JUSTUS-LIEBIG-
UNIVERSITÄT
GIESSEN

FACHBEREICH 09
Agrarwissenschaften,
Ökotrophologie und
Umweltmanagement

Use of delivered energy in a food process chain: A case study of the Kenyan fluid milk chain

A dissertation submitted to the Faculty of
Agricultural, Nutritional and Environmental
Sciences (FB 09) in partial fulfilment for the
requirements of the award of a Doctorate in
Agricultural Sciences of Justus-Liebig-University
Gieβen, Germany

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Declaration

I hereby declare that this dissertation is my original work and that it has not previously been presented to this or any other university in partial fulfilment for the award of any degree.

Dedication

To my sweet little angels Lynn Ndimu and Liam Musyimi and my soulmate Mwongela Musyimi. To my parents and siblings: you have all believed in me. To all the Mijikenda women aiming for academic excellence.

This dissertation was presented to the faculty of Agricultural, Nutritional and Environmental Sciences of the Justus-Liebig University-Giessen, Germany and was examined and defended on 28th April 2009.

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Acknowledgements

I would like to sincerely acknowledge my first supervisor Prof. Ing. Dr. E. Schlich. He has supported me from the beginning as I applied for the DAAD scholarship that gave me the opportunity to travel to and study in Germany. Additionally, his invaluable support and supervision during the entire period of study is part of what has made this work a success. I also thank my second supervisor Prof. S. Bauer for his support during the entire period of this research. Prof. S. Mahungu and Prof. Faraj of Egerton University Njoro are thanked for their collaborative efforts during data collection in Kenya. My sincere thanks also go to current members of staff and former colleagues at Prof. Schlich's research group: Susanne Schroeder, Birgit Schieber, Frank Krause, Bettina Herdtert, Daniela Thorme, Bernd Weber, Mr Ulrich Bauer and Mrs Doris Wagner are all thanked for their various forms of support. I also express my gratitude to Ms Carolina Babendererde: Manager of Environmental Affairs in Tetra-pak – Germany for taking interest in my work from the very beginning and offering her unwavering support to me.

The painstaking process of data collection would have been completely impossible were it not for the selfless efforts of the Managing Director of Kilifi Plantations- Mr Chris Wilson. I therefore would like to express my heartfelt gratitude to Mr Wilson for his invaluable input. I would also like to thank Mr Bartenge, Head of Production at the New-KCC and all factory managers of the participating New-KCC branches countrywide for their cooperation in this work. All the staff of New-KCC who helped me in data collection especially: Mr Keter Kipleting- Sotik, Mr Alex Mureithi- Nyahururu, staff in Kiganjo, Molo and Miritini, Mr Gervas Ngati of Dandora are sincerely thanked. My gratitude must also go to the General Manager of Brookside Dairies Company Ltd: Mr David L. Heath and all his friendly and helpful staff team who assisted me to carry out this survey at their premises. The plant managers: Mr. George Ouma at Ol'kalou, Mr Karimi in Kiganjo and Mr Ruto in Eldoret whose support is greatly appreciated are also thanked. The General Manager of Limuru Milk Processors Ltd. and his staff are also thanked. The efforts of the management and staff of Adarsh Developers were also very much appreciated. The Managing Director of Tetra-pak – Kenya, Mr Lindgren, and Mr Felix Kariuki of Tetra-pak are also thanked for their assistance. The members of my relatives and friends are also thanked: the Mazeras, the Mulewas, the Waihenyas, Esther Nyambura, Mrs Wanjiru Githua, Margaret Mathenge and Irene Anzazi for hosting me as I travelled the vast countryside to collect data. I thank Alice Temu for her support in this work. I also express my gratitude to Diana for carefully reading through my work and editing it, and the entire Christian family of IBC Giessen for their spiritual support.

Most of all, I would like to express my heartfelt gratitude to my family. My loving husband: Dr. *rer. nat.* B. Mwongela Musyimi for his complete and dedicated support and encouragement during the entire period of my Doctoral studies. My daughter: Lynn Ndimu and my son: Liam Musyimi for being tender and patient children during the period when '*Mama'* had to study. Your sacrifices are incalculable and cannot be appreciated enough; I surely could not have managed if you were not there for me. I am also extending my appreciation to my parents: Mr and Mrs William and Lydia Mwangome, sisters: Dr Nimwaka, Kaeni and Mbeyu and their families- Dr Mwangi Githua, Cello Githua, Felicity Njeri and William Mwangome, my brother Muye for always believing in me and supporting me in unaccountable ways. I am also thanking Mwendwa and Maanzo Musyimi, Raphael Munyao, Robert Mailu and their families for their continued support. I thank my friends Amukelani, Annette Schauss and her daughter Lisa for spending time with Lynn so I could work.

Last but not least, I sincerely would like to thank the German Academic Exchange Service (DAAD- Deutscher Akademischer Austausch Dienst) for awarding me the scholarship to travel to and study in Germany, without which none of this work would have been accomplished.

