ABSTRACT

CHIZONDA, SHALIMBALA. Comparative Energy Flow Analysis on Dairy Farms in North Carolina and Malawi. (Under the direction of Dr. Jonathan C. Allen).

Milk production in developing and countries is subject to different constraints than in the US. Even large, advanced dairies in Malawi have different inputs of energy and materials to optimize their milk output compared to moderate sized dairy farms in the US. The objective of this study was to compare energetic inputs, outputs, and efficiencies of dairy farms in Malawi (Southeast Africa) and North Carolina to assess sustainable milk production. Feed consumption and milk production data were collected from Katete Dairy herd in Lilongwe, Malawi, consisting of 408 cattle with 108 lactating cows, and the NCSU Dairy Research and Teaching Farm, housing 245 Holstein and 55 Jersey cows and 160 lactating cows. Both are teaching farms that employ extensive record keeping. Milk production averaged 34 and 19.5 kg/cow/day (91 and 53 MJ/cow/day) at NCSU and Katete, respectively. Feed energy intake was 359 MJ/cow/d at NCSU and 427 MJ/cow/d at Katete. The energy efficiency of milk production for the farm was 0.66 MJ. MJ^{-1} at NCSU and 0.07 MJ. MJ^{-1} in the lower producing cows at Katete. Manure is recycled for crop production at Katete, and is processed with a solids separation and lagoon system at NCSU. Additional factors that impact the overall farm efficiencies include inputs of petroleum fuels and electricity, and the number of calves, heifers and dry cows fed. The project identifies factors in dairy production that should be considered to improve efficiency, sustainability and milk supply. Both farms had a substantial portion of the energy fed to the cows lost to the environment as composted manure in soils or lagoons that did not capture the heat or methane generated.

Comparative Energy Flow Analysis on Dairy Farms in North Carolina and Malawi

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Nutrition

Raleigh, North Carolina

2015

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DEDICATION

To my parents Cecilia and Amex.

BIOGRAPHY

Shalimbala Chizonda earned her Bachelor's degree from the University of Malawi – Bunda College of Agriculture in 2007. She entered graduate school at North Carolina State University in the Department of Food, Bioprocessing and Nutrition Sciences in August 2012 and will complete her Master of Science degree in Nutrition in December 2015.

ACKNOWLEDGMENTS

I wish to thank the staff at Katete and North Carolina State University Dairy farm, for support and participation in the study. I also wish to thank Drs. Allen, Fellner and Fogleman, my advisory committee, for all the guidance that was rendered to me during the study. I would like to acknowledge fellow students Yawang Sun and Adsos de Pasos, for their contribution to this study. To my lab mates, thank you for making this a wonderful journey.

Last but definitely not least, I would like to thank the people and government of The United States of America for the support rendered to me through the United States Agency for International Development (USAID) under the USAID Long Term Training and Capacity Building Scholarship Program in Malawi. This material is based upon work supported by the United State Agency for International Development under award number EEM-G-00-04-00013 and BFS-G-11-00002. Coming to study at North Carolina State was a life changing experience for me. I am forever grateful.

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CHAPTER ONE

1 INTRODUCTION

There have been several attempts to describe food security. It is regarded as a situation "when all people at all times have a physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (World Food Summit, 1996). It is estimated that the world population will grow to 9.6 billion people by 2050 (UN, 2013) mostly in developing countries (UN 2013; World Bank 2007). Even though food is currently available worldwide (Grote, 2014), food insecurity still exists, with 12% of the global population having chronically undernourished energy level intake (FAO, WFP, and IFAD 2012). This is further characterized by hunger and micronutrient deficiencies, mainly in developing countries with most prevalence in Sub-Saharan Africa and the malnutrition of being overweight in developed countries (WHO, 2013).

WCED (1978) described sustainable development as the requirement to meet the needs of the present without compromising the ability of future generations to meet their own needs. With this in mind, WWF (2014) reviewed the definition of sustainable agricultural system for the 21st Century by looking at a divergent view from experts and coming up with its principal characteristics. Among these is the ability for the system to produce food that is safe, secure, affordable, accessible and nutritious. As the global population grows, a sustainable agricultural system should grow with it while using natural resources in a highly efficient, resilient and adaptive manner, at the same time, protecting ecosystems.

The FAO (2009) identified a need to increase food production by 70% to feed the global population by 2050. There is an expected twofold rise in demand for meat and milk between years 2000 and 2050 (Steinfeld et al., 2006). There is need to achieve higher yields without harming the natural ecosystem (Cassman et al., 2003). The “yield gap,” which is common name for the difference between attainable and current yields, is now at 50% (Foley et al., 2011; Lobell et al., 2003). A “diet gap” looks at human-edible crops production that is put to nonfood use. It is estimated that the United States is one of the countries that accounts for the global diet gap by 26% (West, 2014). The challenge that exists is to come up with strategies that will improve the efficiency of farming and this includes matching inputs and outputs of a farm (Garnett, 2013). A dairy farm is a complex system made up of several interacting subsystems (Schils et al., 2007) and functions as a system within the ecosystem. Inputs like feed, fuel, water from the ecosystem are used for the production of milk (Singh et al., 2002). Agricultural yields are high in North American and Organization for Economic Co-operation and Development Countries (OECD) countries (Paillard et al., 2010). The concern lies in developing countries where there are emerging middle class that will drive up demand for livestock products. An analysis of dairy systems in different regions is a starting point for future designs of more efficient systems.

Objectives of the study

The objective of this study was to compare energetic inputs, outputs, and efficiencies of dairy farms in Malawi (South East Africa) and North Carolina to assess sustainable milk production.

The specific objectives were:

1. To compare feed energy provided to farms in North Carolina and Malawi

2. To carry out an input-output analysis of the two dairy farms and

3. To analyze efficiency of production for dairy farms using different production systems

HYPOTHESIS

In this study, we hypothesize that there will be a difference in energetic inputs, outputs and efficiencies between farms in Malawi and North Carolina. Due to differences in geographical location, the feed energy provided will also differ. The two farms also have different systems of production. One feeding a total mixed ration while the other employs semi-grazing. We hypothesized that efficiency of production will differ between the two farms.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Dairy farming in Malawi

In Malawi, the livestock sector contributes more than 11% of total Gross Domestic Product (GDP) and 36% of total agricultural domestic products. Livestock provide an efficient way to recycle crop residues and by-products and use areas that are not fit for arable farming. This is advantageous for a small country with increasing population and shrinkage in land holding size (DAHLD, 2006).

Farmers in the southern region of Malawi were the first to start producing milk for sale. An increase in demand for liquid milk led to the onset of market oriented milk production. The first milk plant, which pasteurized 2500 liters a day, was set up in 1961. To meet this increasing demand for milk, the strategy employed was to increase milk production per animal through use of improved or temperate breeds. This led to the setup of the Malawi Canada Dairy Development Project in 1979 by the Malawian and Canadian governments. Over a period of 5 years, about 400 Canadian Holstein Friesians were imported as a foundation stock. This stock depended on use of imported (Canada) semen for breeding. There was a difference in production as accounted for by Stanton et al., (1991) and Ron & Hillel, (1993) where the differences in the environment of the two countries, apart from physical and climatic factors, also included production and health management, economic constraints, prevailing agricultural policies and/or a combination of these. The project was later (in 1988) combined with the Malawi Milk Marketing project to form a statutory organization involved in producing, processing and marketing milk and milk products (Chagunda, 2009). Dairy cattle population has continued to rise as shown in Table 1, from 7,500 in 1998 to 30,000 in 2007.

Table 1: Dairy cow population in Malawi

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Number of dairy cows	7,500	8,200	9,000	10,000	12,700	15,000	17,500	20,000	26,000	30,000

Source: Goyder and Mang'anda (2009)

2.2 Scale of production

Dairy production in Malawi is mainly made up of smallholder farmers and large scale producers (Banda et al., 2012). Smallholder dairy farmers dominate in milk production with 49,193 tons of milk in 2008, which was about 80 percent of the total milk production (Chagunda et al., 2006 and DAHLD, 2008). For smallholder farmers, most of the land is allocated to crop production since animals are incorporated to form a mixed crop-livestock production system.

Smallholder farmers belong to milk bulking groups, which collectively sell milk in a bid to lobby for higher prices and easier access to inputs. Farmers that use the cooling center come from within a radius of 8 kilometers of the Milk Bulking Groups (MBGs).The cooling center functions as a milk collection point for processors and are run by committee elected by farmers. Before processors load up milk into tanks, it is first tested for adulteration and sourness using a lactometer and alcohol test, respectively.

The most common method for milking used by smallholder farmers is hand milking (Dodd, 1986). Cows produce an average of 7 liters per day, even though there is a potential for 40 liters a day (Zimba et al., 2010). Milk Bulking Groups are registered and organized by the Malawi Milk Producers Association (MPA). Milk bulking groups are organized into three Milk Shed Areas (MSA) around the three major cities of Malawi; Blantyre, Lilongwe and Mzuzu. The Shire Highlands Milk Producers Association (SHMPA) caters for famers in Blantyre, the Central Region Milk Producers Association (CREMPA) is for farmers in Lilongwe and Mpoto Dairy Farmers Association (MDFA) caters for farmers in and around Mzuzu city.

Farmers receive support from government and non-governmental organizations (NGOs) such as Land O' Lakes and Small-Scale Livestock Promotion Program in the form of extension services and initial stock on a pass on program (Chagunda, 2009 and Banda et al., 2012) that work with the bulking groups. Farmers cross exotic breeds such as Friesians with indigenous Malawi Zebu (Imani, 2004; Chagunda, 2009; Banda et al., 2011).

Large scale farmers differ from smallholder farmers due to differences in herd size, breed and level of management (Chagunda, 2009; Banda et al., 2012). There are 15 private large-scale dairy farms with about 2200 milking cows. The main breed kept is the Holstein Friesian with some farms also having Aryshire and Jersey. Dairy cattle management in Malawi is mainly focused on increasing milk yield per animal, therefore leading to a dependence on breeding strategy of Artificial Insemination with semen from temperate regions, in particular, Canada (Chagunda et al., 2004).

2.3 Milk consumption, processing and marketing

At present, milk production is below the national requirement leading to importation (Gondwe, 2009). Malawi has the lowest African per capita consumption of milk, estimated at 5 kg/capita/year compared to an average of 15 kg/capita/year for Africa and 90 kg/capita/year in the US (USDA, 2014). This is mainly due to low purchasing power and supply. Despite being a small country, Malawi milk marketing structure is similar to that of other Sub-Sahara African countries characterized by the presence of smallholding production; both a formal and informal supply chain for marketing processed products and a processing sector (Revoredo-Giha, 2012).

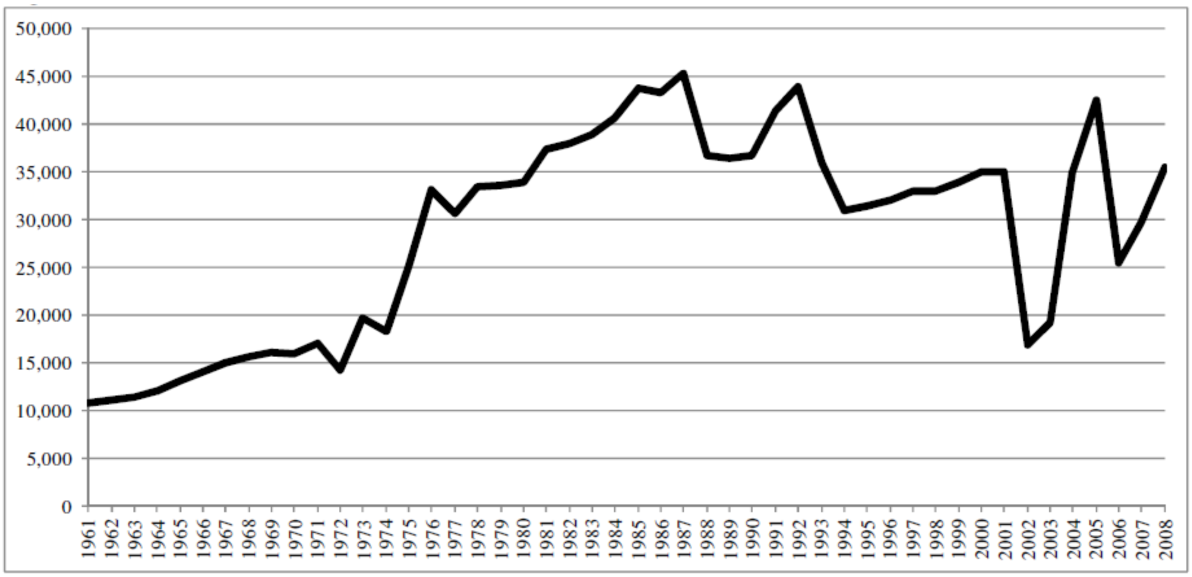

Figure 1: Malawi: Production of milk 1961-2008 (tons)

[Source: Revoredo-Giha, 2012

The trend in milk production for Malawi is illustrated in Figure 1. From the establishment of the first processing plant to around 1997, there was intensive smallholder production and the setup of milk marketing, which accounts for the rise in production.

