely scrutinized to reduce uncertainty. The sensitivity for a variable is defined as the percent change in greenhouse gas emissions as a percent of the change in the parameter, (Equation 3.1).

Equation 3.1 Sensitivity of net emissions to changes in parameter values assumed in the dairy models.

$$\text{Sensitivity} = \frac{\dfrac{\Delta Y}{Y}}{\dfrac{\Delta X}{X}}$$

where X is the parameter and Y is the net greenhouse gas emission.

Sensitivity tests for non-numerical assumptions, such as allocation methods, provide the percentage change in greenhouse gas emissions due to the change in assumption, according to Equation 3.2.

Equation 3.2 Sensitivity of net emissions to changes in non-numeric and assumptions in the dairy models.

$$\text{Sensitivity} = \frac{Y_2 - Y_1}{Y_1}$$

where Y_1 is the net greenhouse gas emissions in the base scenario, and Y_2 is the net greenhouse gas emissions resulting when the alternate assumption is used.

Economics and land use

The CO_2-equivalent emissions calculated in this analysis will be used with predicted prices of carbon credits for additional consideration of the economic implications of emissions regulations, (Paltsev et al. (2007).

Switching production from one system to another carries impacts beyond greenhouse gasses. To further explore other impacts, land used in each dairy system for production of feed will be calculated using the land classes defined in SimaPro: arable land and pasture/meadow. Hayed and ensiled grasses and grazed fodder are assumed to be grown on pasture/meadow and all cultivated crops are assumed to be grown on arable land. Land occupied by the infrastructure of the dairy is not considered.

Results

Total environmental impact

The total global warming potential emissions from the dairy systems, without considering credits for co-products, are quite similar, at 1.04 kg CO_2-eq (kg ECM)$^{-1}$ for the grazing system, 1.07 for the combination grazing/conventional system, and 1.02 for the conventional system (Table 3.2). The emission credit from co-products is 34.7 percent of the total emission for the grazing system, 30.9 percent for the combination system, and 27.0 percent for the conventional system. Net emissions attributable to the milk product are 0.681 kg CO_2-eq (kg ECM)$^{-1}$ for the grazing system, 0.736 for the combination grazing/conventional system, and 0.742 for the conventional system.

Global warming potential (GWP) emissions from the dairy systems are classified into five categories to facilitate discussion of positive and offsetting factors that determine net emissions. These categories are enteric fermentation, manure management, feed production, energy, and co-product credits. Figure 3.1 illustrates the balance of gasses emitted from each emission category and the relative contribution of each emission category to net emissions of the dairy systems. Each emission category will be discussed individually in the following sections.

Enteric fermentation

Emissions of methane (CH_4) from enteric fermentation are the largest contributor to environmental impacts in each dairy system, accounting for 50.3 percent of total GWP emissions from the grazing system, 42.5 percent from the combination system, and 37.7 percent from the conventional system (Table 3.2). Lactating and dry cows in each system emit over 80 percent of CH_4 due to enteric fermentation, with the remainder coming from heifers. Enteric fermentation from beef cattle is accounted for in the co-product credits category.

COWPOLL estimates considerably higher CH_4 emissions per megajoule of gross energy feed intake for rations with high amounts of forage than for diets based on concentrates (Table 3.3). The calculated methane conversion factor (MCF) from enteric fermentation using this method ranges from a high of 6.96 percent for grazing dry cows to a low of 4.63 percent for lactating conventional cows. All diets for the grazing dairy system and the combination herd's summer dry cow diet are calculated to have an MCF very near or in excess of the IPCC default value of 6.5 percent. All other diets have an MCF considerably below this value, with a maximum MCF of 5.68 percent for diets not named here. The beef animal diets are assigned a fixed emission per year by IPCC Tier I methods, and therefore have no MCF.

The choice of MCF estimation method for the dairy cattle has a much larger impact on the combination and conventional dairy than the grazing dairy. Using the IPCC default MCF, net emissions and enteric fermentation emissions from the grazing system rise 4.3 percent and 5.4 percent, respectively, over the base case using COWPOLL results. Net emissions and enteric fermentation emissions increase 15.2 percent and 24.6 percent, respectively, for the combination herd, and increase 18.5 percent and 35.8 percent, respectively, for the conventional herd, when the IPCC default emission factor is substituted for COWPOLL (Table 3.4).

Feed production

The feed production impact category accounts for 15.3 percent of total GWP emissions in the grazing system, 23.6 percent in the combination system, and 27.5 percent in the conventional system (Table 3.2). The inverse relationship between enteric fermentation emissions and emissions from feed productions was similar to results reported elsewhere.

The GWP emissions from the production of 1 kg of each feed used is shown (Table 3.5). The feed ingredient with the highest emissions per unit was roasted soybeans, with .885 (kg CO2-eq (kg as fed)$^{-1}$). The feed with lowest emissions per unit was grass/legume pasture, with 0.021 (kg CO2-eq (kg dry matter)$^{-1}$).

Emissions to produce complete daily diets are compiled in Table 3.3. Substantial differences in emissions are shown to exist between high-input and low-input diets. For lactating cows, producing the diet for a grazing cow in summer is associated with emissions of 1.62 kg CO_2-eq day^{-1}, while the diet for a cow in the conventional system is associated with 6.41 kg CO_2-eq day^{-1}. These emissions are directly attributed to the cow, and are not calculated on a kg energy corrected milk basis. A disparity exists for dry cows, where 1.03 kg CO_2-eq day^{-1} is attributed to producing feed for a grazing cow in summer, and 2.27 kg CO_2-eq day^{-1} for a combination or conventional cow during the winter.

Net emissions from the dairy systems are very sensitive to the method used to allocate GWP emissions within crop processing systems that produce co-product feeds. Economic allocation is assumed in the base case. When system expansion, rather than economic allocation, is used with by-product feed as the functional unit, net emissions from the systems rise considerably. With this change from the base case, net emissions and feed production emissions rise by 4.3 percent and 21.4 percent, respectively, for the grazing system, 25.3 percent and 76.7 percent respectively, for the combination system, and 29.5 percent and 80.8 percent for the conventional system (Table 3.6).

Net emissions are very insensitive to changes in the assumed number of days grazing (Table 3.7). Net emissions have a sensitivity of -0.022 and 0.014, for the grazing and combination systems, respectively, measured in percent change in emissions per percent change in assumed days grazing. Feed production emissions decrease slightly with additional days grazing, but these reductions are offset by increases in enteric fermentation and manure management emissions, resulting in a slight increase in emissions for the grazing system, and a slight increase in emissions from the combination system.

Manure management

Emissions from manure management are very similar among the three systems tested per kg ECM. Emissions from manure management account for 25.9 percent of total emissions from the grazing system, 25.0 percent from the combination system, and 25.3 percent of the conventional system (Table 3.2). While emissions from manure management, accounting for the fertilizer credit, are nearly equal, manure management in the three dairy systems differs significantly on the species of gases emitted from manure management. The grazing system derives 65.0 percent of the manure management GWP emissions from nitrous oxide (N_2O), largely due to nitrogen in manure excreted to pasture, with the balance emitted as CH_4 (Table 3.8). The combination system emits 62.0 percent N_2O and 38.0 percent CH_4. GWP emissions due to manure management from the conventional system are 63.0 percent CH_4, with the balance emitted as N_2O. Manure management emissions offset by avoided fertilizer production total 5.0 percent for the grazing system, 6.0 percent for the combination system, and 8.8 percent for the conventional system (Table 3.9).

Net emissions from the dairy systems are estimated using an alternate manure management system, using IPCC Tier II default values for an anaerobic digester manure management system. The result is a 29.1 percent reduction in overall emissions, and a 13.3 percent reduction in manure management emission within the grazing system. These reductions were 13.2 percent and 31.5 percent for net emissions and manure management emissions, respectively, and for the conventional system, 23.5 percent and 76.3 percent (Table 3.10). The conventional system benefits much more from an anaerobic digester system than the other systems because a higher percentage of manure is captured in the MMS, reducing emissions more effectively and transforming the emission of methane into a useable stream that avoids production of natural gas.