Abstract

Food is a basic need, but so is a sustainable society. There is an urgent need to increase our knowledge on the environmental consequences of food production, processing and handling in order to make improvements that promote sustainability (Berlin, 2002). However, in order to make real improvements in the environmental performance of a food supply chain, specific empirical data on systems energy requirements need to be assessed in a specific manner prior to decision making (Owens, 1997). The theory of ecology of scale may hold an important key to more sustainable food processing as it suggests that the major influence on ecological performance of food supply chains results from the scale associated with the involved companies (Schlich, 2008).

The present study sought to gather empirical data on the delivered energy requirements of the Kenyan fresh milk chain while applying the Life Cycle Assessment (LCA) technique. The study aimed at investigating whether the operation efficiency as influenced by the size of the surveyed dairy enterprises is more important than corresponding transport distances by regarding all energy efforts in this process chain. Energy balances were used as a component of LCA to establish the energy consumption, and from this database the primary energy and environmental impacts were then calculated as carbon dioxide (CO_2) emissions related to the main processes involved in this milk chain. The total energy uses were then allocated to a functional unit of 1 kg of milk ready for retailing to obtain the specific energy use. Comparisons were then drawn between the specific energy turnovers and corresponding business sizes presented as milk throughput per year. The environmental "hot spots" (life cycle steps that are more burdensome to the environment) were also identified. This method has also been extensively applied by Schlich *et al.*, (2006) to investigate a number of food supply chains, such as lamb, wine, beef and pork. Strong logarithmic digression relation between firm size and specific energy turnover were observed; thus supporting the theory of ecology of scale similar to the findings of this study. Additionally, this study also identified the farming stage as an important environmental hot spot, consuming the most energy compared to all other stages investigated in this product chain. Diesel emerged as the most important fuel useful for any energy saving interventions aimed at reducing the CO_2 emissions of this product chain; although electricity and wood were also quite popular.

The application of energy balances as part of the LCA methodology is useful in studying the environmental performance of food supply chains in developing economies to establish hot spots and optimum business sizes for more energy-efficient food supply chains.

Kurzfassung

Lebensmitteln zählen zu den Grundbedürfnissen des Menschen neben Kleidung und Behausung, ebenso wie eine nachhaltige Gesellschaft. Um Nachhaltigkeit fördern zu können, ist es notwendig das eigene Wissen um die Auswirkung von Lebensmittelproduktion, -verarbeitung und –handel auf die Umwelt zu erweitern (Berlin 2002). Zur Verbesserung der ökologischen Auswirkungen der Prozessketten der Lebensmittelbereitstellung, müssen vor der Entscheidungsfindung spezifische empirische Daten anhand des entsprechenden Fallbeispiels bezüglich des Endenergiebedarfs der Systeme bewertet werden (Owens 1997). Die Theorie der ***Ecology of Scale*** könnte ein wichtiger Schlüssel für die Entscheidung nachhaltiger Prozessketten der Lebensmittelbereitstellung darstellen. Sie verdeutlicht, dass von der Großenordnung der beteiligten Betriebe einen bedeutlichter Einfluss auf die ökologischen Auswirkungen von Prozessketten der Lebensmittelbereitstellung ausgeht (Schlich, 2008).

Im Rahmen der vorliegenden Arbeit werden empirische Daten zum Endenergiebedarf der Kenianischen Bereitstellung von Frischmilch gesammelt, unter Anwendung der Technik der Ökobilanzierung. Das Ziel der Studie liegt darin zu untersuchen, ob die Effizienz der Arbeitsabläufe beeinflusst durch die Größe der beteiligten Betriebe, wichtiger ist als die Transportentfernung, bei Berücksichtigung des kompletten Energieaufwands dieser Prozesskette. Energiebilanzierung als ein Teil der Ökobilanzierung wird angewendet, um Endenergieverbrauch und Kohlendioxidemission (CO_2), verursacht durch die wichtigsten Prozessketten der Milchbereitstellung, zu ermitteln. Die absoluten Endenergieumsätze werden auf die funktionelle Einheit 1 kg verkaufsfertige Milch bezogen, um spezifische Endenergieumsätze zu erhalten. Die spezifischen Endenergieumsätze werden mit den zugehörigen Betriebsgrößen, die als Milchdurchsatz pro Jahr angegeben werden verglichen. Des Weiteren werden ökologische „hot spots“ identifiziert. Diese Methode wird von Schlich *et al.* (2006) bereits zur Untersuchung der Bereitstellung weiterer Lebensmittel wie Lammfleisch, Wein, Rindfleisch und Schweinefleisch angewendet. In diesen Untersuchungen wird eine starke logarithmische Abnahme des spezifischen Energieumsatzes mit steigender Betriebsgröße beobachtet, was die Theorie der ***Ecology of Scale*** unterstützt, ebenso wie die Ergebnisse der vorliegenden Arbeit. Zusätzlich wird in dieser Studie die Stufe der Landwirtschaft als wichtiger ökologischer „hot spot“ identifiziert, der den größten Endenergieverbrauch im Vergleich zu allen anderen Bereichen dieser Prozessketten der Lebensmittelbereitstellung aufweist. Diesel stellt sich als wichtigster Treibstoff dieser Prozesskette heraus, der für Endenergiesparmaßnahmen mit dem Ziel der Reduktion von CO_2-Emissionen genutzt werden kann, Elektrizität und Holz sind jedoch ebenfalls sehr gängige Triebstoffe.