2.4 Feeding strategy

These large scale farms are concentrated in the southern region and Holstein, Friesian and a few Jerseys are the animals in stock. Some of these animals are crossbred with local Zebu animals. Most of these farms grow maize and Napier grass for making silage. Rhodes grass and other forage legumes are established for grazing and hay production. Supplement feeds are generally based on groundnut, cotton seed and sunflower cakes, maize and their by-products, and soybean all of which are fed with mineral supplements. However, the supply of concentrate feed is often interrupted, and generally expensive. This is because the source is located away from intended utilization locations (Chintsanya et al., 2004).

A baseline survey indicated that the majority of smallholder farmers in Malawi (94%) use zero grazing feeding system. Only a few farmers in Lilongwe (4%) and Mzimba (2%) used herded grazing. In the zero grazing system, cows are kept in pens throughout the year, and feed is always provided for them. Maize bran was the major type of concentrate that most farmers (96%) provided to the animals. Most farmers had established pastures (76%). Fewer farmers (37%) had pastures in Thyolo, a district in the southern part of Malawi than in Lilongwe (95%), Mzimba in the north (87%) and Kasungu in the central region (86%). This could be attributed to land being a limiting factor in Thyolo. A considerable proportion of farmers (65%) conserved feeds, and most of these were from Mzimba (25%) and Lilongwe (21%). The types of pastures were mainly grasses as evidenced by Napier (Pennisetum purpureum, 89%) and Rhodes (Chloris gayana, 10%) grass from the survey (Banda et al., 2012).

2.5 Energy and nutrient flow

The focus on the relationship between energy and agriculture has come about due to a need to develop a field of agro-ecosystems. In agriculture, primary production is highly dependent on fossil fuels (McLaughlin et al., 1999) and energy conservation takes the form of integrating on-farm resources such as biological cycles and controls as a way to make the most efficient use of non-renewable energy (Gold, 1994).

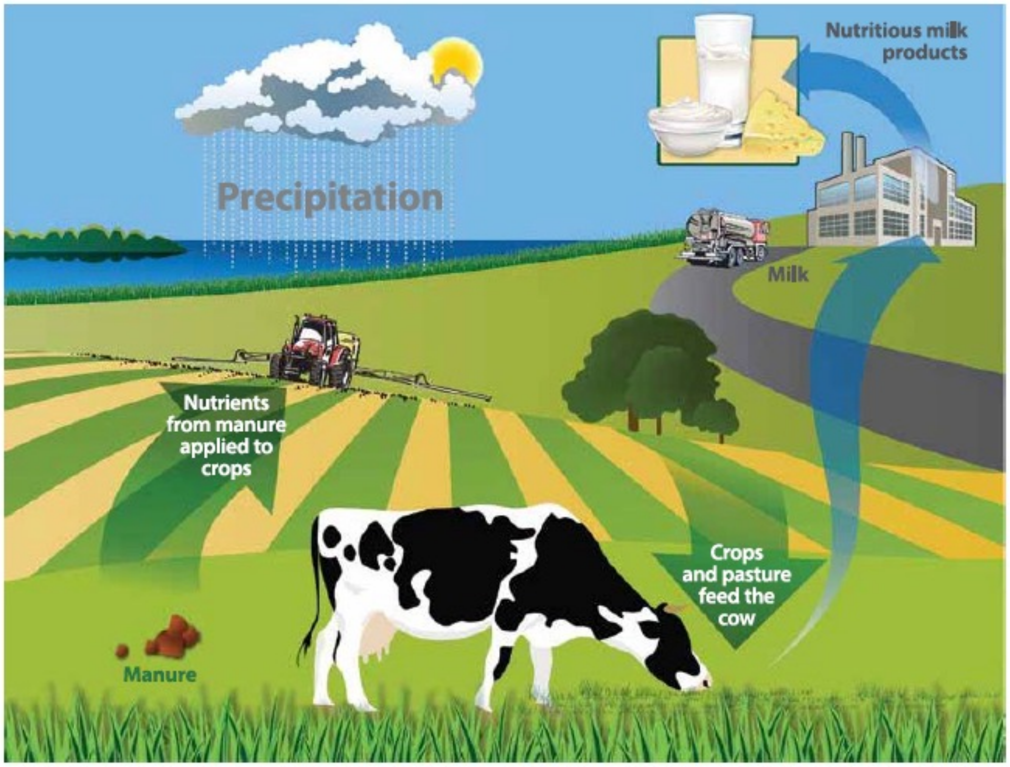

Figure 2: Dairy Nutrient cycle

Source: U.S. Dairy, 2014

The nutrient cycle for dairy starts with the growth of crops that are fed to cows (Figure 2). This is required for milk production. Manure is used as fertilizer and returns nutrients to the field that in turn is moved to feed (U.S. Dairy, 2014). Reliance on non-renewable energy such as petroleum and natural gas, which can be defined as unsustainable, has contributed to the dairy industry receiving negative attention regarding its carbon footprint (Godfray et al., 2010). There is minimal peer-reviewed information available on energy use by the dairy industry which uses petroleum and electrical energy sources (von Keyserlingk et al., 2013).

Large scale studies on farm energy use make gross assumptions that are not applicable to all farms in the economy. This can be resolved by carrying out studies on different sized farms which would provide detailed information on flows of energy and nutrients. Therefore, a vast research endeavor would provide a more definitive answer (Zucchetto and Bickle, 1984). Von Keyserlingk et al., 2013 suggested that there is great variation (from 300 to 1500 kWh/cow annually) in energy use among farms. This is brought about by differences in efficiencies of the farming system. Improved efficiency of energy use within the dairy industry may become increasingly important (Schade and Pimentel, 2010) since the global energy use is projected to increase (IPCC, 2007).

Dairy production in developing countries mainly has high costs associated with energy use. In an illustration by Das et al., (2001), cows mainly raised on pasture fertilize the field and in turn aid in turning sunshine into milk, a plight not easily matched by many nonruminant systems (Figure 2). Labor and energy costs for calf management are reduced by restricted access to dams, where calves only nurse twice a day and for 30 minutes only. Energy consumption on a farm is used up directly or indirectly (McLaughlin et al., 1999; Hu¨lsbergen et al., 2001; Pervanchon et al., 2002; Corre´ et al., 2003). Direct energy use is measurable and it mainly comprises non-renewable resources like diesel fuel, electricity and natural gas. Indirect energy use comprises energy used to produce farm inputs such as pesticides, forages, mineral fertilizers, seeds and machinery (McLaughlin et al., 2000, Muel et al., 2007 and Vigne et al., 2012). It can be considered as energy used to produce, package, transport, purchase, and sell the supplies used by the dairy industry.

Zucchetto and Bickle (1984) attributed a total of 79.6% of total energy use to indirect energy, on a farm of 160-lactating cow dairy farm, with an annual milk production of 8.081 kg/cow. Proportion of energy cost (Table 2) was high in fertilizer (23%) and the least cost came from veterinary supplies. In a study by Muel et al., 2007, the total energy use on farms was studied including efficiency. The results indicated that indirect energy use, particularly mineral fertilizers and animal feed, took up the highest share of energy use while diesel took up the majority of direct energy use.

Table 2: Energy cost on a dairy farm in Pennsylvania

Description	Energy value (GJ)	Percent
Fuel	1287	20.4
Fertilizers	1458	23.1
Pesticides	955	15.1
Seed	519	8.2
Capital	934	14.8
Electricity	431	6.8
Food supplement	583	9.2
Veterinary supplies	153	2.4
Total energy	6320	100

Zucchetto and Bickle, 1984

2.6 Current energy use assessment methods

There are several methods that have been developed for use, to assess different livestock production systems. A literature review study by Vigne et al., (2012a) used 197 references that looked at energy use in agricultural systems from an environmental perspective. From this study, 3 energy analysis methods were identified. These are Energy Analysis (EA), Ecological Footprint (EF) and Emergy Synthesis (EM). Of the 197 references, 42% of the case studies were from Europe and of this, 92% followed EA (Figure 3). Only 9 studies were from Africa.

Energy Analysis (EA) is one of the earliest methods developed (Pimentel et al., 1973) for environmental assessment with a focus on agricultural systems. It deals with fossil energy use with a focus on both direct and indirect energy consumption. Other sources of indirect energy consumption like veterinary services (Rabier et al., 2010), buildings and machinery (Schils et al., 2007), plastics (Veysset et al., 2010) and pesticides (Hanegraaf et al., 1998) are not usually considered. Energy Analysis studies have shown plant production to be more efficient than livestock systems. When it comes to mega joules (MJ) of food energy produced per MJ of non-renewable energy consumed, fruits and vegetables have a range of 1 (Kizilaslan, 2009) to 5 $MJ \cdot MJ^{-1}$ (Ozkan et al., 2007). Livestock systems only just reach 1 MJ (Benoit and Laignel, 2010; Veysset et al., 2010) while crops can reach 15 $MJ \cdot MJ^{-1}$ (Deike et al., 2008; Nguyen and Haynes, 1995).

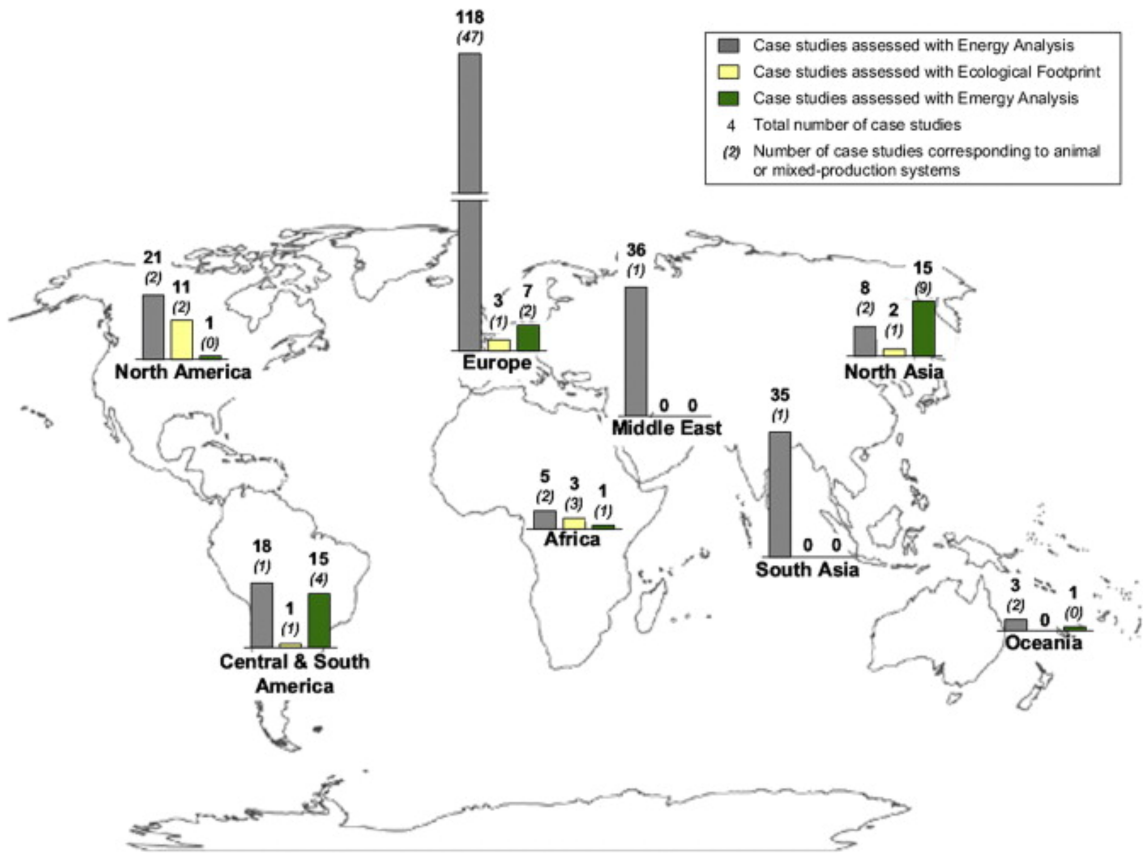

Figure 3: Geographical distribution for the 304 case studies application of EA, EF and Em

Source: Vigne et al., 2012a

Application of EA has been in both single and multicriteria assessments such as life cycle analysis. This provides information on impact of management changes on energy use (Cleveland, 1995), a record of energy use for a specific agricultural system or product (Franzluebbers and Francis,1995) and comparison of production systems such as organic vs. conventional (Grönroos et al., 2006) or manual vs. mechanized (Gajaseni, 1995).