Co-products

The production of co-products of meat and surplus calves in the dairy system results in a net reduction of emissions associated with milk production due to avoided burdens of producing the meat and calves in another system. Emissions avoided by producing these products within the dairy system equals 34.7 percent of total emissions for the grazing system, 30.9 percent for the combination system, and 27.0 percent for the conventional system (Table 3.2). In addition to the difference in percentage of total emissions offset, the balance between offsets from calves and cull cow meat is different between the systems (Table 3.12).

Production of one calf in the beef cow-calf system is associated with emissions of 2,520 kg CO_2-eq (Table 3.11). This quantity of GWP emissions is directly credited to the dairy production system for every calf produced that is not needed to replace cows that are currently milking or dry. Due to calving and replacement rate assumptions made in this study, resources for 1.33 beef cow-years are needed to produce one calf available to be grown in a feedlot system. Production of meat in a beef production system is associated with emissions of 14.2 kg CO_2-eq per kg of dressed weight (Table 3.11).

Net emissions calculated from each dairy system are sensitive to the assumption that co-products produced directly offset production in other systems. Sensitivity to the calf equivalency and meat equivalency are -0.338 and, -0.115, respectively, for the grazing system, -0.250 and -0.136, respectively, for the combination system, and -0.181 and -0.143, respectively, for the conventional system, measured in change in net emissions per percent change in the variable (Table 3.7).

Sensitivities

Many input variables in this analysis are tested to determine net emission sensitivity, as discussed in each emissions category. Additional variables were tested and are presented in Table 3.7. Net emissions are most sensitive to the interval between calving in each dairy system, as reported by the USDA Dairy 2007 report (USDA, 2007). The grazing dairy system has a sensitivity of 0.338, the combination system, 0.360, and the conventional system, 0.303, measured in percentage change in net emissions per percentage change in the variable. Testing the sensitivity of this variable did not include accounting for milk production effects of changing the interval between calving.

The emissions categories as discussed above are recalculated and displayed in Table 3.13 on a net emissions basis to determine the sensitivity of net emissions to direct changes in emissions in each of these categories. Of the impact categories, enteric fermentation has the most influential effect on net emissions, with a sensitivity of 0.767 for the grazing system, 0.618 for the combination system, and 0.519 for the conventional system, measured in percentage change in net emissions per percentage change in the variable. Net emissions of all three systems are also sensitive to feed production and manure management emissions changes, with the conventional system most sensitive to feed production, and all the systems nearly equally sensitive to manure management emissions.

Default emissions factors used from IPCC literature was tested for sensitivity as well to find their effect on net emissions (Table 3.14). The Tier I emission factor for enteric fermentation from beef cattle was found to have strong influence on net emissions in all three systems. This sensitivity is larger than many of the variables in the dairy system that may be paths to reducing emissions.

The methane conversion factor for the manure management system in the conventional system also has a large influence on net emissions in the base case. The influence of this factor is almost completely eliminated, however, in the test case with an anaerobic digester system, as all methane is assumed to be captured, and the amount of methane converted influences only the avoided production of natural gas, which is a very small part of the impact of the system.

Land use and carbon prices

Land use for feed production in each system is calculated in Table 3.15. Total and net land use are 1.46 m^2/kg ECM and 0.326 m^2/kg ECM, respectively for the grazing system, 1.22 and 0.210 m^2/kg ECM for the combination system, and 1.13 and 0.314 m^2/kg ECM for the conventional system. These values reveal a considerable offset of land use due to avoided production of co-products in other systems. The use of arable land and pasture/meadow varies considerably between systems per kg ECM, with the grazing system using less arable land and greater pasture/meadow. Land use per cow-year is also presented in Table 3.15. Differences in land use per cow-year are exacerbated by differing levels of production in the three dairy systems. A cow in the grazing system occupies slightly less land than a cow in the conventional system, but produces much less milk.

The possible value of carbon credits over the next 25 years, as predicted by Paltsev et al. (2007) is presented in Table 3.16. Combining these prices with predicted net CO_2-equivalent emissions from each dairy system in this study, the possible value of carbon credits needed to offset production of one kg ECM is extremely small. However, after inflating to a hundredweight, as milk is sold in the U.S., climate regulation could have economic impacts of $1.77-1.92 per hundredweight of milk for these dairy systems.

Figure 3.1 Global warming potential emissions for dairy systems in this study with results separated by emitted gas

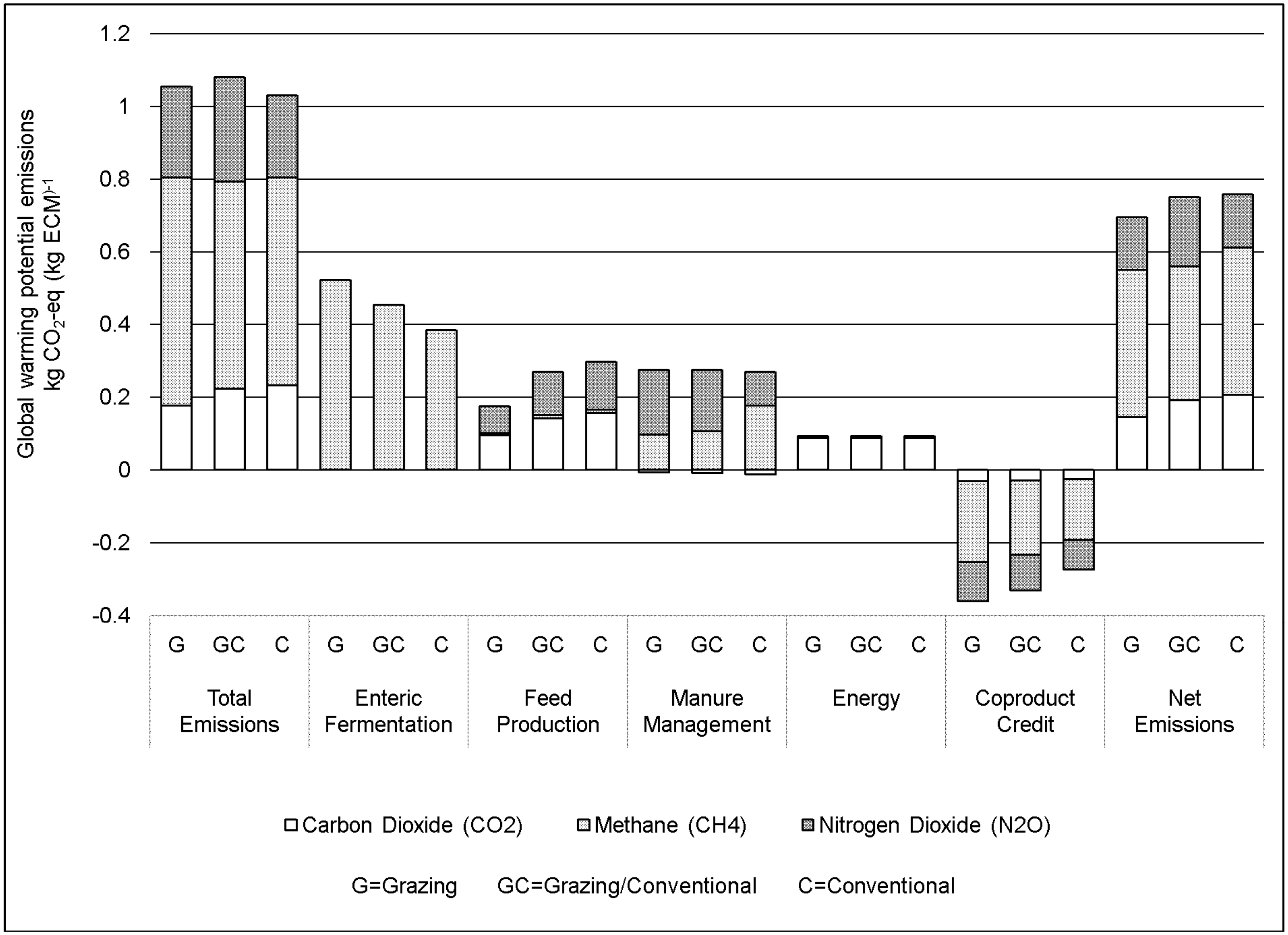

Table 3.1 Emission and conversion factors used to calculate emissions from manure management systems*