Die Anwendung von Endenergiebilanzierungen als Teil der Ökobilanz ist geeignet zur Untersuchung ökologischer Auswirkungen in Form von „hot spot“ und zur Ermittlung von optimalen Betriebgrößen für eine effiziente Endenergienutzung innerhalb von Prozessketten der Lebensmittelbereitstellung in einer sich entwickelnden Wirtschaft.

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List of Abbreviations and Symbols

Abbreviations

Ad	A surveyed dairy company code
ALCA	Attributional Life Cycle Assessment
Bk	A surveyed dairy company code
BOD	Biological Oxygen Demand
CLCA	Consequential Life Cycle Assessment
Col 1-	Milk collection or bulking centre
D1-9	Milk distribution centre
DE	Delivered energy or metered energy
DRDC	Dairy Research and Development Corporation (Australia)
elec	Electricity
EPZ	Export Processing Zone
FAO	Food and Agricultural Organisation of the United Nations Organisation
FAOSTAT	Statistical Division of the FAO
Far 1-6	Dairy farms 1-6
FU	Functional Unit
GDP	Gross Domestic Product
GHG	Green House Gas
GWP	Global Warming Potential
$GWP_{(100)}$	Global Warming Potential in a hundred years time frame
HACCP	Hazard Analysis and Critical Control Points
HDPE	High Density Polyethylene
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardisation
Kb	A surveyed dairy company code
KCC	Kenya Co-operative Creameries
KDB	Kenya Dairy Board
Ken	Kenya
KENGEN	Kenya Electricity Generation Company

LCA	Life Cycle Assessment
LCEA	Life Cycle Energy Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
Lm	A surveyed dairy company code
LPG	Liquefied Petroleum Gas
OECD	Organization for Economic Cooperation and Development
PE	Primary energy
Pl	A surveyed dairy company code
POEMS	Product Oriented Environmental Management Systems
POS	Point of sale
Pro 1-9	Milk processing plant
ref	Refinery
SCE	Specific carbon dioxide emission
SDET	Specific delivered energy turnover
SDP	Small-holder dairy project
SPET	Specific primary energy turnover
UBA	Umweltbundesamt
UHT	Ultra High Temperature
UK	United Kingdom
USA	United States of America

Symbols and Units

$CaCO_3$	Calcium carbonate
CO_2	Carbon dioxide
f	specified conversion factor
g	Gram
H_u	Calorific value
kg	Kilogram
kJ	Kilojoules
kWh	Kilowatt-hour
kWh/kg	Kilowatt-hour per kilogram
L	litre
m	Mass in kilograms
m^3	cubic metre
n	number of cases
N_2O	Nitrous oxide gas
PO_4^{3+}	Phosphoric ion
SO_2	Sulphur dioxide
t	Tonnes
v	volume of fuel
W	Total energy turnover
η	efficiency
ρ	density

1 General Introduction

1.1 An Overview of the Kenyan dairy industry

Kenya is a country named after the second highest mountain in Africa, standing at 5,199 metres above sea level. Kenya covers an area of about 582,650 square Kilometres and is located in the East African region 1 00N and 38 00E; it borders Ethiopia and Sudan to the north, Somalia to the east, Tanzania to the southwest and Uganda to the west. It also borders the Indian Ocean to the southeast. The country has seven (7) administrative provinces and one (1) area. The population is estimated at 35 million people with a 2.6% (2006) population growth rate. Kenya also hosts an estimated 250,000 refugees from neighbouring countries.

Agriculture plays an important role in the country's economy as it composes 16.3% of the gross domestic product (GDP) and involves 74.6% of the population. The livestock sector contributes 7% of the GDP (IFC, 2006). Of the total land area, 46% is under cultivation and 80.5% under pasture. Kenya's economy comprises more imports than exports; she is a net but modest importer of meat and milk (FAOSTAT, 2005). Kenya is among the leading dairy producing countries in Africa and is reported as being largely self-sufficient in milk production, except during dry spells (KDB, 2007; Reynolds *et al*., 2003). Currently, 3.5 billion litres of milk are produced per annum by a dairy herd of 3.3 million cows; although this is sufficient for domestic consumption, a lot more is needed for export (IFC, 2006). Dairy production is an important source of livelihood for about 625,000 small-holder farmers who contribute 56% of Kenya's milk and over 70% of all marketed milk. It is estimated that more than 2 million people are employed in the sub-sector in one way or another (EPZ, 2005 and Omore *et al.,* 2004). Therefore, any factors affecting this sub-sector affect many small-scale business people and farmers. Similarly, any growth in this sub-sector will lead to growth in the whole economy (IFC, 2006).