Ecological footprint (EF) uses a biologically productive area as its main indicator, an estimate of land requirements necessary for the sustenance of a specific population. This area results from a sum of four components (Wackernagel and Rees, 1996). These are direct surface areas, indirect surface area, non-used surface area and surface area corresponding to fossil energy use. Direct surface area deals with land allocated to buildings, crops and all other areas directly related to production. Indirect surface area deals with area requirements for production of purchased goods. Ecological footprint can be used as an assessment tool for different agricultural production systems (Niccolucci et al., 2008) as well as efficiency of agricultural systems at different scales (Vigne et al., 2012a).

Emergy is available energy previously used up directly and indirectly in a production or for service (Vigne et al., 2012a). Emergy synthes (Em) measurement is another energy analysis method. The focus is on total energy use. Even though fossil energy, industrial inputs and services are included, Em also calculates energy fluxes into natural resources. Em is quantified in solar energy equivalents and expressed as solar emJoules (seJ) (Ulgiati and Brown, 2009). Through a series of indicators, this method assesses the performance of a production system in terms of efficiency and intensity in the use of resources from nature and inputs from the economic system, from the objective perspective of thermodynamics (Ferraro and Benzi, 2015).

Emergy synthesis analysis is becoming more common in recent years with studies being done in different production systems (Agostinho et al., 2010, Castellini et al., 2006, Cavalett et al., 2006, Chen et al., 2006, Cohen et al., 2006, Cuadra and Rydberg, 2006, De Barros et al., 2009, La et al., 2008, Lefroy and Rydberg, 2003, Lu et al., 2009, Marchettini et al., 2003, Martin et al., 2006, and Zhang et al., 2007) and processes (Brown and Ulgiati, 2004, Chen et al., 2009, Hau and Bakshi, 2004 and Zhang et al., 2009).

Energy Analysis method can be used to link energy consumption and its environmental impact through depletion of natural resources and greenhouse gas (GHG) emissions. This method can detect large energy fluxes and is a useful tool in proposing actions to decrease them. Ecological Footprint analysis does not propose any measures to increase energy efficiency. On the other hand, Em cannot provide a quantifiable link between renewable energy use and environmental impact since solar energy used in has no negative impact on the environment (Vigne et al., 2012a).

Pluri-energy analysis is a recently introduced method that takes into account both direct and indirect use of fossil energy while distinguishing the four energy types like Em. Energy use efficiency is the focus and no single unit is used to describe preferential energy sources (Vigne et al., 2013). Conversion efficiencies are used to assess energy in agricultural systems. Conversion figures are derived from literature (Table 2) and used for calculations. A generic framework is used for the quantification of the energy (Figure 4). There are three principles that are employed in the framework. The first one looks at the four energy types in agricultural systems which are fossil, gross, labor and solar energy.

Table 3: Energy equivalents of inputs

Input–Output	Livestock buildings		Energetic values	
	Data	**Units**	**Value**	**Units**
A. Inputs				
1. Direct energy				
Diesel	Amount of diesel	L	40.68	MJ L^{-1}
Lubricant	Amount of diesel	L	3.6	MJ L^{-1} diesel
Electricity	Amount of electricity	kW	5.65	MJ kWh^{-1}
Human Labor	Energy equivalent	H	2.2	MJ $unit^{-1}$
2. Indirect energy				
Machines	Energy equivalent	Kg	71.38	MJ $unit^{-1}$
Concentrates	Amount of purchased forage	Kg	6.3	MJ kg^{-1}
Maize silage	Amount of purchased forage	Kg	5.5	MJ kg^{-1}
Grass silage	Amount of purchased forage	Kg	1.5	MJ kg^{-1}
Clover	Amount of purchased forage	Kg	10	MJ kg^{-1}
Hay (straw)	Amount of purchased forage	Kg	12.5	MJ kg^{-1} DM
B. Output				
1. Milk	Amount of milk	L	3.0	MJ L^{-1}

Adapted from Uzal, 2013.

The second principle looks into six components, which are material and buildings capital, crops, livestock, the family, manure storage and the plant production storage. All these components are within the agricultural system. The third principle looks at all energy inflow and outflow for the system and fifty-two energy flows have been identified (Vigne et al., 2013).

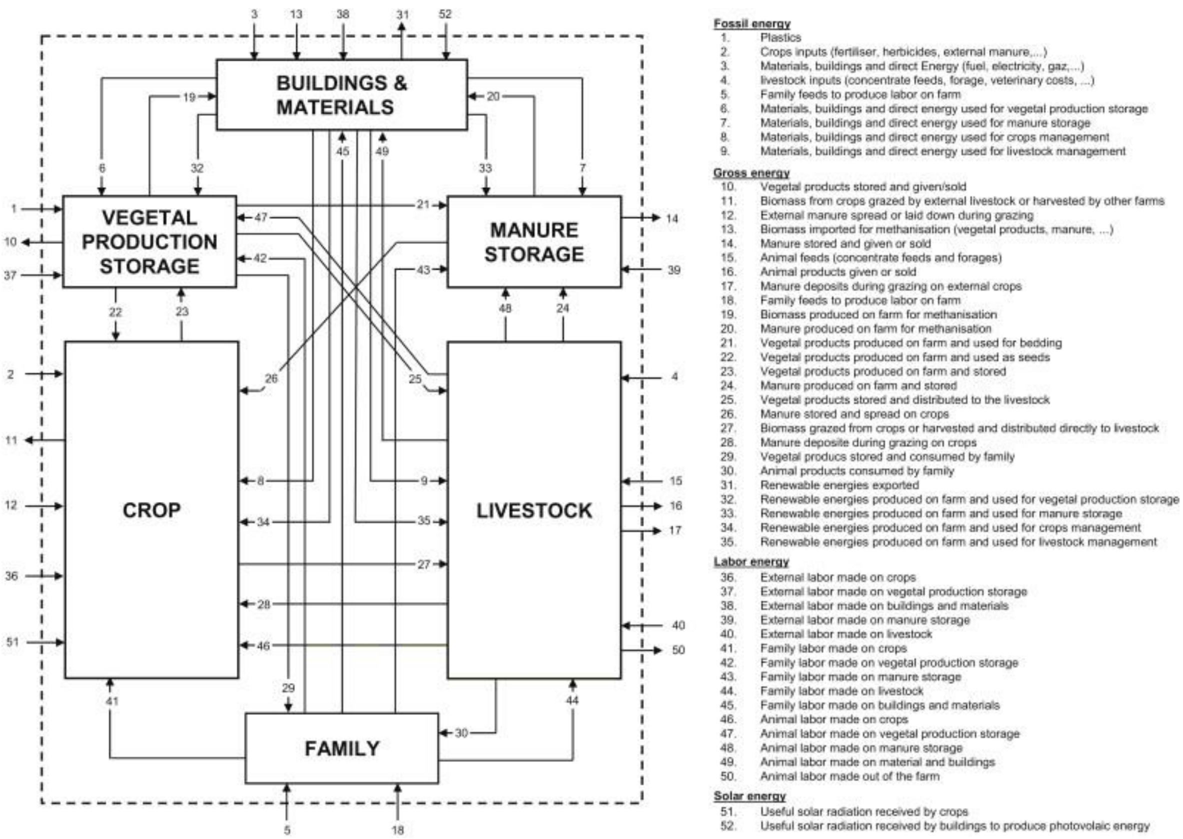

Figure 4: Conceptual model of energy flows entering, circulating in and leaving a dairy system

Source: Vigne et al., 2013

2.7 Energy value calculations and expression

From the four energy analysis methods described, there are some differences in calculations that is apparent. A comparison of three of these analysis methods (Figure 5) indicates that inputs are quantified and converted into fossil, land and solar energy for EA, EF and Em respectively using conversion factors (Vigne et al., 2012a). Pluri energy uses fossil, land, solar and labor energy (Vigne eta al., 2013). Energy coefficients are either calculated or from literature and are equivalence factors that represent life cycle fossil energy use (Vigne et al., 2012a and Vigne et al, 2012b).

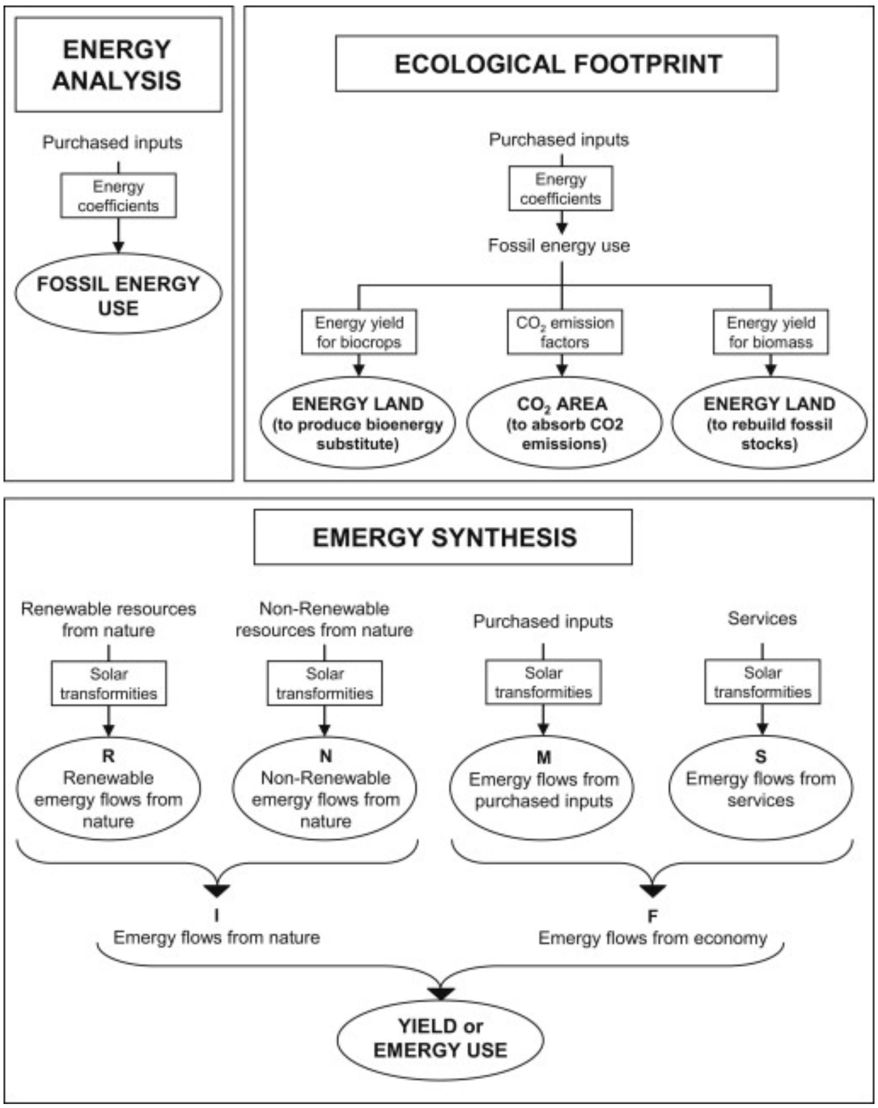

Figure 5: Comparison of energy use calculation in EF, EA and Em

Source: Vigne et al., 2012a

Conversion factors for Em named “transformities” and expressed in solar emjoules (seJ) per unit of input the amount of solar energy needed to produce the inputs. Emergy takes into account non purchased inputs e.g. renewable and non-renewable energy flows from nature, labor and other services. Emergy flows from natural origins (renewable or not) and the economy are then calculated. Both EA and Em use a one-step conversion procedure.