Manure Management System	Usage[a]	CH_4 emissions factor[b]	N loss from MMS (volatilization of N-NH_3 and N-NO_x)	N Loss from MMS (leaching)	Total N loss from MMS	Direct N_2O emission factor (kg N_2O-N (kg N)$^{-1}$)
Lagoon	16.8%	66.0%	35%	42%	77%	-
Liquid/slurry	30.3%	17.0%	40%	-	40%	0.005
Solid storage	29.5%	2.0%	30%	10%	40%	0.005
Daily spread	20.6%	0.1%	7%	15%	22%	-
Other (pit storage)	2.9%	17.0%	28%	-	28%	0.002
Weighted average		17.4%	29.1%	13.1%	42.2%	0.003

* All values used in the model are weighted average values as calculated here. All dairy systems are assumed to use the same mix of manure management systems, though systems that include grazing will deposit some percentage of manure directly to pasture, the emissions of which are calculated separately.

[a] Percent of usage in North American dairy systems, after factoring out Pasture/Range/Paddock (IPCC, 2006a)

[b] System-specific methane conversion factor (MCF) that reflects the portion of theoretically potential methane conversion (B_o) that is achieved

Table 3.2 Quantity and classification of global warming potential emissions per kg energy corrected milk, measured in kg CO_2-equivalent, using the IPCC 100 year characterizations (IPCC, 2006a)

	Graz	Graz/Conv	Conv
Total Emissions (No Allocation)	**1.04**	**1.07**	**1.02**
Enteric Fermentation[a]	0.523	0.455	0.385
Manure Management[b]	0.269	0.267	0.258
Feed Production[c]	0.159	0.253	0.281
Energy[d]	0.092	0.092	0.092
Co-Product Credit[e]	-0.361	-0.331	-0.275
Net Emissions (System Expansion)	**0.681**	**0.736**	**0.742**
Enteric Fermentation[f]	50.3%	42.5%	37.7%
Manure Management[f]	25.9%	25.0%	25.3%
Feed Production[f]	15.3%	23.6%	27.5%
Energy[f]	8.9%	8.6%	9.0%
Co-Product Credit[f]	-34.7%	-30.9%	-27.0%

[a] Calculated using COWPOLL enteric fermentation emission estimation method (Kebreab et al, 2004)

[b] Emissions calculated according to IPCC (2006a), and includes reduction in emissions from avoided production of fertilizer due to nutrient value of manure, subject to losses outlined in IPCC (2006a).

[c] By-product feed ingredients are allocated using economic allocation. Transportation distances for processed feed ingredients are derived from Gervais and Baumel (1996) and the USLCI database (National Renewable Energy Laboratory, Golden, CO).

[d] Energy use derived from the energy audit of Iowa dairy production (Ensave, 2008), Ozkan (1985), and the United States Department of Agriculture Energy Consumption Awareness Tool (http://ahat.sc.egov.usda.gov/Dairy.aspx).

[e] By-products of the diary system offset beef and calves modeled in this study using assumptions from Pelletier, et al. (in press).

[f] Percentages are calculated using total emissions as the denominator

Table 3.3 Global warming potential emissions from production and digestions of daily diets fed to cattle

				Enteric fermentation			Production	Manure management	
	Dairy system	Diet		Gross energy content[a] (MJ)	IPCC CH_4[b] (kg day^{-1})	COWPOLL[c] CH_4 (kg day^{-1})	COWPOLL calculated MCF[d]	Total emissions (kg CO_2-eq day^{-1})	Volatile solids[e] (kg day^{-1})	N excretion[f] (kg day^{-1})
Lactating cows	Grazing	Summer	337	0.393	0.385	6.36%	1.62	5.216	0.527
		Winter	337	0.393	0.385	6.36%	3.20	5.264	0.408
	Graz/Conv	Summer	371	0.433	0.379	5.68%	3.97	5.971	0.521
		Winter	381	0.445	0.322	4.70%	5.25	6.713	0.466
	Conv		415	0.485	0.346	4.63%	6.41	7.439	0.537
Dry cows	Grazing	Summer	240	0.280	0.300	6.96%	1.03	3.103	0.410
		Winter	240	0.280	0.300	6.87%	1.49	3.130	0.330
	Graz/Conv	Summer	244	0.285	0.299	6.84%	1.01	3.654	0.369
		Winter	240	0.280	0.240	5.56%	2.27	5.109	0.290
	Conv		240	0.280	0.240	5.56%	2.27	5.109	0.290
Dairy heifers				0.201	0.157	5.07%	2.19	3.108	0.173
Beef cows			-	0.145[g]	-	-	1.02	-	-
Beef heifers			-	0.145[g]	-	-	0.47	-	-

[a] Estimated by Dr. Ermias Kebreab, University of Manitoba

[b] Using IPCC default MCF of 6.5 percent conversion of GE to CH_4 and diet-specific GE from diets outlined in this study (IPCC, 2006a)

[c] COWPOLL methodology from Kebreab et al. (2004) using diets outlined in this study

[d] Calculated using diet specific GE and COWPOLL predicted CH_4 emissions per day

[e] Calculated using the IPCC (2006a) method and diet-specific GE and DE, IPCC default urine energy loss, Ash percentage calculated in CNCPS for the diet

[f] Calculated from system-specific diet using the Cornell Net Carbohydrate and Protein System (CNCPS)

[g] IPCC Tier I default value for "other cattle"

Table 3.4 Sensitivity of net emissions and enteric fermentation emissions to the method used to calculate enteric fermentation, measured in kg CO_2-eq (kg energy corrected milk)$^{-1}$

		Graz	Graz/Conv	Conv
COWPOLL (Kebreab et al., 2004)	**Net emissions**	**0.681**	**0.736**	**0.742**
	Total enteric fermentation emissions[a]	0.523	0.455	0.385
IPCC (IPCC, 2006a)	**Net Emissions**	**0.710**	**0.848**	**0.879**
	Total enteric fermentation emissions[a]	0.551	0.567	0.523
Net emissions change[b]		4.3%	15.2%	18.5%
Enteric fermentation change[b]		5.4%	24.6%	35.8%

[a] Emissions only from dairy animals. Enteric fermentation calculations from the beef system were not calculated using COWPOLL, and are therefore not subject to this assumption.

[b] Results differed based on method of estimating enteric fermentation emissions (COWPOLL and IPCC methods). In this analysis, COWPOLL is the base method, and emissions calculated using COWPOLL are used as the denominator in calculation of sensitivity.