Before 1954, commercial dairy production was the sole preserve of the white farmers living in the "white highlands" of the Rift Valley and around the Nairobi area. The period after independence in 1964 was marked by a large drop in cattle population and in large-scale farms, and a significant increase of small-holder contribution in dairying activities. This was because of the large transformation in the land acquisition, division and redistribution, shifting from the large-scale "white settlers" farms to much smaller portions. Co-operatives and other agencies emerged to assist small-scale farmers to market their produce both in the rural (informal) and urban (formal) markets. Between 1969 and 1992, the Kenyan dairy industry was controlled by the government, which gave the policy guidelines, set prices and determined the players in the industry, as well as setting the market rules. This resulted in a protected monopolistic market by one major government-owned milk processor, the Kenya Co-operative Creameries (KCC). All dairy farmers had to supply their milk to the KCC which had branches and milk collection centres countrywide. In 1992, the government of Kenya decided to implement specific policy actions that liberalised the dairy market and encouraged commercialisation and privatisation of dairy support services.

Most dairy farming activities are found in the Central and Rift Valley provinces and the Coastal Lowlands, with a higher concentration of small-holder dairy farms in peri-urban areas. There is also a limited number of large-scale dairy farms owned both by private firms and private institutions (Chilonda, 2005). The total milk produced comes mainly from cows, goats and camels, each accounting for 71%, 28% and 1% respectively (FAOSTAT, 2006). Milk production is by rain-fed agriculture, mainly carried out by up to 635 000 small-scale dairy farmers and about 2 000 medium- to large-scale farmers. Most small-scale farmers use manual and animal labour for transporting on-farm requirements. Sunlight is mainly used for most drying operations and biomass energy for heating operations. Electricity is mainly afforded by medium- to large-scale farmers. In 2003, the Kenya Electricity Generation Company (KENGEN) produced a total of 4.343 billion kilowatts hour [kWh], out of which 4.238 kWh was consumed. The main source of electricity is hydroelectric power generation. Other electricity sources include: geothermal, thermal, diesel, gas and wind energy. Kenya utilises no nuclear resources for electricity generation (KENGEN, 2006). Farmers employ a variety of milk production systems, including large-scale open grazing, small-holder open grazing, and small-scale zero grazing employed mainly by small-holder dairy farmers. These include stall-fed cut-and-carry systems and supplementation with purchased concentrated feed in areas of high population density where extensive farming systems are not possible (Reynolds *et al.*, 2003).

Most of the dairy producers have no on-farm cooling facilities and must transport their milk to cooling/ bulking stations owned by large dairy processors or dairy co-operative groups. In the rural areas, farmers resort to a wide range of transport means, including hired vehicles, *matatus* (14-passenger vehicles), bicycles, pulling carts, and even on donkey backs. In many cases, the milk is delivered on foot over long distances of up to 10 km or more to a collection point, cooling plant, co-operative society, processing factory or directly to consumers.

Cooling and short-term storage takes place before the milk is collected and transported by large milk tankers to the milk processing plants. Milk cans made of aluminium and plastics are mainly used on bicycles, animal carts and pick-up vehicles, depending on volume and distance to the delivery point. Unlike in some developed countries, Germany for example, where farmers are contracted to supply their milk to the nearest milk processor, in Kenya the farmers choose the processor or bulking facility they prefer. Sometimes these preferences involve a lot of transport efforts as farmers ignore the closest collection facility to send their milk to a much farther station of choice. This pattern, therefore, has large implications on the transport effort involved in the milk chain. Most milk processors are compelled to source raw milk from more distant places as the immediate milk shed area is increasingly being dominated by the itinerant trader; a trend that further increases milk transport distances.

Energy is a major input in all parts of the food processing industry as most processes involved in food production and processing consume energy. Recent increases in energy costs and concerns about global warming have encouraged food processors to try and optimise their use of energy. Energy use--especially the burning of fossil fuel--contributes significantly to the production of green house gases (GHGs) and ultimately climate change. It is also clear that with increasing energy prices and depleting natural petroleum reserves, the issue of energy use has, in the recent past, taken a centre stage in many round-table discussions among food producers and processors. This is not only for ecological reasons but also for economic reasons, as it is getting increasingly difficult to maintain reasonable profit margins without considering the high cost of the energy input. The Kenyan milk chain is quite unique compared to other countries' milk chains; it is of interest to study the total energy balance of the whole chain so as to establish any relationship between the size of the enterprises and energy turnover, since the industry is dominated by small-holder enterprises. However, there is a lack of empirical data on energy use in the Kenyan dairy chain. This has created the necessity to apply the Life Cycle Assessment (LCA) technique to collect data on total energy turnover for the complete dairy chain for the time period of one year. With regard to time, a distinction can be made between a time frame between LCAs that is very short (less than a year), short (years), long (decades), or very long (centuries) (Thomassen *et. al.,* 2008). Therefore, the present study may be termed as a very short LCA because it was carried out for a period of one year.