Fossil energy use in dairy farms is expressed as MJ L^{-1} of raw milk produced. The formula used is

Fossil Energy Use (MJ) = $\Sigma\, C_i I_i$,

Where C_i is the energy coefficient of each farm input i, and I_i is the quantity consumed for each farm unit I (Vigne et al., 2012b). To calculate for energy efficiency for EA and Transformity (T) for Em, the equations used are:

$$\text{EE (dimensionless)} = \frac{\text{Gross energy produced (MJ)}}{\text{Fossil energy use (MJ)}}$$

$$\text{T (seJ}\cdot\text{J}^{-1}) = \frac{\text{Total solar emergy input (seJ)}}{\text{Energy produced (J)}}$$

EF follows a two-step conversion procedure. Inputs are first converted into fossil energy by use of coefficients then energy consumption is converted into land use according to three categories; Carbon dioxide area required to absorb carbon dioxide emission, energy land required to rebuild energy consumed and area required to produce an amount of renewable energy equivalent to the amount of non-renewable energy consumed (Vigne et al., 2012a).

2.8 Greenhouse gas emission and energy (GGE)

The agricultural sector makes up more than a third of global CH_4 emissions, a byproduct of ruminant digestion and 65% of global N_2O emissions. Dairy farming in particular contributes about 4% of global anthropogenic GHG emissions (Kirby, 2008). This indicates a need for methodologies that estimate the carbon footprint reduction of farming technologies. One such method is anaerobic digestion, which can help reduce the emissions (FAO, 2010). Biogas produced from this process, about 50 to 65% CH_4, can be collected and converted to electricity or direct burn applications (Appels et al., 2011). Apart from GHG, dairy farms are a potential source of pollutants, if poor manure management practices are employed. If pollutants leak to waterways, the quality of water supply can be compromised (Lieffering et al, 2008). Another for GHG emission reduction is by applying manure to land for crop use (Aguirre-Villegas et al., 2015).

A study by Malcom et al., (2015), analyzed energy and greenhouse gas emission of northeast U.S. dairy cropping systems. The study found that farms that produce forage only (FOR) emitted 29% and 51% higher total GHGs per hectare than the Forage and grain (FORGr) and Forage grain and fuel on farm (NSVO) systems respectively. Expansion of farm area and reduction of herd size were shown to reduce off farm energy input dependence while having similar GHG emission. Growing more grain crops was shown to also emit similar GHG emission.

GHG emission is incorporated into farm energy analysis when calculating for Net Energy Intensity (NEI), which is measured in MJ. NEI is the net energy from activities related to milk and bioenergy production and is done under life cycle analysis (Aguirre-Villegas et al., 2015). The equation used for NEI is:

$$NEI = \frac{E_I - E_O}{FPCM}$$

Where E_I is the required energy inputs for crops and biofuel production and E_O is the energy output. These are both in MJ. FPCM is the fat and protein corrected milk and is in kilograms. FPCM is calculated using the equation

$$FPCM = M \times \frac{(0.0929 \times MF) \times (0.0547 \times MP) \times (0.0395 \times ML)}{0.7436},$$

from NRC (2001), where M is milk production in kg, MF is milk fat expressed as a percentage, MP and ML are the percent milk protein and milk lactose respectively.

2.9 Energy efficiency in different species and regions

Energy efficient agricultural systems that have a low energy input compared to energy output help to reduce emission of GHG in agriculture (Uzal, 2013). Energy use efficiency (EUE) is the amount of energy that is required for the production of one unit of product (Heidari, 2011), in the case of a dairy farm, milk. It is calculated with the equation

$$EUE = \frac{\text{Energy out}}{\text{Energy input}}$$

where EUE is amount of product produced per one unit of energy (Uzal, 2013). Productivity energy (PE) is the ratio between the amount of product and the total energy input. In Belgium, energy use efficiency for 90% of specialized dairy farms in Flanders was found to be 21.6 l milk 100 MJ^{-1} from 1989-1990 and 16.7-39.0 L milk 100 MJ^{-1} from 2000-2001 (Muel et al., 2007). In the same study, specialized pig fattening herds had an average energy efficiency of 6.0 kg carcass 100 MJ^{-1}.

A study by Singh et al., 2002, analyzed energy flow for dairy farms in India and found a gross energy efficiency of 37% suggesting that 63% of the energy is being used for purposes other than production. The farms had average herd size of 2.87. These were Jerseys and/or Holstein Friesians. This gross energetic efficiency was higher than that for crossbred animals in the same country, which was 18%. Using different housing systems, Uzal, (2013), found that the total energy consumption required for milk production differed for different housing systems. Free stall housing system required 4,880,754 MJ ha^{-1} and loose housing systems 5,561,281 MJ ha^{-1}. In Iran, 1000 bird total energy input for broiler chickens was found to be 186,886 MJ $(1000\ bird)^{-1}$ while the output energy was 27,461 MJ $(1000\ bird)^{-1}$. Diesel fuel and feed had the biggest share of energy inputs at 59.2% and 39.74%, respectively (Heidari, 2011).

2.10 Modeling in dairy farms

Models in dairy farms have been developed based on specific nutrient management (Nousiainen et al., (2011); Huhtanen et al., (2011)) or the whole farming system (Schils et al., (2007); Beukes et al., (2008)). The dairy farm nutrient management model also named Lypsikki (Nousiainen et al., 2011) allows estimation of crop and milk yield in response to fertilization and increased nutrient supply and is based on empirical regression equations. It was validated with data from 21 dairy farms in Finland. The model includes three sub models; (1) soil and crop, (2) dairy herd and (3) manure management. The model had two levels of productivity; mean and low. Validation of the model indicated a strong (M: R2 = 0.77 and L: R2 = 0.80) relationship between model predicted and farm phosphorous values.

Modeling a farm system can include linking other sub models to form a complete whole-farm model (WFM; Wastney et al., 2002) that can be used as a tool for design and analysis of new dairy farming systems. Using a computer program, its framework is written in VisualWorks Smalltalk with sub models written in other programming languages linked to the framework using Microsoft COM protocol. It has user friendly interfaces and can run simulations stand-alone on a PC. Beukes et al., (2008) validated WFM for pasture-based dairy systems and showed that the model has accuracy.

DairyWise (Schils et al., 2007) is a whole farm dairy model that was developed to simulate technical, environmental and financial processes. It is integrated and consists of subsystems of a dairy farm (Figure 6). The main component of DairyWise is the Feed Supply model; its output goes to different environmental, technical and economic sub models.

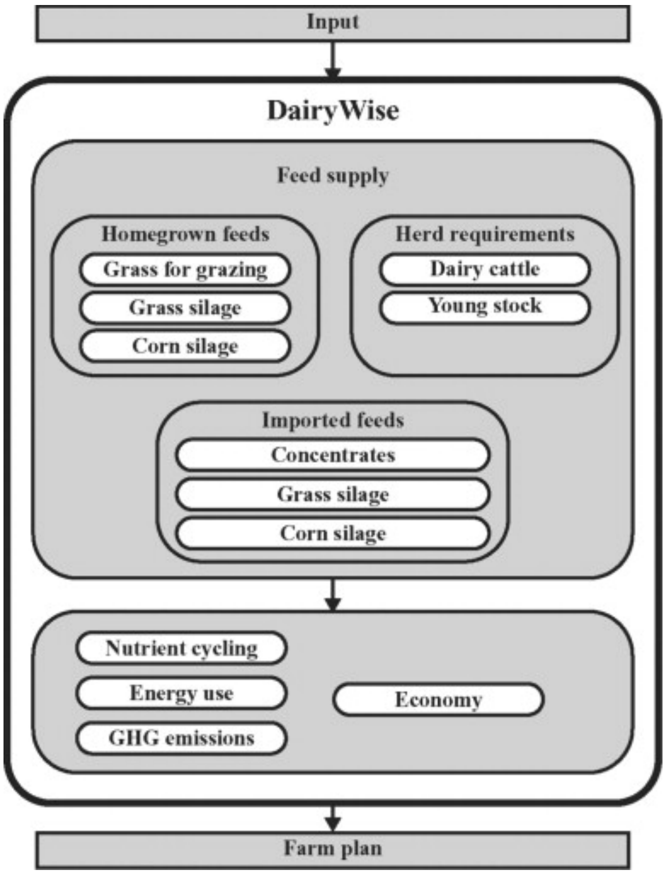

Figure 6: Modular structure of DairyWise

Source: Schils et al., 2007

The Feed Supply model strikes a balance between homegrown and imported feeds. Other models used include crop and animal models. The final model output is a Farm plan that has the economic, environmental and technical data of the farm.

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Study area

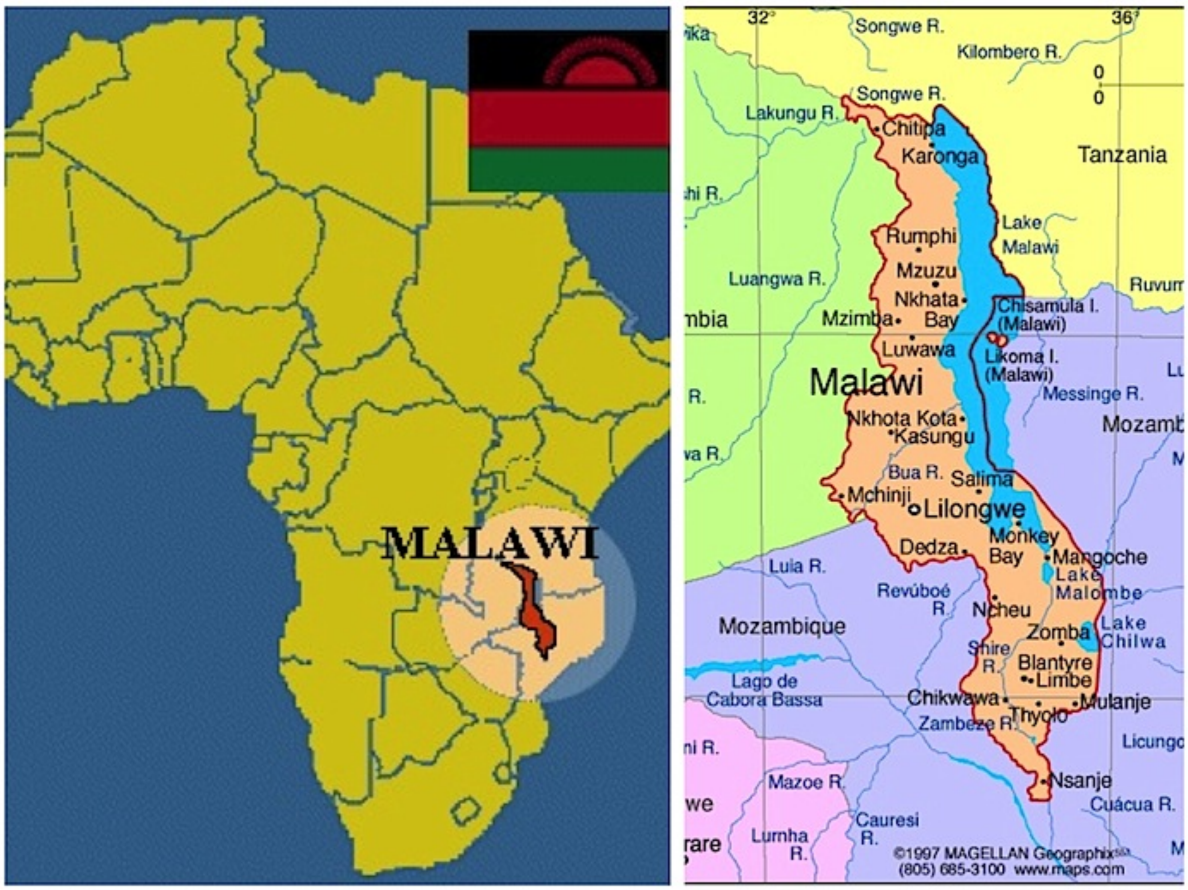

Figure 7: Map of Malawi

Source: http://www.africaeducationaid.co.uk

Katete Dairy Farm and North Carolina State University Dairy Education and Research unit farm were used for this study. Katete Dairy Farm is located in Lilongwe, Malawi. A large scale dairy farm was chosen because smallholder farmers (in Malawi) practice limited record keeping. The records kept are included mainly for the purpose of milk sales (Mayuni et al., 2009). At present, there is no institutionalized and countrywide recording system in Malawi, so farmers keep on-farm records in various formats (Chagunda, 2009).