Table 3.5 Global warming potential emissions from production of individual feed ingredients included in the diets of cattle

Feed	**GWP emissions ($kg\ CO_2$-eq kg^{-1}) as fed**	**Notes**	**Sources**
		Grains & Residues	
Corn, grain	0.256	USLCI, removed carbon uptake by plant, replaced "dummy process" of K fertilizer with production process copied from LCA Food DK database, updated with U.S. Energy. Updated herbicide/pesticide dummy production process with energy assumptions from West and Marland (2002)	West and Marland (2002)
Corn silage	0.072	Updated Corn, Grain process above with fertilizer recommendations (percentage change from corn following corn) and yield for same years as USLCI data (1998-2000)	Iowa State University (2009); NASS (2009)
Soybean, grain	0.840	USLCI, removed carbon uptake by plant, replaced "dummy process" of K fertilizer with production process copied from LCA Food DK database, updated with U.S. Energy. Updated herbicide/pesticide dummy production process with energy assumptions from West and Marland (2002)	
Roasted soybeans	0.885	Soybean grain processed according to documentation provided by Dietz-Wetzl equipment manufacturing company	www.Dietz-Wetzl.com (2009)
Wheat straw (Energy Alloc)[a]	0.173	USLCI, adjusted allocation between grain/straw (Originally 100%, 0%) to reflect energetic value of each product (58% grain, 42% straw).	Sauvant (2001); Brian Lang, Iowa State University Extension, pers. comm.
Wheat straw (USLCI default alloc)[d]	*0.000*	*USLCI without modification, assumes entire burden of crop is borne by grain production*	
		Byproducts	
Dry distillers grains (Econ Alloc)[b]	0.296	Dry mill ethanol process, allocated impacts between DDG and ethanol using 5 year average ethanol price of \$2.20 and \$115/ton DDG, and yields as reported in literature.	Shapouri et al. (1995); Futures.tradingcharts.com (2009); CARD (2009)
Dry distillers grains (Sys Exp)[cd]	*1.620*	*Dry mill ethanol process as reported in literature, system expansion with ethanol offsetting gasoline production at energetic equivalent*	*Shapouri et al. (1995)*

Table 3.5 (Continued)

Feed	**GWP emissions ($kg\ CO_2$-eq kg^{-1}) as fed**	**Notes**	**Sources**
Corn gluten feed (Econ Alloc)[b]	0.432	Wet mill ethanol process, allocated impacts between ethanol, corn gluten feed, and corn oil using 5 year average prices of $2.20/gallon, $231/ton corn gluten meal, $96/ton corn gluten feed, and $.37/lb corn oil, and yields as reported in literature.	Wang (1999); GREET (Argonne National Laboratory – Argonne, IL); Renouf et al. (2008); Futures.tradingcharts.com (2009); CARD (2009)
Corn Gluten feed (Sys Exp)[cd]	*1.060*	*Wet mill ethanol process, system expansion with ethanol offsetting gasoline production at energetic equivalent, unrefined corn oil offsetting palm oil on mass basis, and corn gluten meal offsetting soybean meal on mass basis.*	*Wang (1999); GREET (Argonne National Laboratory – Argonne, IL); Renouf et al. (2008)*
Soybean meal (Econ Alloc)[b]	0.660	LCAFood DK database, replaced European/Danish energy processes with U.S. soybean grain input, U.S. energy mix, and U.S. Transportation assumptions. Oil yield offsets USLCI crude palm oil.	Gervais and Baumel (1996)
Soybean meal (Sys Exp)[cd]	*0.703*	*LCAFood DK database, uses replaced European/Danish energy processes with U.S. energy mix, soybean grain input, U.S. energy mix, and U.S. Transportation assumptions. Oil yield offsets USLCI crude palm oil.*	*Gervais and Baumel (1996)*
Soy hulls	0.660	Assumed to be same impact as soybean meal - both co-products of soybean processing, and soy hulls generally included in soy meal unless fiber content limit is reached.	Ohio State University (2009)
Forages			
Grass-legume pasture (Dry Matter)[e]	0.021	Yield from NASS, establishment inputs detailed in ISU Extension AG-96, stand assumed to last 4 years.	Iowa State University (2001); Iowa State University (2008)
Grass hay	0.104	Yield from NASS, establishment and fertilizer inputs detailed in ISU Extension AG-96, stand assumed to last 4 years	Iowa State University (2001); Iowa State University (2008)
Alfalfa hay	0.042	Establishment inputs and fertilizer, and fuel use for harvesting as detailed in Extension publications	Iowa State University (2001); Iowa State University (2008); Kopecky et al. (2008); Schulte and Kelling (2009)

Table 3.5 (Continued)

Feed	GWP emissions ($\mathrm{kg\ CO_2\text{-}eq\ kg^{-1}}$) as fed	Notes	Sources
Alfalfa haylage	0.028	Establishment inputs and fertilizer, and fuel use for harvesting as detailed in Extension publications,	Iowa State University (2008); Iowa State University (2001); Kopecky et al. (2008); Schulte and Kelling (2009)
Manufactured Products			
Corn Syrup	0.285	Dry matter basis impact same as sugar (USLCI)	

[a] Energy Allocation - Impacts of production are allocated by the relative mass and energy content per unit mass of each product

[b] Economic Allocation - Impacts of production are allocated by the relative mass and value per unit mass of each product

[c] System Expansion - Impacts of production are allocated by system expansion, using the listed feed as the functional unit

[d] Was not used in the analysis - used for comparison of allocation method only

[e] Dry Matter basis

Table 3.6 Sensitivity of net emissions to the allocation method used to account for impacts of by-product feed production. Emission units are CO_2-eq (kg energy corrected milk)$^{-1}$

		Graz	Graz/Conv	Conv
Economic Allocation	**Net emissions**	**0.681**	**0.736**	**0.742**
	Feed production emissions	0.159	0.253	0.281
System Expansion	**Net emissions**	**0.710**	**0.922**	**0.961**
	Feed production emissions	0.193	0.447	0.508
Net emissions change		4.3%	25.3%	29.5%
Feed emissions Change		21.4%	76.7%	80.8%

Table 3.7 Sensitivity of net emissions to change in the given parameter in each dairy system. Unit of measurement is percentage change in net emissions per one percent change in the variable.

	Graz	Graz/Conv	Conv
Interval between calving	0.338	0.360	0.303
Dairy calf equivalency with beef calves	-0.338	-0.250	-0.181
Cull cow meat equivalency with feedlot beef	-0.115	-0.136	-0.143
Culling Rate	0.117	0.129	0.115
Mortality Rate	0.059	0.068	0.074
Number of days grazing per year	-0.022	0.014	-

Table 3.8 Percentage contribution of methane (CH_4) and nitrous oxide (N_2O) to total global warming potential emissions from manure management (MM). Emission units are CO_2-eq (kg energy corrected milk)$^{-1}$

	Graz	Graz/Conv	Conv
Total MM emissions (no fertilizer offset)	**0.283**	**0.283**	**0.284**
Nitrous Oxide (N_20)	0.184	0.176	0.105
Methane (CH_4)	0.099	0.108	0.179
Nitrous Oxide	65.0%	62.0%	37.0%
Methane	35.0%	38.0%	63.0%

Table 3.9 Emission offset of manure management due to fertilizer value of manure and, therefore, avoided production of synthetic fertilizer. Emission units are CO_2-eq (kg energy corrected milk)$^{-1}$

	Graz	Graz/Conv	Conv
Manure management emissions (no fertilizer credit)	0.283	0.284	0.283
N Fertilizer credit	-0.013	-0.015	-0.023
P Fertilizer credit	-0.001	-0.001	-0.001
K Fertilizer credit	-0.000	-0.000	-0.001
Net manure emissions (with fertilizer credit)	**0.269**	**0.267**	**0.258**
Fertilizer credit of manure emissions	-5.0%	-6.0%	-8.8%

Table 3.10 Sensitivity of manure management emissions to changing manure management system to anaerobic digester*, using IPCC default emission factors. Emission units are CO_2-eq (kg energy corrected milk)$^{-1}$

		Graz	Graz/Conv	Conv
Weighted average MMS	**Net emissions**	**0.681**	**0.736**	**0.742**
	Manure management emissions	0.269	0.267	0.258
Anaerobic digester	**Net emissions**	**0.588**	**0.635**	**0.561**
	Manure management emissions	0.191	0.183	0.061
	Avoided natural gas production	-0.009	-0.009	-0.016
Net emissions change		-13.7%	-13.7%	-24.4%
Manure management emissions change		-29.1%	-31.5%	-76.3%

* This calculation assumes that all manure handled in a manure management system is handled in an anaerobic digester designed to capture and utilize the methane. Nutrient losses and emissions of other gasses are calculated according to default emission factors and system-specific activity data as outlined in IPCC (2006a). A 100 percent capture of methane is assumed. 35 percent of the energetic value of the captured gas is assumed to be used in the digester, and 65 percent is assumed to offset natural gas production.