LCA has been greatly applied to study milk production, mostly in developed economies (Hospido *et al.,* 2003; Casey & Holden, 2005, Halberg *et al.*, 2005, Vergé *et al.,* 2007); nevertheless, concerning LCA in developing economies, little work has been reported, and a global and reliable inventory of the same is still lacking. Moreover, there is no reported study of LCA application to establish energy turnover for a developing economy like Kenya. Given its already described unique features, the empirical data available from very developed milk chains reflect little of the Kenyan situation. Therefore, there is need for Kenyan scientists to apply this modern LCA technique to establish energy requirements for this rapidly growing industry. Therein lays the possibility of identifying inefficiencies and most of the burdensome stages that can help to lower production costs in terms of energy use, as well as the environmental burden of milk processing.

Energy balances are part and parcel of LCA studies. However, a full LCA would include inventorying all emissions rather than just energy and greenhouse gas emissions, including the impacts of pollutants released to the air, water and land during production, processing, storage, transport, use and disposal of a food product. Using the energy component of LCA as a standardised method of all the energy efforts of the whole process have been identified and allocated to the food items as functional units (Schlich and Fleissner, 2003). The scope of this LCA study is limited to energy consumption, since energy consumption may lead to reduction in the direct cost of the products, in addition to being directly linked to the environmental performance of a product (Tokyo, 2000). The turnovers of energy in all steps of the process were first evaluated then allocated to the functional units. From this database, the primary energy and environmental impacts were then calculated (Schlich and Fleissner, 2003).

The present study aims at investigating whether operation efficiency and logistics of the dairy industry in Kenya, as influenced by the size of the business enterprises, are more important than transport distances by regarding all specific energy efforts of the whole process chain. Policy makers and food manufacturers can use the information generated by this research to formulate policies that will lead to unit process improvement and lowering of production costs of the fluid milk chain in Kenya.

1.2 Objectives of Study on Life Cycle Assessment on the Kenyan dairy industry

- To use the energy balances as a component of Life Cycle Assessment (LCA) as standardised method to establish a specific database of energy consumption and environmental emissions related to the main processes involved in the fluid milk life-cycle, starting from the agricultural to the milk distribution stage.
- To allocate the energy data to an adequate functional unit and establish the specific energy turnover of milk production, collection and cooling processing and distribution stages of the milk processing chain in Kenya.
- To use the established database to calculate primary energy and environmental impacts using CO_2 emissions of the fluid milk chain.
- To establish the minimum business size advisable for energy-efficient milk production, processing and distribution that enjoys the advantages of “ecology of scale” in the Kenyan milk industry by comparing different business sizes in terms of energy.
- To identify the environmental “hot spots” (life cycle steps that are more burdensome to the environment) of the Kenyan milk chain with respect to energy consumption and emissions that can contribute to global warming.

1.3 Justification

Food is a basic need, but so is a sustainable society. Sustainability has been defined as the ability to meet the needs of today without reducing the ability of future generations to meet their needs. There is an urgent need to increase our knowledge of the environmental consequences of food production so we can make improvements that promote sustainability (Berlin, 2002). With increased prosperity, people are consuming more meat and dairy products every year. Global meat production is projected to more than double from 229 million tonnes in 1999/2001 to 465 million tonnes in 2050, while milk output is set to climb from 580 to 1043 million tonnes. Fossil fuel energy use and the resulting GHG emissions from food production, transport and consumption contribute significantly to global warming. According to a report published by the United Nations Food and Agriculture Organization (FAO), the livestock sector generates more GHG emissions as measured in carbon dioxide (CO_2) equivalent –18 percent more – than transport. It is also a major source of land and water degradation (Steinfeld *et. al.*, 2006). Energy consumption also has been linked to a reduction in the direct cost of the products in addition to directly affecting environmental performance of a product (Tokyo, 2000).

However, in order to propose real improvements in the environmental performance of a food chain, specific empirical data on the systems energy needs to be compiled and assessed in a circumstance-specific manner prior to decision making (Owens, 1997). The influence of business size and transport also need to be established in order to identify points of effective environmental performance improvement. The lack of empirical data on energy consumption of the Kenyan milk processing chain has made this study necessary so as to generate data that can be used to advise on energy-efficient milk processing--hence less **CO_2** emissions and lower processing costs, bringing increasing profit margins for industry players. Additionally, the liberalisation of the dairy industry in 1992 led to the emergence of many small-scale dairy producers and processors. This created a need to closely study energy turnover in the industry in order to establish the "ecology of scale" in terms of business size and energy turnover. This may hold a key to improve efficiency of production and processing, lower the costs of production and improve market prices.