3.1.1 Katete dairy farm

The farm is of about 700 hectares of land located in the capital city of Malawi, Lilongwe. It is characterized by sandy loam soils with arable land of about 300 hectares. The average rainfall for Lilongwe is 900 mm (MET, 2014) and it experiences a cool dry winter season from May to August and a hot dry season from September to October.

Crops

The crops that are planted on farm include Soya bean, Maize and Rhodes grass. Soya is planted on 110 hectares of land, maize 170, and Rhodes grass takes up about 80 hectares. The crops are rain fed, that is, irrigation is not used, but the farm has built a dam that will serve the purpose of irrigation in the future. There is also an orchard on the farm.

Animals

The herd consists of 408 Holstein cattle with 108 lactating cows. The farm owns one bull, but it is rarely used to reduce chances of inbreeding. Milk is at an average daily production of 19.5 liters and the highest producer makes 32 liters per day. All feed is made on farm; that is, there is no use of a commercially made concentrate, but some ingredients are purchased.

Other feed provided on farm is silage. Once milk is harvested, the farm also has a processing unit that makes processed milk, yoghurt, ice cream and chambiko (fermented milk). For the sake of this study, energy flow was followed only up to milk collection in tank.

The farm also keeps sheep that are used as a tool to control ticks, by grazing them ahead of cows. Ticks attach to the fleece of the sheep therefore reducing the number that attach to the cattle. These sheep are periodically dipped to kill/remove any ticks.

3.1.2 NCSU dairy farm

Figure 8: Map of North Carolina

Image from www.netstate.com

NCSU dairy farm is a research and training farm for students consisting of 157 hectares of land. Milk produced from the farm is processed into various milk and milk products at the Department of Food, Bioprocessing and Nutrition Sciences on campus.

Crops

There are 9 major pastures grown. Corn and triticale forage are used for silage. Grasses grown include Fescue and Bermuda. The management of these crops is outsourced; therefore, the dairy unit is only responsible for placing an order of specific amount of feed required for a set period of time.

Animals

The farm currently stocks a total of 183 mature cows, which include 33 Jerseys, 52 low group Friesians (Holsteins), 54 high group Friesians and 44 overflow cows. Currently, the farm has also 194 heifers and 18 calves. Milking cows produce an average of 34 liters/cow/day. Milking cows are composed of Friesian/Holstein and Jersey cows. The farm also has 40 steer calves. These steer calves are sold when they reach a certain stage as this unit is only specialized in dairy cows.

Steers, replacement heifers and dry cows are allowed to graze within these pastures and rotational grazing is practiced. Corn and triticale which is used for making silage is grown in other fields out of the dairy unit premises.

The farm primarily relies on a Total Mixed Ration that is formulated by independent contractors and is mixed on the farm. This TMR is fed to milking cows throughout. Dry cows are also fed TMR and are allowed to graze in the pastures. Cows are fed in groups based on milk production level.

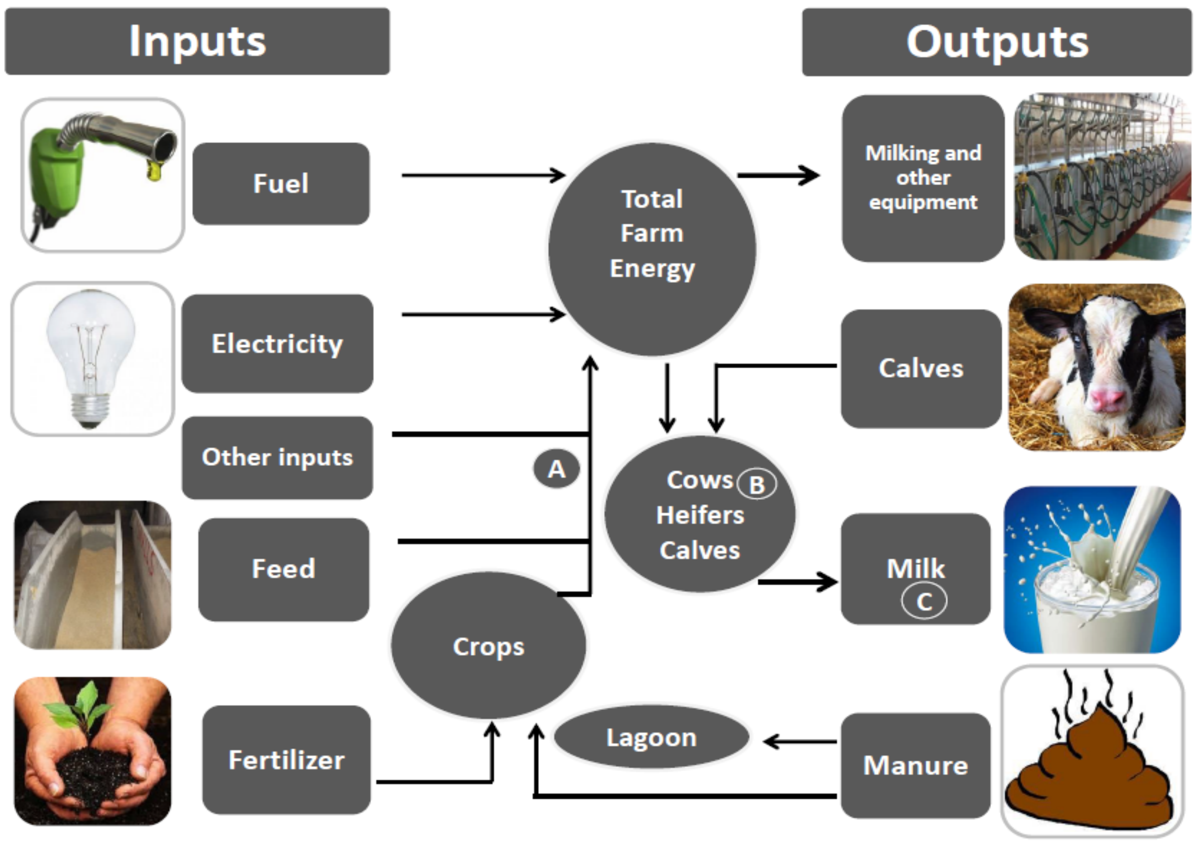

Figure 9: General flow of energy per cow per day

Feed energy per cow was calculated from dividing A (energy from feed) by B (Number of cows). Feed energy per Kg of milk produced was calculated from dividing A by C (Figure 9).

Labor

The dairy unit mainly depends on students' labor force. There are a few permanent dairy unit employees. Though this scenario may reduce labor cost, the uncertainty of student availability may pose a problem in management.

3.2 Study design

Several methods of energy analysis have been reported in the literature and include statistical analysis, input-output analysis, and process analysis. Statistical analysis using global statistics, such as for fertilizer sales is used to arrive at an estimate of total energy use but does not achieve the accuracy which could be obtained with other methods, e.g. FEAT program (Fluck and Baird 1980). For this study, the Energy Analysis (EA) assessment method (Pimentel et al., 1973) was used. Inputs that are quantified in time and physical units were transformed by use of conversion factors into total fossil energy use for EA. These inputs were:

- Diesel fuel
- Human labor
- Concentrates
- Corn silage
- Hay
- Molasses
- Triticale silage

Annual records were analyzed to determine energy cost for individual farms and an input-output analysis was done.

3.3 Data collection

The primary data collection was done from the farms via records and interviews. The data included milk production, herd structure, inputs as well as outputs. All the inputs and outputs were expressed on their dry matter basis. The dry-matter was determined by use of Feed Guides (Mtimuni 2011 and Preston 2012). To calculate feed consumption, amount of feed given to an animal was subtracted from the leftover feed.

3.4 Farm inputs

Energy values for inputs were obtained on an annual and daily basis. Feed consumption and milk production data were collected from Katete Dairy herd in Lilongwe, Malawi, consisting of 408 cattle with 108 lactating cows, and the NCSU Dairy Research and Teaching Farm, housing 245 Holstein and 55 Jersey cows and 170 lactating cows. Both are teaching farms that employ extensive record keeping. Energy coefficients were used to calculate total energy for inputs. Feed guidelines for respective countries were used for conversion into digestible energy values. Electricity data for Katete was not available at the time of data collection Hence this was excluded from the study.

Human Labor Energy

Labor requirements for animal care, milking and feed distribution are what made up Human Labor Energy (HE). The HE for farm labor was calculated as below:

HE = (hours of work) x EE

where EE is the energy equivalent of human labor (MJh^{-1}). The energetic equivalent used was as reported by Uzal, (2013).

Energy Efficiency

Energy Efficiency (EE) for EA method was calculated to find mega joules (MJ) of food energy produced per MJ of non-renewable energy consumed. This value is measured in $MJ.MJ^{-1}$. This is the ratio of gross energy output and total energy input using the following equation (Vigne et al., 2012a):

$$\text{EE (dimensionless)} = \frac{\text{Gross energy produced (MJ)}}{\text{Fossil Energy use (MJ)}}$$

3.5 Outputs

The main output considered in this study was milk. Manure were included in the data collection because the quantity produced was large. Cull animals, heifers or meat were not included for the reason that both dairy farms have milk as their primary product.

In this study, the energy input was defined as total amount of energy used to produce only milk and energy output was defined as total amount of milk production. Energy output was calculated by multiplying the amount of milk produced with its energy equivalent. Calculations were on a daily and annual basis. The conversion factors for milk to energy were 3 MJ per liter (Uzal, 2013) for NCSU farm. Fresian milk sampled in Malawi, contains 2.7 MJ per liter (Neba, 2015).

CHAPTER FOUR

4 RESULTS

The results indicate that Katete dairy farm had more feed energy input compared to the NCSU dairy farm. This was for all classes of livestock kept on the farms. This does not necessarily reflect a higher cost of production due to the differences in feed costs.

Lactating cows

Digestible energy intakes were calculated to find the energetic values assigned. For lactating cows, NCSU dairy farm had less feed energy, with 359 MJ per cow per day while Katete dairy farm fed about 427 MJ per cow per day (Table 4). The energy from hay was higher for Katete dairy farm, at 209 MJ versus NCSU at 21 MJ, due to higher quantity fed.

Table 4: Feed energy content provided for lactating cows

Feed	Katete Energy/cow/day (MJ)	NCSU Energy/cow/day (MJ)
Concentrate	126	205
Corn Silage	79	83
Hay	209	21
Molasses	13	0
Triticale Silage	0	83
Total	427	359

The feed profile (Figure 10) indicates Katete farm fed 9 kg dry matter of concentrate per cow per day, while the NCSU dairy farm was at 12 kg dry matter. Most of the energy for Katete came from feeding more pasture compared to NCSU dairy farm.