Table 3.11 Emissions associated with beef feedlot and cow-calf production system modeled in this study according to assumptions developed in Pelletier et al. (in press). Emission units are kg CO_2-eq per unit specified in each column

	Beef[a] (kg dressed weight)$^{-1}$	Beef cow (yr^{-1})	Beef heifer[b] (yr^{-1})	Beef calf[c]
Total emissions	**14.2**	**2,320**	**1,830**	**2,520**
Beef calf	6.66	-	-	-
Enteric fermentation	4.08	1,220	1,220	-
Feed production	2.43	374	170	-
Manure management	1.03	450	396	-
Energy	0.03	8	12	-
Beef heifer	-	270	-	-
Cull meat offset	-	-426[d]	-	-
Net Emissions	n/a	**1,890**	n/a	n/a
Beef calf	46.9%	-	-	-
Enteric fermentation	28.7%	52.6%	66.7%	-
Feed production	17.1%	16.1%	9.3%	-
Manure management	7.3%	19.4%	21.6%	-
Energy	0.2%	0.3%	0.7%	-
Beef heifer	-	11.6%	-	-
Cull meat offset	-	-18.4%	-	-

[a] Meat produced in a beef feedlot system; all assumptions from Pelletier et al. (in press)
Dressed weight assumed to be 62 percent of live weight for meat-type animals (Iowa State University, 2005)

[b] Emissions from heifers as calculated here includes only the emissions relating to the maintenance and growth of the animal during one year. Emissions associated with the calf that becomes a heifer and emissions after the first calving are calculated with the calf and cow.

[c] Calf at birth, for comparison to surplus dairy calves that are exported from the dairy system 48 hours after birth. 1.33 beef cow-years are required to produce 1 calf for export to the beef feedlot system due to death loss and retention of heifers to replace cows.

[d] Dressed weight of 440 lbs, at 55 percent dressed weight yield from live weight (Pelletier et al, in press; Rob Petersohn, pers. comm.)

Table 3.12 Percentage of total emissions offset by avoided production of beef calves and beef from a feedlot production system. Emission units are CO2-eq (kg energy corrected milk)$^{-1}$

	Graz	Graz/Conv	Conv
Total Emissions	**1.04**	**1.07**	**1.02**
Calf Offset	-0.229	-0.185	-0.133
Meat Offset	-0.133	-0.147	-0.142
Calf Offset	-22.09%	-17.3%	-13.0%
Meat Offset	-12.8%	-13.7%	-13.9%

Table 3.13 Sensitivity of net emissions to change directly in the emissions categories defined in this study. Unit of measurement is percent change in net emissions per one percent change in the variable

	Graz	Graz/Conv	Conv
Enteric Fermentation	0.767	0.618	0.519
Feed Production	0.394	0.363	0.348
Manure Management	0.233	0.344	0.379
Energy	0.135	0.125	0.125
Co-Product Credit	-0.529	-0.450	-0.371

Table 3.14 Sensitivity of net emissions to changes in IPCC default emissions factors and conversion factors used in this study

	Graz	Graz/Conv	Conv
Enteric Fermentation emission CH_4 - Beef Cattle	-0.317	-0.269	-0.218
CH_4 conversion factor - manure management system	0.135	0.133	0.235
N to N_2O-N conversion factor - pasture deposited manure	0.162	0.128	-
Daily N excretion factor - beef cattle	-0.106	-0.090	-0.070
N to N_2O-N conversion factor - manure handled in MMS	0.026	0.022	0.038
Indirect N to N_2O-N conversion factor - N volatilization from MMS	0.023	0.022	0.035
Indirect N to N_2O-N conversion factor - N leaching from MMS	0.009	0.005	0.011
Manure management emission CH_4 - Beef Cattle	-0.006	-0.005	-0.005
CH_4 conversion factor - pasture deposited manure	0.006	0.005	-

Table 3.15 Direct land use in the modeled dairy systems,* measured in m^2

	Graz	Graz/Conv	Conv
Total land use (per kg ECM)	**1.46**	**1.22**	**1.13**
Arable land[a]	0.349	0.771	0.848
Pasture/meadow[b]	1.11	0.447	0.281
Net land use (per kg ECM)	**0.326**	**0.210**	**0.314**
Arable land	0.277	0.689	0.765
Pasture/meadow	0.049	-0.478	-0.450
Offset land use	-1.13	-1.01	-.816
Total land use (per cow-year)	**10,228**	**9,557**	**10,540**
Arable land	2,398	6,057	7.890
Pasture/meadow	7,830	3,500	2,650

*This calculation is a measure of land used directly in the dairy production system for the growing of crops to be consumed by animals.

[a] Arable land is land used for growing crops which will be fed to animals in these systems.

[b] Pasture/meadow land occupation, as classified in SimaPro 7.1, is used for production of mechanically harvested hay and for grazed fodder.

Table 3.16 Predicted value of carbon allowances needed to offset milk production in each system*

	Carbon price ($/ton[a])	Graz	Graz/Conv	Conv
Net emissions (kg ECM[b])$^{-1}$		0.681	0.736	0.742
Per kg ECM	$5.00	$0.00	$0.00	$0.00
	$25.00	$0.02	$0.02	$0.02
	$50.00	$0.04	$0.04	$0.04
Per U.S. hundredweight of milk	$5.00	$0.17	$0.18	$0.19
	$25.00	$0.85	$0.92	$0.93
	$50.00	$1.70	$1.84	$1.86
Per U.S. gallon of milk[c]	$5.00	$0.01	$0.02	$0.02
	$25.00	$0.07	$0.08	$0.08
	$50.00	$0.15	$0.16	$0.16

* Carbon prices as predicted over the next 25 years (Paltsev et al. 2008).

[a] U.S. standard ton.

[b] Energy corrected milk; while milk is not purchased at retail using an energy corrected milk factor, at the wholesale level prices are generally based on specified components, with price adjustments for milk with higher component analysis.

[c] Assuming 8.6 lb gallon^{-1} and assuming all emissions from raw milk production are allocated to retail milk. This accounts only for the on-farm production phase of milk production and does not account for additional processing or co-products that may occur before consumer delivery.

CHAPTER 4 DISCUSSION AND CONCLUSION

Discussion

The LCA model described in this thesis was designed to quantify greenhouse gas emissions from three dairy systems in Iowa and determine variables within each dairy system that could reduce emissions. The results show that, in the base case, one system does emit less GWP emissions than the other systems. The possibilities for reduction in each system are larger than the difference between systems. The system with the highest emissions may have more potential for reduction than the others. This is possible because the conventional system is further from the optimum in many variables within the dairy system which leaves room for improvement. The conventional systems also has a greater ability to improve emissions from manure management due to the fact that all of the manure produced is managed in a system which theoretically could capture emissions, where grazing herds deposit much manure to pasture, which is not easily managed.

It was hypothesized that the dairy systems, due to their different positions on a low input-low output to high input-high output spectrum, would have considerably different sensitivities and recommended steps for reduction of GWP emissions. The results show that the dairy systems are largely sensitive to the same variables, but achieving reductions in each system may present different challenges. Some factors for reduction within a dairy system may be determined by the dairy system used but, between the systems, the theoretical steps that can be taken to reduce emissions in the systems are largely the same.