1.4 The current state of the Kenyan dairy chain

1.4.1 Development of the dairy sub-sector

The English Lord Delamare pioneered the dairy industry in Kenya when he returned to Nairobi in 1904 to acquire land for farming, having first set foot there in 1897. He imported the first Jersey bull in 1920 and bred him with the local Zebu cattle. Over the years, the industry has grown tremendously, putting Kenya among the leading dairy producing countries in Africa. The release of the Swynnerton Plan in 1954 brought about a significant policy change that permitted indigenous Kenyans to engage in commercial dairy farming and strengthened marketing of farm produce by small-scale farmers (KDB, 2007).

1.4.2 The collapse of Kenya Co-operative Creameries (KCC)

Before 1992, KCC received the bulk of its milk from dairy co-operative societies and individual farmers because it was the only major milk processor. When the government of Kenya liberalized the market in 1992 and encouraged the entry of many new players, approximately 318 dairy co-operatives and 27,527 individual dairy farmers were supplying the KCC with milk. These measures brought KCC to a near collapse because of its inability to compete effectively with the new players in the industry. By 1996, the supply of milk to the KCC had dropped to a mere 205 dairy co-operatives and 21,765 farmers (SDP, 2004). This drop was due to reduced deliveries by farmers who were frustrated by late and irregular payments for supplied milk, and who had found more attractive outlets through informal traders (Owango *et al.* 1998). Presently, the industry is regulated by the Kenya Dairy Board (KDB) mandated by an act of Parliament (EPZ, 2005).

1.4.3 Dairy farming and milk production

Kenya's milk comes from cows, goats and camels, with each producing 71%, 28% and 1% respectively of total milk produced. Milk production relies mainly on rain-fed agriculture practiced by individual households for different goals. A recent study by the International Livestock Research Institute identified four types of small-holder dairy farmers based on landholding, access to resources, and availability of marketing channels.

1.4.3.1 Resource-poor dairy farmers

Resource-poor farmers represent the highest proportion of practicing dairy farmers. They purchase the least amount of cattle concentrates, have the smallest level of annual income and off-farm employment, and have smaller land units. Most of the milk produced in these farms is for domestic consumption, with close to one-quarter of their total milk production being sold.

1.4.3.2 Part-time dairy farmers

Part-time dairy farmers are farmers whose main economic activity is not dairy farming. Although acreage of land, number of cattle, and purchase of cattle concentrates and fodder is higher than resource-poor farmers, these are still low in relative terms. Percentage of milk sold by these farmers is estimated at 28 percent.

1.4.3.3 Small-scale intensive farmer

Close to 70 percent of milk produced by small-scale intensive farmers is sold, and more than three-quarters of these farmers belong to dairy co-operatives and self-help groups. These farmers have good marketing opportunities, practice commercially orientated, intensive dairy farming and appear to be working hard to become commercial dairy farmers.

1.4.3.4 Crop-orientated farmer

Although they have large land holdings, dairy farming is not a core activity for the crop-orientated farmer, but rather serves a subsistence purpose. Depending on the type of dairy farmer producing the milk and a few other factors such as distance from the markets, the amount of milk left for marketing and the price offered per litre milk sold among others, the milk could be marketed through either the formal or informal marketing chain.

1.4.4 Formal and informal milk marketing chains

Not all produced milk is sent for processing; some farmers choose to sell their milk directly to consumers or small-scale entrepreneurs, who then hawk it to consumers. This channel is referred to as the informal marketing channel, while the processed milk goes through the formal marketing channel. Formal institutions include dairy processors, cooling centres, co-operative societies and farmer groups, while informal institutions comprise consumer households and private traders such as milk bars, retail shops, hotels and restaurants. The sale of raw milk to informal institutions, especially consumer households, makes up the majority of raw milk sales, while the sale of raw milk to dairy co-operative societies comprises the largest sale to formal institutions.

Due to the relative proximity of informal institutions, the sale of raw milk to such institutions is regarded as more convenient (see figure 1). There are more than 300 licensed milk bars currently operating in major towns in Kenya and jointly selling more than 150 thousand litres of milk per day. A further 500 milk handlers or more are believed to be operating without licences because they do not meet the minimum requirements for licensing by the KDB (SDP, 2004). Furthermore, informal institutions pay more for milk deliveries than formal institutions, hence their importance and popularity as a market outlet for raw milk amongst dairy farmers (IFC, 2006). The leading milk producing areas are located in relatively high rainfall areas. Given the poor conditions of the roads, incidents of breakdown by milk collection vehicles from large milk processing companies tend to increase in the rainy season. This is also the time when milk production reaches its peak, leading to a lot of waste as a result of spoilage. At other times, the milk collection vehicles take too long to reach the factory. This also comes with high fuel consumption associated with milk collection, especially by large-scale processors using large modern milk tankers with cooling systems that transport milk across the country for long distances. These are some of the factors that encourage the informal milk chain.