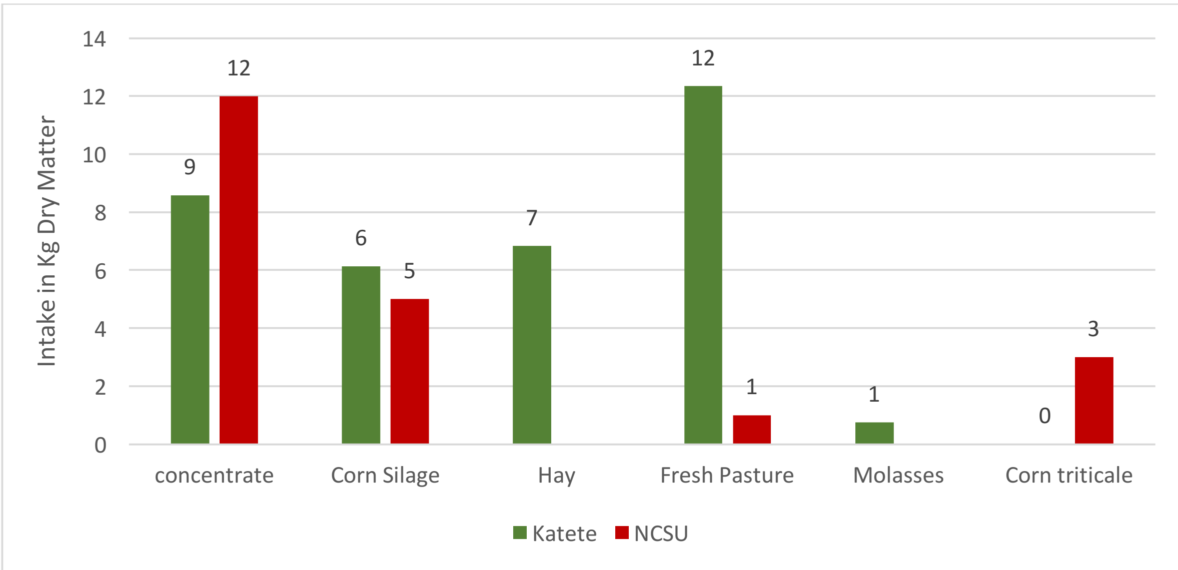

Figure 10: Dry matter intake kg/ lactating cow/day

The only difference for lactating animals was that only Katete farm fed molasses, which are given to improve palatability of feed and mostly provided at milking. NCSU dairy farm also fed triticale corn silage, which is absent at Katete dairy farm.

Dry cows and heifers

There was a 138 MJ difference between feed given at the two farms (Table 5). Katete fed its cows more energy than did NCSU. Birth weights of calves were not recorded, but would give a better picture of feed effects. There was not much of a difference in terms of corn silage fed but hay and pasture intake was higher at Katete.

Table 5: Feed energy intake: dry cows

Feed	Katete Energy/cow/day (MJ)	NCSU Energy/cow/day (MJ)
Concentrate	39	22
Corn Silage	68	77
Hay/Pasture	209	85
Molasses	6	0
Total	322	184

Katete provided 209 MJ energy to the animals compared to NCSU, which provided 85 MJ. Heifer feed energy differed between the two farms. Katete fed more energy than did NCSU. There were some feeds that were only provided at Katete and not at NCSU and these are corn silage (45 MJ) and molasses (6 MJ).

Table 6: Feed energy intake for heifers

Feed	Katete Energy/cow/day (MJ)	NCSU Energy/cow/day (MJ)
Concentrate	39	24
Corn Silage	45.	0
Hay/Pasture	209	91
Molasses	6	0
Total	299	115

Energy intake and output and efficient energy use

The data analyzed indicates that for all phases of production, Katete provided more feed energy compared to NCSU (Figure 11). The highest energy phase was for lactating animals.

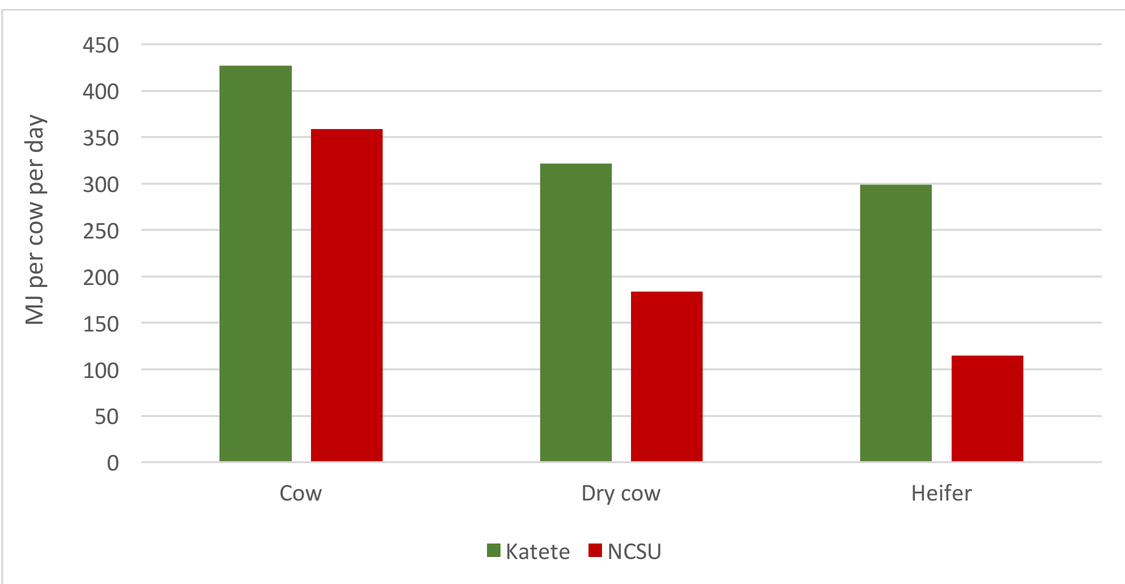

Figure 11: Feed energy intake per stage of development

The two farms differ in terms of system design in that NCSU is more mechanized than Katete. NCSU farm did not directly grow their own pasture, but it was out-sourced. Therefore, fertilizer costs were incurred indirectly. The manure is taken into a lagoon prior to spreading on cropland. Katete did not provide electricity data and manure is applied into the crop fields.

Table 7: Dairy farm daily energy

	Dairy farm daily energy			
Inputs/output	Katete		NCSU	
	MJ	**%**	**MJ**	**%**
1. Direct energy input				
Diesel fuel	334.36	0.4	5635.8	4.9
Human labor	256	0.3	123.2	0.1
2. Indirect energy input				
Concentrates	18678	21	39000	33.6
Corn silage	15762	18	16035	13.8
Hay	49742	57	19345	16.7
Molasses	2184	3	0	0.0
Triticale Silage	0	0	35960	31.0
Total Input	86957	100	116099	100
Output				
Milk production	6156		72550	

Milk production was around 1,985,600 liters for NCSU and 786,000 liters for Katete annually. Energy from milk production was 262,000 MJ at Katete and 661,867 MJ at NCSU annually. An input/output analysis (Table 7) indicated that the highest proportion of input for

NCSU farm was the concentrate feed (34%). On the other hand, Katete farm had the highest proportion of inputs coming from pasture, at 57%, followed by concentrate feed (21%). Triticale pasture also contributed a high proportion to inputs for NCSU, with an energy input of 35,960 MJ representing 31% followed by hay (16%). Even though molasses was the feed that was provided at Katete but absent at NCSU, its contribution was minimal, at 3%.

Table 8: Energy Efficiency output/ input (MJ.MJ^{-1}) for Katete and NCSU Farms, where output is milk energy and input is the item listed on each line.

Items	Katete	NCSU
All feed	0.07	0.66
Labor	24.00	942.36
Fuel	18.41	12.87
Overall energy efficiency of milk production	0.07	0.63

Fuel used for farming activities had a higher proportion at NCSU (4.9%) compared to Katete (0.4%). Human labor energy was 123 MJ for NCSU but almost twice that amount for Katete. This is because NCSU is more mechanized. Energy use efficiency (Table 8) for the farms was 0.07 MJ. MJ^{-1} for Katete and 0.63 MJ.MJ^{-1} for NCSU. This indicates that NCSU was more energetically efficient.

CHAPTER FIVE

5 DISCUSSION

Energetic inputs for the two farms mainly differ in the to proportions of feed given.

Katete had a 21% concentrate feed proportion while NCSU had 37%. Overall, feed had the highest proportion of energy input for both farms. This is in agreement with Seedpari, (2012) with 52% concentrate and Vigne et al., (2003) with 61% concentrate.

Katete farm practices semi-grazing, with hay also being provided while NCSU used a Total Mixed Ration. This is a major difference between the two that greatly influences milk production. Katete fed its cows about 2% molasses. Increasing dietary sugar content up to 10% DM has been shown not to affect rumen pH or volatile fatty acid profile (Broderick and Radloff, 2004 and Oelker et al. 2009) but leads to an increase in dry matter intake. In addition, an increase from 2.4 to 7.2% on a DM basis does not affect milk yield and composition (Broderick and Radloff, 2004). Therefore, the high intake of forages in Katete cows is complemented by the addition of sugars (Molasses fed are from sugarcane) to the diet.

One noteworthy difference between the two farms is labor. Apart from having permanent staff, Katete farms also have seasonal labor that increases the input energy. The same can be said of NCSU, which has more diesel fuel use. Data for electricity were not available. The proportion of forage fed by NCSU (16.7%) was in agreement with Uzal, (2013) study that found 17.76% and 21.21% for two specialized farms that had different barn planning. Katete had a 57% hay contribution. Even though Katete fed more hay, the type of grass grown is Rhodes grass (*Chloris gayana*), which is native to Africa. Since tropical forages are often coarse, animals select leaves and basal parts to achieve high digestible DMI (Paladines, 1979; Zemmelink, 1982). Nutritive value of Rhodes grass declines with age (Mbwile and Uden, 1997). Even though increase in intake of Rhodes grass was not explained by increase in digestibility (Mbwile and Uden 1996), it is necessary to allow high level of selection in order to maximize production. In terms of cost, the forage fed is still a cheaper option for Katete farm.

NCSU had the highest amount of energy from concentrates, which was 58% of the total feed while Katete only fed it at 18% of the total feed. A comparison of feed input and output in indicated that NCSU produced more (34 Kg per cow per day) milk than Katete (19 Kg per cow per day) despite feeding less energy. NCSU fed more crude protein (CP). This is in line with Robinson (2010) who found that an increased CP level caused an increase in milk yield.

When it comes to fuel use, the marked difference between the two farms (0.4% for Katete and 5% for NCSU are not in agreement with other papers. Seedpari, 2012 found 10% while Zucchetto and Bickle, 1984 found that fuel contributed 20%. Vigne et al., (2003) also compared farms in two French territories and found 19% for Poitou-Charentes (PC) and 9% for Reunion Island (RI). NCSU uses a more advanced system of mechanization, compared to Katete. This meant less labor force. Katete should investigate this mechanized system, which would sufficiently cut down on labor costs.

All manure produced at Katete farm is used in crop production. This is about 47200 Kg used in Soya and Rhodes grass fields annually. Nutrients are therefore recycled even though this may not hold true for energy, which is lost to bacterial respiration. But if the nutrients are made available to the plant, there is more growth and plants can capture more solar energy, therefore in a sense, recapturing the lost energy. Manure is processed with a solids separation and lagoon system at NCSU. Some energy is lost during storage, although this has not been analyzed. Both farms had a substantial portion of the energy fed to the cows lost to the environment as composted manure in soils or lagoons that did not capture the heat or methane generated. However, our feed energy analysis is based on digestible energy, which excludes the energy in feces.

The production of milk (per cow per day) had a difference of 15 liters between the two farms. This is in line with a Muel et al., (2007) study that found that the most efficient farms had highly productive cows (+8 liters) and a high stocking rate. Hofstetter et al., (2014), also found that pasture fed cows had lower milk yield, fat and protein output compared to indoor fed cows. The only difference between the two, which also applies to Katete and NCSU is that the pasture fed farms are self-sufficient, while the indoor fed farms use purchased feed. Rising feed prices all over the world suggest that pasture-based dairy production systems could gain importance in the foreseeable future but with the increase in population, this system might face some challenges. Ecological footprint (EF) analysis which takes into account the biologically productive area in calculations, could give an opposite picture of the importance of pasture-based dairy production systems.

Energy that doesn’t go into milk production is used for cooling for the farm (NCSU), reproduction, basal metabolism and some is lost as heat. From the Energy Analysis (EA) assessment method, which calculates the ration of milk production to input, Katete had an energy use efficiency value of 0.07 $MJ.MJ^{-1}$. NCSU had an energy use efficiency of 0.63 MJ. MJ^{-1}. Uzal (2013), found 0.12 $MJ.MJ^{-1}$. So far, the highest livestock systems have reached, is 1 $MJ.MJ^{-1}$ (Benoit and Laignel, 2010; Veysset et al., 2007). This does not reflect how well the farm is doing financially but it is an indicator of how efficiently fossil fuel energy is being used for production.