The dairy systems analyzed in this study emit fewer greenhouse gasses per unit milk than predicted by Phetteplace et al. (2001), which predicted emissions of 1.09 kg CO_2-eq/kg milk, without consideration of an energy correction factor or allocation of emissions to co-products. The results of this study, without the ECM factor are presented in Table 4.1 for comparison with studies that did not use this factor. Total emissions of the conventional system, after removing the ECM factor from this study, predicts emissions to be 10 percent below emissions predicted by Phetteplace. Phetteplace also predicted a 12 percent difference in GWP emissions between conventional and intensive grazing systems, with grazing systems having the lower emission. Without considering co-product credits, this study finds emissions of the grazing system to be higher than the conventional system by 2.0 percent and, after considering co-products, emissions from the grazing system are 9.2 percent below the conventional system.

The results of this study differ further from other, more recent literature. With no ECM transformation, Capper et al. (2009) calculated emissions of the U.S. Dairy industry to be 1.35 kg CO_2-eq per kg milk, focusing on conventional production. Those results are 40.2 percent above the non-ECM total emissions of the conventional system found in this study. Net emissions from Iowa dairy systems are compared to other literature results in Table 4.2.

Emissions from production of co-products in the beef production system are compared to literature results in Table 4.3. Emissions associated with calf production in the beef system are similar to those found in literature, though the emissions from beef production are considerably less than those found in dairy LCA literature. The difference in results may represent true differences in production systems between European systems found in the literature, and the U.S. Further research is needed on beef systems to be able to accurately compare the differences.

Comparison of dairy systems and methods for emissions reduction

The grazing system in this study emits less net greenhouse gas with lower climate change potential per kg energy corrected milk (ECM) than the conventional system by 9.2 percent, and the combination system emits 0.7 percent less than the conventional system. Emissions differ considerably between these systems in the categories of enteric fermentation, feed production and co-product credits. The differences in enteric fermentation and feed production largely offset due to correlation of consumption of high-energy feeds, which are emissions intensive to produce, but results in lower enteric fermentation emissions due to easy digestibility of these feeds. The inverse of this relationship holds true as well, with low energy-density feeds requiring lower emissions to produce, but higher emissions to digest.

This study probes many aspects of dairy production as factors potentially affecting GWP emissions which had not been previously explored in detail. The sensitivity of net emissions to these factors within the dairy system can provide a guide to target efforts to reduce global warming potential. The improvement methods discussed here are listed with sensitivity in the previous chapter. Many of these emissions-reducing strategies, if implemented in the beef production system as well, may not result in decreased emissions allocated to the milk production system. If total emissions are reduced by a practice, and off-set credits are reduced as well due to less emissions-intense production in the alternate system, the details of the reduced emission would determine if a net reduction from the milk production system would result. Some of these reduction strategies may be implemented more easily or economically than others, but will be discussed here in order of their net emissions sensitivity.

Enteric fermentation

Sevenster and de Jong, (2008) predict that systems with high enteric fermentation will have lower overall GWP emissions. The grazing system has the highest enteric fermentation emissions: 14.9 percent higher than the combination herd and 35.8 percent higher than the conventional herd. As predicted by Sevenster and de Jong, the grazing herd also has lower net emissions. In this study, the COWPOLL method predicts higher enteric fermentation per unit of feed energy intake for diets containing significant amounts of forage. This finding agrees with other literature on GWP emissions, and also agrees with literature which discusses this problem in terms of other factors important in livestock rearing, such as the economics of losing feed energy to volatilized gases.

Net emissions of all three systems are most sensitive to changes in emissions from enteric fermentation. This emission is easily reduced in the grazing herds by substituting concentrated feed for forage, but the tradeoff will likely increase emissions from other sources. Feed additives such as monensin have shown some promise in reducing enteric fermentation emissions, though effects can be short-lived or inconsistent (Odongo et al., 2007).

Feed Production

Feed production also has a significant effect on net emissions from the dairy systems, with net emissions from the conventional and combination systems being more sensitive to this variable then the grazing system. Strategies to reduce emissions from cropping practices are already being recognized within carbon trading markets (CCX, 2004). These recognized strategies focus on reduced tillage as a way to save fuel and prevent the oxidation of carbon in the soil, which would result in GWP emissions. Results of this study indicate that N_2O, which is not addressed by current agricultural emissions reduction schemes, is an important emission from cropping systems due to application of nitrogen fertilizers. Emission of CO_2 from liming of soil is another impact not currently considered in carbon trading schemes, and this study suggests that this may be a considerable source of GWP. Implementing practices which reduce tillage, fertilizer, and liming needs may reduce the emissions from feed production, and thus lower the emissions from the systems that depend on these feeds. These reductions must be carefully applied as to not increase in other areas or reduce yields, which would have land use and cause negative greenhouse gas emission impacts.

Manure Management

Manure management emissions are highly dependent on the amount of manure that is collected in the manure management system or is deposited directly to pasture by the cattle, due to the large difference in conversion factors from N to N_2O-N. The avoided production of fertilizer due to capture of nutrients in a MMS is small in comparison to the reductions in CH_4 and N_2O achieved by directing more manure to manure management systems.

Manure management systems have the potential to reduce GWP emissions by utilizing digester systems that concentrate methane into a usable stream from which heat or electricity can be produced, generating another co-product credit (Barker, 2001; IPCC, 2006a). Most of the benefit of this type of system comes from preventing the release of CH_4 into the atmosphere, rather than from the avoided production of natural gas. Therefore, what is done with the gas is of little importance. Utilizing a digester and simply flaring the methane is still a significant advantage over open manure systems, and this strategy avoids much of the complexity of systems to capture the energetic value of the methane. By assuming the relevant IPCC default emission and conversion factors for an anaerobic digester system and avoided production of natural gas, net emissions from the conventional system are predicted to be 4.6 percent less than the grazing system and 11.7 percent less than the combination system. While net emissions of the grazing system are also sensitive to emissions from manure management, the majority of that herd's emission result from N_2O conversion of manure deposited to pasture. Management strategies to reduce nitrogen excretion, or to prevent the conversion of N to N_2O on pasture, would be more effective than advanced manure management systems to reduce manure management emissions from grazing and combination systems.

Energy

Net emissions are not highly sensitive to reductions in GWP emission from energy use, but this is one area that producers can directly reduce expenses on the dairy farm while improving the carbon metric as well. Savings from energy use does not depend on carbon regulation, though if regulation were to happen, economic saving from these reductions would be even larger. The Ensave (2007) energy audit focusing on Iowa dairy production presents a number of ways to reduce energy consumption, from more efficient pumps and electric motors to improved lighting and ventilation systems. The Ensave audit predicts an electrical energy use decrease of 27 percent and payback periods from 0.6 to 4.7 years.

Variables within dairy systems that can reduce emissions

Interval between calving

Interval between calving is an important management metric that has direct implications for the GWP emissions of a dairy system. Net emissions from each of the three dairy systems are more sensitive to this metric than any other single variable. A calving interval of 12 months is theoretically possible, and even claimed by some producers (Dale Thoreson, pers. comm.; Jerry Burkhart, Picket Fence Creamery, Elkhart, IA, pers. comm.), yet it is not achieved by the average dairy farm in the U.S., according to the USDA Dairy 2007 report. While all systems show a significant reduction in emissions with reduced interval between calving, the conventional system has a greater potential for reduction because its performance is further from the optimum.

Shortening the interval between calving increases fractionally the calves produced per year, allowing the export of more calves from the dairy system, and thus greater co-product credits. Improving this metric, however, has uncertainties not modeled here, including changes in milk production due to reduced days of lactation in each cycle, which could amplify or mitigate any change in emissions. Management practices that can reduce the interval between calving include better detection of heat and timely breeding practices, as well as chemically inducing estrus to ensure timely insemination, increasing the chance of pregnancy during each cycle (Penn State, 2008b).