Among consumers, most dairy consumption is in the form of liquid milk, and the preference for un-pasteurised milk is very high, even in urban areas. The direct sale of milk by farmers to consumers is very popular. Despite strong marketing within the formal sector, informal milk sales account for more than three-quarters of all marketed milk. Buying un-pasteurised milk, directly from farmers or local milkmen, is convenient even for wealthier households, as the high butterfat content is particularly valued for its taste and nutritional value (SDP, 2004).

1.4.5 Milk processing and distribution

Most of the milk produced is consumed as liquid (up to 80 percent). Less than 10 percent of processed milk is converted into high-value products. Most processors produce fresh milk, ultra high temperature (UHT) yoghurts, butter, ghee, cream, powder and flavoured milk. The products are packaged in tetra packs, pouches, cups and high-density polyethylene (HDPE) bottles. Currently, there are estimated to be 36 registered processors, most of whom serve a limited geographical area. The current processing capacity utilisation is estimated at about 40 percent (KDB, 2007). This limitation in capacity utilisation is attributed to high cost production and competition from the informal segment. The high cost of this market structure is mainly caused by inefficiencies in the milk chain. Figure 2 shows the trends in milk production, processing and marketing in the recent past years. Available data indicates that only 8 percent of all milk produced is processed. An informal raw milk market accounts for 24 percent of all milk production. In effect,, 68 percent of all milk produced is consumed at farm level or goes to waste. The challenge for the industry is to direct the milk waste into the formal market channel through increased investment in on-farm cooling and bulking facilities; and to promote consumption of processed milk as a way of enhancing a healthy life style.

Figure 1: A milk bar attendant selling milk in a transparent plastic bag to a customer (SDP 2004)

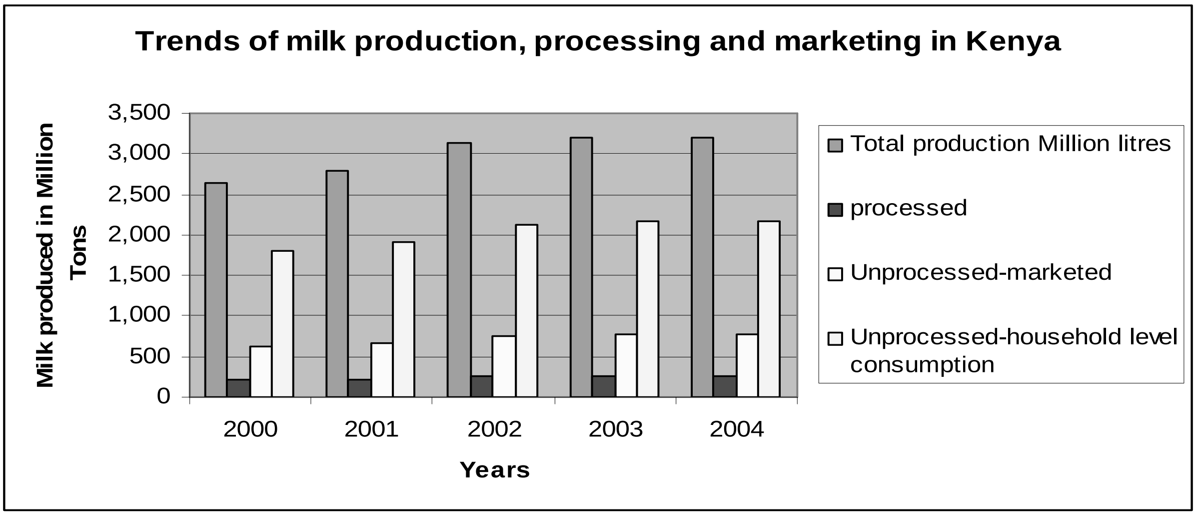


Figure 2: Trends of milk production, processing and marketing over the years (KDB 2007)

Evidently, the amount of processed milk has remained constant despite increased milk production over the years. This is due to, among other factors, high costs of transportation, processing and distribution of milk. A comparative research of milk production costs between Kenya and New Zealand revealed that the Kenyan production costs are 27% higher than New Zealand's, but are comparable to the Australian production costs (DRDC, 2002). New Zealand farmers were shown to receive more money per litre of milk compared to their Kenyan counterparts, with the margin being even narrower for small-holder farmers in Kenya (Karanja, 2003). There is, therefore, evidently a need to improve the dairy industry in Kenya by increasing milk production and processing while lowering the processing costs and consumer prices for packaged milk.