Unfortunately, the data available from both farms were insufficient to use a comprehensive farm model such as DairyWise (Schils et al., 2007). The model can estimate crop and milk yield because it requires three sub models; (1) soil and crop, (2) dairy herd and (3) manure management. Several factors in dairy production should be considered to improve efficiency. Most dairy farms in the sub Saharan region are highly dependent on pasture. Therefore, there is need for better nutritional management of existing pastures since this is a cheaper and more sustainable system of production in that region. Introduction of better quality, high yielding pastures that have been tested in the region could help improve efficiency of Katete dairy farm. Increasing the amount of concentrate given to cows at Katete is a possible solution but this can only be adopted if proven to be cost effective. This study did not look into costs associated with the two production systems which could provide more information for decision making. The external energy required to produce purchased feed was also not evaluated.

CHAPTER SIX

6 CONCLUSION

Energy flow analysis indicates that North Carolina State University has more milk per unit of feed energy input compared to Katete dairy farm. Katete farm can improve milk production by changing the nutrient profile and providing more concentrates to cows. Improving Malawi Dairy cattle diets could increase milk availability to the country, where annual intake is currently 3.8 kg per capita. Energy analysis of milk and feed alone is not enough to provide information on sustainability. There is need to incorporate an element of economic feasibility for Malawi with comparison of commercial scale and small-holder farms. There is need for a large scale analysis, which will include other input factors like electricity, lubricants, machines as well as inputs for production of pasture and or crop. It would also be of interest to look at the greenhouse gas effect on farms and to collect more data to do an analysis on carbon footprint. In the future, whole dairy farm models that capture external energy used to make purchased feed would be of benefit for agricultural planning in various geographical locations.

7 REFERENCES

Agostinho F, Ambrósio LA, Ortega E. Assessment of a large watershed in Brazil using Emergy Evaluation and Geographical Information System. Ecological Modelling. 2010;221:1209–20.

Aguirre-Villegas HA, Passos-Fonseca TH, Reinemann DJ, Armentano LE, Wattiaux MA, Cabrera VE, Norman JM, Larson R. Green cheese: Partial life cycle assessment of greenhouse gas emissions and energy intensity of integrated dairy production and bioenergy systems. Journal of Dairy Science. 2015;98:1571–92.

Appels L, Lauwers J, Degrève J, Helsen L, Lievens B, Willems K, Van Impe J, Dewil R. Anaerobic digestion in global bio-energy production: Potential and research challenges. Renewable and Sustainable Energy Reviews. 2011;15:4295–301.

Banda LJ, Gondwe TN, Gausi W, Masangano C, Fatch P, Wellard K, Banda JW, Kaunda EW. Challenges and Opportunities of Smallholder Dairy Production Systems: A Case Study of Selected Districts in Malawi [Internet]. Livestock Research for Rural Development. 2011 [cited 2014 Nov 12]. Available from: http://www.lrrd.org/lrrd23/11/band23226.htm

Banda LJ, Kamwanja LA, Chagunda MGG, Ashworth CJ, Roberts DJ. Status of dairy cow management and fertility in smallholder farms in Malawi. Tropical Animal Health Production. 2012;44:715–27.

Benoit M, Laignel G. Energy consumption in mixed crop-sheep farming systems: what factors of variation and how to decrease? Animal 4. 2010;9:1597–1605.

Beukes PC, Palliser CC, Macdonald KA, Lancaster JAS, Levy G, Thorrold BS, Wastney ME. Evaluation of a Whole-Farm Model for Pasture-Based Dairy Systems. Journal of Dairy Science. 2008;91:2353–60.

Broderick GA, Radloff WJ. Effect of Molasses Supplementation on the production of lactating dairy cows fed diets based on alfalfa and corn silage. Journal of Dairy Science. 2004;87:2997–3009.

Brown MT, Ulgiati S. Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. Ecological Modelling. 2004;178:201–13.

Cassman KG, Dobermann A, Walters DT, Yang Y. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environmental Resources. 2003;28:15–58.

Castellini C, Bastianoni S, Granai C, Bosco AD, Brunetti M. Sustainability of poultry production using the emergy approach: Comparison of conventional and organic rearing systems. Agriculture, Ecosystems & Environment. 2006;114:343–50.

Cavalett O, Queiroz JF de, Ortega E. Emergy assessment of integrated production systems of grains, pig and fish in small farms in the South Brazil. Ecological Modelling. 2006;193:205–24.

Chagunda MGG, Msiska ACM, Wollny CBA, Tchale H, Banda JW. An analysis of smallholder farmers' willingness to adopt dairy performance recording in Malawi. Livestock Research for Rural Development 2006;18 (5). Available from: http://www.lrrd.org/lrrd18/5/chag18066.htm

Chagunda MGG. Historical Perspective. In: Smallholder Dairy Production in Malawi: Current Status and Future Solutions. 2009; SAC: Edinburgh. Available from: http://www.sruc.ac.uk/download/downloads/id/1069/current_status_and_future_solutions

Chagunda MGG, Bruns EW, King JM, Wollny CBA. Evaluation of the breeding strategy for milk yield of Holstein Friesian cows on large-scale dairy farms in Malawi. The Journal of Agricultural Science. 2004;142:595–601.

Chen B, Chen ZM, Zhou Y, Zhou JB, Chen GQ. Emergy as embodied energy based assessment for local sustainability of a constructed wetland in Beijing. Communications in Nonlinear Science and Numerical Simulation. 2009;14:622–35.

Chintsanya, NC, Chinombo DO, Gondwe TN, Wanda G, Mwenda ARE, Banda MC, Hami JC. Management of farm animal genetic resources in the SADC region: Malawi. 2004. Available from: http://www.fao.org/ag/againfo/programmes/en/genetics/documents/Interlaken/countryreports/Malawi.pdf.

Cleveland CJ. The direct and indirect use of fossil fuels and electricity in USA agriculture, 1910-1990. Agriculture, Ecosystems & Environment. 1995;55:111–121.

Cohen MJ, Brown MT, Shepherd KD. Estimating the environmental costs of soil erosion at multiple scales in Kenya using emergy synthesis. Agriculture, Ecosystems & Environment. 2006;114:249–69.

Corré WJ, Society IF, Schröder JJ (Jaap J), Verhagen A. Energy use in conventional and organic farming systems [Internet]. York: International Fertiliser Society,; c2003. 24 p. Available from: http://catalog.lib.ncsu.edu/record/NCSU1711167

Cuadra M, Rydberg T. Emergy evaluation on the production, processing and export of coffee in Nicaragua. Ecological Modelling. 2006;196:421–33.

Das SM, Redbo I, Wiktorsson H. Behaviour of Zebu and crossbred cows in restricted suckling groups. Applied Animal Behaviour Science. 2001;72:263–70.

de Barros I, Blazy JM, Rodrigues GS, Tournebize R, Cinna JP. Emergy evaluation and economic performance of banana cropping systems in Guadeloupe (French West Indies). Agriculture, Ecosystems & Environment. 2009;129:437–49.

Deike S, Pallutt B, Christen O. Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. European Journal of Agronomy. 2008;28:461–470.

Department of Animal Health and Livestock Development (DAHLD). Annual

Livestock Census. 2008; Ministry of Agriculture and Food security, Lilongwe, Malawi.

Dodd FH. Safeguarding clean milk production in developing countries. 1986; National Institute for Research in Dairying, England.

Department of Animal Health and Livestock Development (DAHLD). Policy Document on Livestock in Malawi. 2005; Ministry of Agriculture and Food Security, Lilongwe, Malawi.

Unites States Department of Agriculture (USDA) Economic Research Service (ERS). Trends in U.S. per capita consumption of dairy products, 1970-2012. 2014; Available from http://www.ers.usda.gov/amber-waves/2014-june/trends-in-us-per-capita-consumption-of-dairy-products,-1970-2012.aspx#.VjaL866rSCQ

Food and Agriculture Organization of the United Nations. How to feed the World in 2050. 2009; Available from: http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

Food and Agricultural Organization of the United Nations. Animal Production and Health Division Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment; FAO: Rome, 2010; pp 32−33;www.fao.org/docrep/012/k7930e/k7930e00.pdf.

FAO, WFP & IFAD. The State of Food Insecurity in the World 2012. Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition. 2012; Rome: Food and Agriculture Organization of the United Nations.

Fluck RC, Baird CD. Agricultural Energetics. AVI Publishing Company, Westpost, CT, c1980. 192 pp.

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Mueller ND, O'Connell C, Ray DK, et al. Solutions for a cultivated planet. Nature. 2013;501:S35–40.

Franzluebbers AJ, Francis CA. Energy output:input ratio of maize and sorghum management systems in eastern Nebraska. Agricultural Ecosystems and Environment.1995;53:271–278.

Gajaseni, J. Energy analysis of wetland rice systems in Thailand. Agricultural Ecosystems and Environment. 1995;52:173–178.

Garnett T. Food sustainability: problems, perspectives and solutions. The Proceedings of the Nutrition Society. 2013;72:29–39.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C. Food Security: The Challenge of Feeding 9 Billion People. Science. 2010;327:812–8.

Gondwe TN. Dairy Cattle Breeding in Malawi. In: Smallholder Dairy Production in Malawi: Current Status and Future Solutions. Scoping Papers: Optimising Smallholder Dairying project. 2009; SAC: Edinburgh. Available from: http://www.sruc.ac.uk/download/downloads/id/1069/current_status_and_future_solutions

Goyder H, Mang`anda, M. Livestock Platform Baseline Study. 2009;Research Into Use Programme, Malawi.

Grönroos J, Seppälä J, Voutilainen P, Seuri P, Koikkalainen K. Energy use in conventional and organic milk and rye bread production in Finland. Agricultural Ecosystems and Environment. 2006;117:109–118.

Grote U. Can we improve global food security? A socio-economic and political perspective. Food Security. 2014;6:187–200.

Hanegraaf MC, Biewinga EE, van der Bijl G. Assessing the ecological and economic sustainability of energy crops. Biomass Bioenergy. 1998;15:345–355.

Hau JL, Bakshi BR. Promise and problems of emergy analysis. Ecological Modelling. 2004;178:215–25.

Heidari MD, Omid M, Akram A. Energy efficiency and econometric analysis of broiler production farms. Energy. 2011;36:6536–41.

Hofstetter P, Frey H-J, Gazzarin C, Wyss U, Kunz P. Dairy farming: indoor v. pasture-based feeding. The Journal of Agricultural Science. 2014;152:994–1011.

Huhtanen P, Nousiainen J, Turtola E. Dairy farm nutrient management model: 2. Evaluation of different strategies to mitigate phosphorus surplus. Agricultural Systems. 2011;104:383–91.

Hülsbergen K-J, Feil B, Biermann S, Rathke G-W, Kalk W-D, Diepenbrock W. A method of energy balancing in crop production and its application in a long-term fertilizer trial. Agriculture, Ecosystems & Environment. 2001;86:303–21.

Imani Development Consultants. Review of the Dairy Industry in Malawi, Regional Agriculture Trade Expansion Support Group. 2004;Nairobi, Kenya. Available from: http://www.docstoc.com/docs15833015/Review-of-the-Dairy –Industry-in-Malawi

IPCC. Summary for policy makers. c2007; Page 23. Cambridge Press, Cambridge, UK and New York, NY.

Kirby, A. Kick the Habit: A UN Guide to Climate Neutrality. United Nations Environment Programme. 2008; Nairobi, Kenya.

Kizilaslan H. Input-output energy analysis of cherries production in Tokat Province of Turkey. Applied Energy 2009;86:1354–1358.

Lefroy E, Rydberg T. Emergy evaluation of three cropping systems in southwestern Australia. Ecological Modelling. 2003;161:195–211.

Lieffering M, Newton P, Thiele JH. Greenhouse gas and energy balance of dairy farms using unutilised pasture co-digested with effluent for biogas production. Australian Journal of Experimental Agriculture. 2008;48:104–8.

Lobell DB, Cassman KG, Field CB. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. Annual Review of Environtal Resources. 2009;34:179–204.

Lu H-F, Campbell DE, Li Z-A, Ren H. Emergy synthesis of an agro-forest restoration system in lower subtropical China. Ecological Engineering. 2006;27:175–92.