Calf Equivalency

Net emissions from all three dairy systems are sensitive to equivalency of surplus calves from the dairy system and beef calves. To reduce emissions from the milk product of dairy systems, preserving and improving the value of surplus calves to other systems should be a priority. As found in literature, the major difference between Holsteins grown for beef and beef-type cattle grown in a feedlot is the overall feed efficiency. Holsteins require additional energy for maintenance, making them consume additional feed for the same gain.

Producing surplus calves from the dairy system that grow more efficiently in a beef system is one way of improving this equivalency. One way to do this is to cross a percentage of Holstein heifers and cows with beef-type bulls (More O'Ferrall, 1982; Penn State, 2008a). The number of heifers needed to maintain a milk production system can be estimated from culling and mortality rate data, and using this information, a percentage of cows or heifers may be crossed with meat type animals to yield sufficient dairy heifers and produce surplus calves that are more suitable for meat production. Further advancement of this technique might include using artificial insemination with sexed semen to produce sufficient replacement dairy heifers. Impregnating the fewest cows necessary with dairy genetics allows more calves to be born as cross-bred meat-type animals (Zotto et al., 2009). Depending on the breed, these cross-bred animals may gain muscle faster and with greater feed efficiency, leading to lower emissions per unit of meat produced. Greater equivalency between surplus calves from the dairy system and calves from a beef cow-calf system would result, generating a larger co-product credit and reducing the emissions from the milk product in a dairy system.

Meat Equivalency

Unlike calf equivalency, the equivalency of cull cow meat with beef from a feedlot system does not depend on circumstances after culling. The condition of the cow and the resulting meat determine if it is able to offset production in a beef feedlot system. Research shows that timing of culling can have a considerable effect on the quality of meat produced from a cull cow (AARD, 2000). Culling directly after weaning a calf or directly after heavy lactation can leave a cow extremely lean, reducing the dressing percentage and quality of the meat. If cull cows are fattened for 60 days prior to slaughter, their dressing percentage and quality of meat yielded will likely increase (AARD, 2000). Feeding for this period of time would give rise to additional emissions not modeled here, but may be an efficient method of reducing the allocated emissions from milk production by maintaining or improving the co-product offset. Additionally, injection site lesions and bruising are particular problems with cull cows, reducing the marketable carcass yield of the animal. Fattening the cow can help reduce bruising during shipment to a slaughter facility and careful application of injections will improve the value and marketability of a cull cow carcass (Thrift, 2000).

Culling Rate

Culling rate differs more between the studied dairy systems than other factors that considerably affect emissions. Culling rate is a choice made by the manager of the herd, but is also influenced by the dairy system being used (Dale Thoreson, pers. comm.). Cows in conventional systems that spend most of their lives on concrete floors may develop leg problems sooner than those that spend a substantial amount of time on pasture or other surfaces more amiable to hooves (Hernandez-Mendo et al., 2007). Cows that can no longer walk, termed “downer cows,” are not permitted to be slaughtered for human consumption, and therefore are much less valuable. The economic reality is that systems that are less able to prevent leg problems in cows must cull more to prevent losses due to downer cattle, with implications for GWP emissions (Dale Thoreson, pers. comm.). There are many factors that go into the decision to cull a cow, including economics, health and diseases, and production. Higher culling rates cause higher GWP emissions, and if these emissions become an important part of decision-making on the dairy farm, culling rates may be a variable that can be adjusted to reduce emissions. Culling rate and mortality rate impact this model differently, as culling leads to a co-product of meat, where mortality contributes only to calculations of needed replacement heifers. While absolute reductions in mortality will reduce emissions more effectively than absolute reductions in culling rate, percentage reductions in mortality will be less effective than percentage decreases in culling rate because mortality rates are much less than culling rates, and therefore bear on emissions less.

Uncertainty and future research

IPCC default values used to calculate many emissions in this and prior LCAs are subject to a large amount of uncertainty. Some emission factors, such as direct conversion of N in manure deposited to pasture to N_2O-N, have large uncertainty ranges and considerable impact on the results of this study. This conversion factor is not directly observable or controllable by a dairy production system. Other values, such as the CH_4 conversion factor for manure management systems, have considerable impact, and are highly determined by the system used, which is a management choice. Some of the net emissions sensitivities to assumed conversion factors are larger than sensitivity to factors directly controlled by management. This casts some doubt on the recommended reduction strategies with lower sensitivity values. Future research should attempt to reduce the uncertainty and sensitivity associated with IPCC default factors.

This analysis attempted to reduce uncertainty in the assumptions with the greatest net emissions sensitivity by using the COWPOLL enteric fermentation estimation method. The IPCC default enteric fermentation emission factor of 6.5 percent carries an uncertainty of ±1 percent. No comparable uncertainty statistic can be found for the COWPOLL model, but it does produce results that take into account the digestibility of the feeds. This important consideration is extremely important when comparing feeding systems with varying feed types. Future research should use advanced tools such as COWPOLL when doing so will likely more accurately distinguish impacts in the modeled systems.

Many assumptions in agricultural systems have uncertainty due to weather conditions, and modeling a system in an extreme environment would introduce uncertainty beyond the norm. The IPCC default emissions factors for manure management, for example, are estimated for the average annual temperature of the area being studied, from 10°C to 28°C. Iowa's average temperature of 9.2°C, for example, is near, but below the lowest estimated category in IPCC methodology. This adds uncertainty to those factors that use temperature as an input, and in addition, having a climate far from the mean of the climates modeled may add uncertainty to variables that are affected by temperature, but have no temperature scaling available in the IPCC default emission factors. Analysis of systems in colder climates needs further development of emission factors and methods to more accurately assess impacts.

The sensitivity of net emissions to the method used to allocate emissions of co-product feed inputs raises questions of why such discrepancy exists, and adds uncertainty to this analysis. The production of these feed ingredients were analyzed using economics allocation instead of system expansion, because preliminary results using system expansion showed extremely high emissions from the production of these products that was seemingly unwarranted. Using system expansion, all inefficiencies of the production system are concentrated on one product. Generally, this allocation avoidance method is used when evaluating the main product of a process, and co-products generally have close substitutes. In the case of by-product feed ingredients, the co-products did not have close substitutes. For example, in a system expansion analysis of dry distillers grain, ethanol is a co-product and is assumed to displace gasoline on an energetic equivalence basis. These production processes are vastly different, and concentrating all of the inefficiencies in the ethanol production process on one by-product leads to extremely high emissions associated with the by-product feeds. These inefficiencies and emissions must be accounted for in one system or another if the goal is lowering overall emissions, but to almost double emissions from feed production by including these feed ingredients with system expansion does not serve this analysis well. Production of inputs to the farming system needs to be allocated in a way that does not create extreme distortion, or these feeds should be substituted for another feed ingredient that is not subject to this uncertainty.

Land Use

Before consideration of co-products, the dairy systems occupy land as predicted considering the intensive nature of land use of the conventional system, and more extensive nature of land use in the combination and grazing herds. According to this study, the grazing system uses 29 percent more total land than the conventional system, with the combination system using an intermediate value. The grazing system, however, uses less than half of the arable land needed to support the conventional dairy. A majority of the land needed by the combination dairy is arable land as well.

The production of beef calves and beef from feedlot systems uses land as well, and as the production of these calves are avoided, land use is offset. With consideration of co-products, the grazing system still uses more total land than the other systems, and the conventional and combination systems result in a net offset of pasture/meadow usage. The total land offset is in line with expectations; since the grazing system has a larger offset of GWP due to co-products, it is not surprising that this is also the case for land use. An interesting result, however, is that after co-product consideration, the combination system uses the least amount of land by a considerable margin. A combination of factors contributes to this unexpected result. The land use values without allocation are closer to those of the conventional system, while the offset of land is closer to that of the grazing system. In this balance, the milk product of the combination system carries a burden of land use 33-35 percent below the other systems.

Land use is an important factor in the placement of these different systems of dairies. The arable land supporting these dairies may be placed far from the cows, while the grazing system requires fodder production immediately adjoining the housing system. Highly perishable products such as milk are expensive to transport, and conventional dairy production systems are generally located with more regard to the consumers than the sources of agricultural commodity inputs. If research of this type recommended that production systems needed to change type instead of making improvements, land use issues of locating dairies close enough to consumers would be a major problem. The recommendations made in this study for reduction of greenhouse gas emissions avoid creating these large scale land use questions and problems.

Carbon regulation and pricing

If greenhouse gas emissions are to come under regulation, cap and trade systems are likely to be used to allocate emissions of global warming potential (Paltsev et al., 2007). If this happens, the CO_2-eqivalent from systems such as those analyzed here will begin to bear on the economics of the production system. LCA is likely not the most appropriate tool to directly assess a tax or other penalty onto a production system for its GWP emissions due to issues of double-counting. Penalties for emissions from fuel and energy consumption may be assessed upstream of the dairy production system, and other products may incorporate economic costs of regulation into their prices. Adding a penalty for the full life-cycle emissions of a system, then, would be double counting for those penalties that are already priced in.

However, LCA can predict the total amount of GWP emissions from a system, which can be assessed a value, and the total economic burden may be predicted for the system. According to Paltsev, et al. (2007), CO_2-equivalent GWP emissions are predicted to be traded for a maximum of \$50 per ton in the next 25 years. Using this maximum carbon emissions price and net emissions from milk production calculated in this study, an economic burden of \$1.70 per hundredweight of milk produced would be placed on the grazing system, \$1.84 on the combination system, and \$1.86 for the conventional system. The five-year average milk price in the U.S. is \$14.40 per hundredweight, making this burden 12-13 percent of the selling price of milk if time and inflation are ignored.

Conclusion

As these Iowa dairy systems exist today, emissions differ between systems by less than 10 percent. With ample practical and effective ways to reduce emissions within each system, it cannot be suggested from these results that production should shift to one model over another. However, it can be concluded that the conventional system is further than the grazing system from optimum values that would decrease greenhouse gas emissions. On the other hand, the conventional system may have more potential for reductions due to its highly controlled environment, which allows for precise control of many variables and resources. The environment that creates this precise control, however, may have implications for the longevity and fertility of cattle that prevents reduction of emissions from reduced culling, mortality, or interval between calving.

Furthering the development of sustainable agriculture systems includes reforming the systems of today for the coming regulatory, social, and climatic conditions. Research shows that global warming may have many different effects on agriculture, but a visible effect today is the attention being paid to greenhouse gas emissions from many sources. Regulation of these emissions may be implemented in the foreseeable future, and producers need to have research to use in improving their production systems to a new regulatory environment.

Development and implementation of practices to directly reduce emissions from enteric fermentation, manure management, and feed production categories should be a priority for research and experimental dairies. In addition, research to find paths to improve variables such as interval between calving and beef calf equivalency within dairies will be important to allow the greatest production of co-products and greatest reduction of emissions. There are substantial tradeoffs to be made on some of these factors, such as those between feed production and enteric fermentation, but a life cycle approach to reducing emissions should be continued as it allows these tradeoffs to be fully accounted for.

It has been said that ruminants are necessary in agriculture, to the extent that they can utilize non-tillable acres and convert carbohydrate energy from sources not edible to humans into protein that is highly valued for human consumption (Peters et al., 2007). Dairy production in Iowa and the U.S. is utilizing ruminants well beyond this threshold, using crops grown on acres that could be supporting human food consumption directly. While there is no implicit problem associated with this trend, in order to feed ourselves sustainably, we must continually analyze agricultural systems from many different angles to reduce environmental impacts and find those systems that create greater benefits to society than costs. Climate change emissions is one of the newest lenses through which agriculture and animal production must be analyzed, and how society chooses to react to the evidence presented on climate change will carry important implications for how we eat in the future.

Table 4.1 Results of this study with and without the energy corrected milk (ECM) factor

	No Allocation (total emissions)			System Expansion (net emissions)		
	Graz	Graz/Conv	Conv	Graz	Graz/Conv	Conv
With ECM factor[a]	1.04	1.07	1.02	0.681	0.736	0.742
Non-ECM	0.98	1.01	0.96	0.644	0.695	0.700

[a] Using the ECM factor defined in Sjaunja et al. (1990) and average Iowa milk analyzed at 3.7 percent fat and 3.0 percent protein. This yields an ECM factor of .944

Table 4.2 Comparison of results of this study to others in literature

	Allocation Method	Allocation		Herd	Emissions kg CO_2-eq (kg ECM)$^{-1}$ [a]	
		Milk	Co-Products		Milk	Co-Products
Current Study	System Expansion	65%	35%	Grazing	0.681	0.361
		69%	31%	Combination	0.736	0.331
		73%	27%	Conventional	0.742	0.275
Arsenault et al. (2009)	Biological	68%	32%	Grazing	0.686[b]	0.323[b]
				Conventional	0.698[b]	0.329[b]
Capper et al. (2009)	None	100%	-	Year 2007	1.35[b]	
				Year 1944	3.66[b]	
Casey and Holden (2005a)	None	100%	-		1.50	-
	Mass	97%	3%		1.45	0.051
	Economic	85%	15%		1.30	0.229
Casey and Holden (2005b)	None	100%	-	Lowest emissions	0.92	-
				Average (11 herds)	1.14	-
				Highest emissions	1.51	-
Cederberg and Mattsson (2000)	Biological	85%	15%	Organic	0.98[c]	0.173[c]
				Conventional	1.08[c]	0.191[c]
Cederberg and Stadig (2003)	None	100%	-		1.05	-
	Economic	92%	8%		0.97	0.084
	Biological	85%	15%		0.89	0.158
	System Expansion	63%[d]	37%[d]		0.66	0.389
Haas et al. (2001)	None	100%	-	Extensive	1.00[b]	-
				Intensive	1.30[b]	-
				Organic	1.30[b]	-
Hospido et al. (2003)	Economic	87%	13%		0.730[d]	0.109[d]
Phetteplace et al. (2001)	None	100%	-	Conventional	1.09[b]	-
				Intensive grazing	0.959[b] [e]	-
Thomassen et al. (2008a)	Economic	92%	8%		1.61	0.140
	Mass	96%	4%		1.56	0.070
	System Expansion	53%[f]	47%[f]		0.90	0.822
Thomassen et al. (2008b)	Economic	90%	10%	Organic	1.50	0.167
		91%	8%	Conventional	1.40	0.123

Table 4.2 (Continued)

[a] Energy Corrected Milk, as defined by Sjaunja et al. (1990)
[b] Analyzed and reported on a kg of milk basis, not ECM
[c] Values estimated from a graph in this publication
[d] Reported on a liter basis
[e] Predicted value—12 percent decrease in emissions predicted from baseline value
[f] Estimated by back-calculation of allocated impacts

Table 4.3 Comparison of emissions from dairy system co-products found in this study and others in literature

	Study	kg CO_2-eq (calf^{-1})
Calf Production	This Study	2,320
	Casey and Holden (2005a)	2,509[a]
		kg CO_2-eq (kg live weight)$^{-1}$
Meat Production	This Study	8.80[b]
	Casey & Holden (2006)	11.26
		kg CO_2-eq (kg live weight)$^{-1}$
Meat production (without cow-calf phase)	This Study	4.67[b]
	Subak (1999)	7.40

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[a] Combined results of two studies--Subak (1999) and Casey and Holden (2005a)--as discussed in Casey and Holden (2005a)

[b] Results of this model are measured in kg CO_2-eq/kg dressed weight. Results scaled to live weight assuming carcass weight is 62 percent of live weight (Iowa State University, 2005)

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