Malawi Meteorological Services. Retrieved May 17, 2014, from http://www.metmalawi.com/climate/climate.php

Malcolm GM, Camargo GGT, Ishler VA, Richard TL, Karsten HD. Energy and greenhouse gas analysis of northeast U.S. dairy cropping systems. Agriculture, Ecosystems & Environment. 2015;199:407–17.

Marchettini N, Panzieri M, Niccolucci V, Bastianoni S, Borsa S. Sustainability indicators for environmental performance and sustainability assessment of the productions of four fine Italian wines. International Journal of Sustainable Development & World Ecology. 2003;10:275–82.

Martin JF, Diemont SAW, Powell E, Stanton M, Levy-Tacher S. Emergy evaluation of the performance and sustainability of three agricultural systems with different scales and management. Agriculture, Ecosystems & Environment. 2006;115:128–40.

Mayuni P, Nkwanda A, Chagunda M. Dairy Herd Recording. In: Smallholder Dairy Production in Malawi: Current Status and Future Solutions. Scoping Papers: Optimising Smallholder Dairying project. (2009); SAC: Edinburgh. Available from: http://www.sruc.ac.uk/download/downloads/id/1069/current_status_and_future_solutions

Mbwile RP, Udén P. The effect of feeding level on intake and digestibility of Rhodes grass (Chloris gayana, cv Kunth) by dairy cows. Animal Feed Science and Technology. 1997;66:181–96

McLaughlin NB, Hiba A, Wall GJ, King DJ. Comparison of energy inputs for inorganic fertilizer and manure based corn production. Canadian Journal of Agricultural Engineering. 2000;42:1–14.

Meul M, Nevens F, Reheul D, Hofman G. Energy use efficiency of specialised dairy, arable and pig farms in Flanders. Agriculture, Ecosystems & Environment. 2007;119:135–44.

Mtimuni JP. Ration Formulation and Feed Guides. Blantyre Printing and Publishing Co. Ltd. c2011. 64–65p.

Niccolucci V, Galli A, Kitzes J, Pulselli RM, Borsa S, Marchettini N. Ecological Footprint analysis applied to the production of two Italian wines. Agricural Ecosystems and Environment. 2008;128: 162–166.

Nguyen ML, Haynes RJ. Energy and labour efficiency for three pairs of conventional and alternative mixed cropping (pasture-arable) farms in Canterbury, New Zealand. Agriculture Ecosystems and Environment. 1995;52:163–172.

Nousiainen J, Tuori M, Turtola E, Huhtanen P. Dairy farm nutrient management model. 1. Model description and validation. Agricultural Systems. 2011;104:371–82.

Nutrient Requirements of Dairy Cattle: Seventh Revised Edition, 2001 [Internet]. [cited 2015 Aug 19]. Available from: http://www.nap.edu/catalog/9825/nutrient-requirements-of-dairy-cattle-seventh-revised-edition-2001

Oelker ER, Reveneau C, Firkins JL. Interaction of molasses and monensin in alfalfa hay- or corn silage-based diets on rumen fermentation, total tract digestibility, and milk production by Holstein cows. Journal of Dairy Science. 2009;92:270–85.

Ozkan B, Fert C, Feyza Karadeniz C. Energy and cost analysis for greenhouse and open-field grape production. Energy. 2007;32:1500–1504.

Paillard S, Treyer S, Dorin B. Agrimonde. Scénarios et défis pour nourrir le monde en 2050. 2010;Quae, Versailles, France.

Paladines O. Feed evaluation systems for the tropics of Latin America. In: Pigden WJ, Batch CC, Graham M. (Editors). Proceedings of the Workshop on standardization of Analytical Methodology for Feeds. 1979;IDRC, Ottawa, pp. 36–37.

Pervanchon F, Bockstaller C, Girardin P. Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agricultural Systems. 2002;72:149–72.

Preston RL. 2012 Feed composition tables. Beef. 2012; 48,60–73

Pimentel D, Hurd LE, Bellotti AC, Forster MJ, Oka IN, Sholes OD, Whitman RJ. Food production and the energy crisis. Science 1973;182:443–449.

Rabier F, Mignon C, Lejeune L, Stilmant D. Assessment of Energy Consumption Pattern in a Sample of Walloon Livestock Farming Systems. Grassland in a Changing World. In: Proceedings of the 23rd General Meeting of the European Grassland Federation. 2010; Kiel, Germany, 29th August-2nd September 2010:121–123.

Revoredo-Giha C. Market structure and coherence of international cooperation: the case of the dairy sector in Malawi. Land Economy Working Paper 2012;64. Scottish Agricultural College, Edinburgh, UK 24 pp.

Ron M. Hillel J. Genotype- environment interaction in dairy cattle and its role in animal breeding programmes. Theoretical and Applied Genetics 1993;66:93–99.

Schade C, Pimentel D. Population crash: prospects for famine in the twenty-first century. Environment, Development and Sustainability. 2010;12:245–62.

Schils RLM, de Haan MHA, Hemmer JGA, van den Pol-van Dasselaar A, de Boer JA, Evers AG, Holshof G, van Middelkoop JC, Zom RLG. DairyWise, A Whole-Farm Dairy Model. Journal of Dairy Science. 2007;90:5334–46.

Seedpari P. Assessment and Optimization of Energy Consumption in Dairy Farm: Energy Efficiency. Iranica Journal of Energy & Environment. 2012;3:213–24.

Sinclair KD, Garnsworthy PC, Mann GE, Sinclair LA. Reducing dietary protein in dairy cow diets: implications for nitrogen utilization, milk production, welfare and fertility. Animal: An International Journal of Animal Bioscience. 2014;8:262–74.

Singh V, Tripatni RK, Chauhan SS, Kumar A. Energy flow through a dairy farm in a village dairy cooperative in the Tarai area of Uttaranchal Himalayas. Indian Journal of Animal Scince. 2002;72:1034–9.

Stanton TL, Blake RW, Quass RL, Van Vleck LD, Carabano MJ. Genotype by environment interaction for Holstein milk yield in Colombia, Mexico and Puerto Rico. Journal of Dairy Science. 1991;74:1700–1714.

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C. Livestock's Long Shadow. Environmental Issues and Options. FAO, LEAD initiative, 2012;Rome, Italy ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e00.pdf.

Ulgiati S, Brown MT. Emergy and ecosystem complexity. Communications in Nonlinear Science and Numerical Simulation. 2009;14:310–21.

UN. World population prospects: The 2012 revision, highlights and advance tables. 2013; Working Paper No. ESA/P/WP.228, United Nations, Department of Economic and Social Affairs, Population Division, New York.

U.S. Dairy. U.S. Dairy's Environmental Footprint; A Summary of Finding, 2008-2012. Retrieved November 12, 2014 from: http://www.usdairy.com/~/media/usd/public/dairysenvironmentalfootprint.pdf.

Uzal S. Comparison of the energy efficiency of dairy production farms using different housing systems. Environ Prog Sustainable Energy. 2013;32:1202–8.

Van Asselt ED, Capuano E, van der Fels-Klerx HJ. Sustainability of milk production in the Netherlands – A comparison between raw organic, pasteurised organic and conventional milk. International Dairy Journal. 2015;47:19–26.

Veysset P, Lherm M., Bébin D. Energy consumption, greenhouse gas emissions and economic performance assessments in French Charolais suckler cattle farms: model-based analysis and forecasts. Agricultural Systems. 2010;103:41–50.

Vigne M, Vayssières J, Lecomte P, Peyraud J-L. Evaluating the ability of current energy use assessment methods to study contrasting livestock production systems. Journal of Environmental Management. 2012a;112:199–212.

Vigne M, Martin O, Faverdin P, Peyraud J-L. Comparative uncertainty analysis of energy coefficients in energy analysis of dairy farms from two French territories. Journal of Cleaner Production. 2012b;37:185–91.

Vigne M, Vayssières J, Lecomte P, Peyraud J-L. Pluri-energy analysis of livestock systems – A comparison of dairy systems in different territories. Journal of Environmental Management. 2013;126:44–54.

Von Keyserlingk M A. G, Martin NP, Kebreab E, Knowlton KF, Grant RJ, Stephenson M, Sniffen CJ, Harner JR, Wright AD, Smith SI. Invited review: Sustainability of the US dairy industry. Journal of Dairy Science. 2013;96:5405–25.

Wackernagel M, Rees WE. Our Ecological Footprint: Reducing Human Impact on the Earth. 1996;New society publishers, Philadelphia, United States.

Wastney ME, Palliser CC, Lile JA, MacDonald KA, Penno JW, Bright KP. A whole-farm model applied to a dairy system. NZSAP. 2002;62:120–3.

World Commission on Environment and Development, Our Common Future (Oxford: Oxford University Press, 1987), 43. Retrieved in June 2015 from: http://www.un-documents.net/wced-ocf.htm

World Wildlife. Facing the Challenge Together: Sustainable food for the 21st Century. , 2014. Available at http://www.worldwildlife.org/publications/facing-the-challenge-together-sustainable-food-for-the-21st-century.

West PC, Gerber JS, Engstrom PM, Mueller ND, Brauman KA, Carlson KM, Cassidy ES, Johnston M, MacDonald GK, et al. Leverage points for improving global food security and the environment. Science. 2014;345:325–8.

WHO. Obesity and overweight. 2013; Fact sheet No.311, World Health Organization, Geneva. Retrieved in February 2015 from: www.who.int/mediacentre/factsheets/fs311/en/.

World Bank. Population issues in the 21st century: the role of the World Bank. 2007; Washington, D.C: Health, Nutrition, and Population Discussion Paper 40583.

World Food Summit. Declaration on World Food Security. 1996; Rome. Available at http://www.fao.org/docrep/003/w3613e/w3613e00.HTM

Zemmelink G. Effect of selective consumption on voluntary intake and digestibility of tropical forages. Animal Feed Science and Technology. 1982;7:105–6.

Zhang LX, Yang ZF, Chen GQ. Emergy analysis of cropping–grazing system in Inner Mongolia Autonomous Region, China. Energy Policy. 2007;35:3843–55.

Zhang LX, Chen B, Yang ZF, Chen GQ, Jiang MM, Liu GY. Comparison of typical mega cities in China using emergy synthesis. Communications in Nonlinear Science and Numerical Simulation. 2009;14:2827–36.

Zimba G, Kalumikiza Z, Chanza W. Application of the Agriculture Science Technology and Innovation (ASTI) Systems to assess performance of Malawi`s Dairy Industry. 2010; Proceedings of the dairy science symposium. Lilongwe, Malawi.

Zucchetto J, Bickle G. Energy and nutrient analyses of a dairy farm in central Pennsylvania. Energy in Agriculture 1984;3:29–47.

APPENDICES

Appendix 1: Energy content for concentrate fed /lactating cow/day for Katete farm

Concentrate	**Quantity (kg)**	**% of ration**	**Amount in 9.75kg**	**DM %**	**DM Kg**	**TDN %**	**Energy (DE)* Mcals/kg**	**Total Energy/cow/day (Mcals)**
Maize bran	440	39.15	3.82	91	3.47	92.00	4.05	14.07
Maize Grain	280	24.91	2.43	89	2.16	88.00	3.88	8.39
Sunflower cake	350	31.14	3.04	91	2.76	57.00	2.51	6.93
Soybean	25	2.22	0.22	90	0.19	94.00	4.14	0.81
Limestone	10	0.89	0.09					
MCP	3	0.27	0.03					
Dairy Premix	1	0.09	0.01					
Salt	15	1.33	0.13					
Total	1124	100	9.75		8.59			**30.19**
Figures from Mtimuni (2011) and farm values								
R.L Preston (2012)Feed compositiontables								

*DE= TDN x 0.044

Appendix 2: Corn Silage, Hay, Grass and Molasses Energy Content/lactating cow/dayat Katete Dairy farm

Feed	Quantity kg /cow/day	DM %	DM Kg	TDN %	Energy (DE) Mcals/kg	Total Energy/cow/ day (Mcals)
Corn Silage	17.5	35	6.13	70	3.08	18.87
Hay	8.75	78	6.83	2.55	2.55	17.40
Fresh Pasture	26.25	47	12.34	2.64	2.64	32.57
Molasses	1	75	0.75	91	4.01	3.01
Total						**71.85**
Figures from Mtimuni (2011) and farm values Livestock Kenya.com						