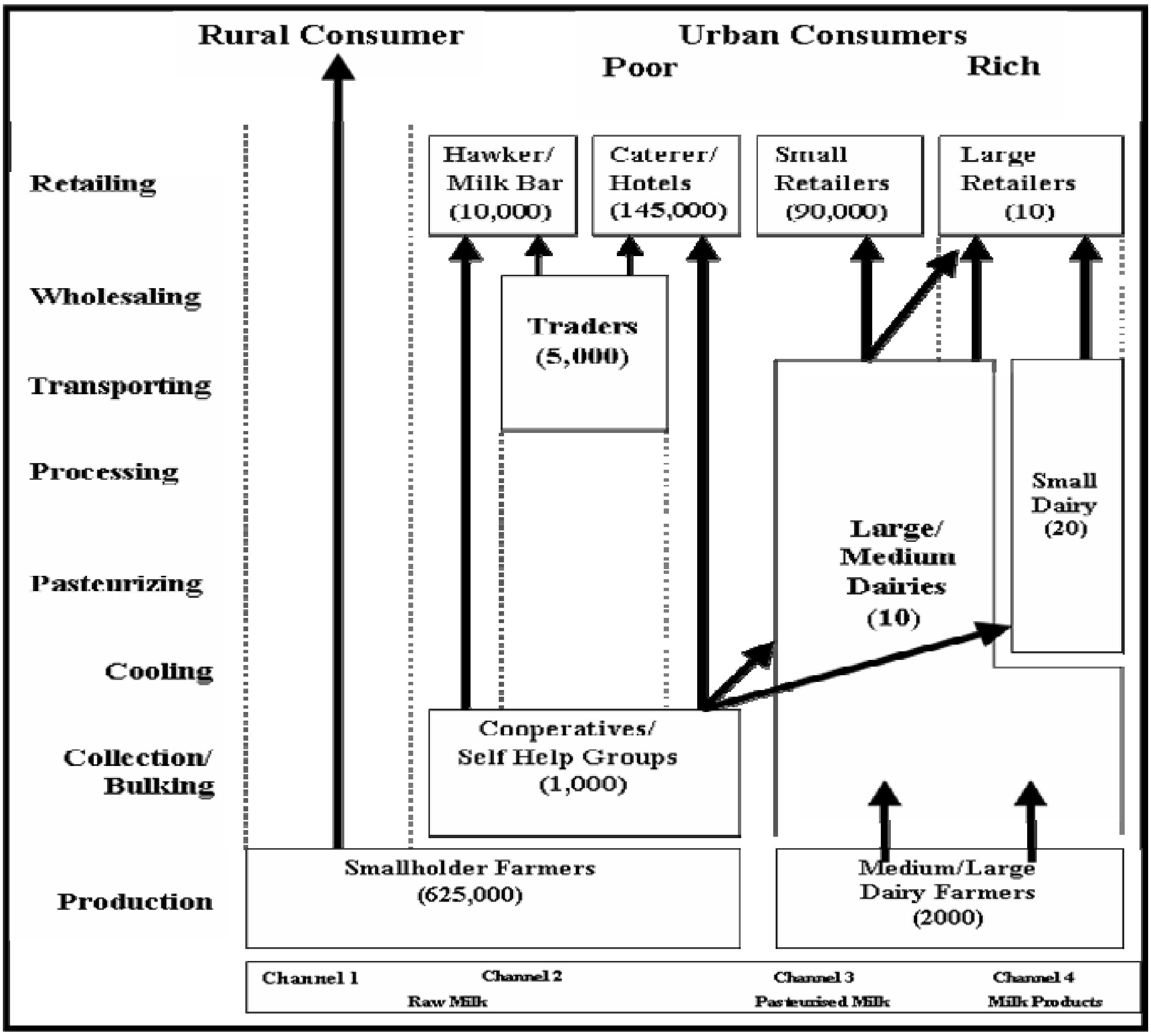


Figure 3: An illustration of the dairy value chain (IFC 2006)

Figure 3 gives a complete synopsis of the typical Kenyan dairy value chain. This product chain has five (5) major stages: production, collection/bulking and cooling, processing (which includes pasteurisation), wholesaling and retailing.

2 Literature Review

2.1 Life Cycle Assessment (LCA)

All activities, or processes, in a product's life result in environmental impacts due to consumption of resources, emissions of substances into the natural environment, and other environmental exchanges (e.g., radiation). Therefore, there are inevitable environmental impacts accompanying the provision of goods and services (both of which are herein summarised under the term "products") to our societies. The products are created and used to fulfil a need, be it an actual or a perceived one. Every product has a "life" starting from the design/development, followed by resource extraction, production (production of materials as well as manufacturing/provision of the product), use/consumption and finally end-of-life activities such as collection/sorting, reuse, recycling and/or waste disposal. These are commonly referred to as the phases or stages of a product's life cycle (Rebitzer,G. 2004). Figure 4 shows a schematic representation of a typical product's life-cycle phases.

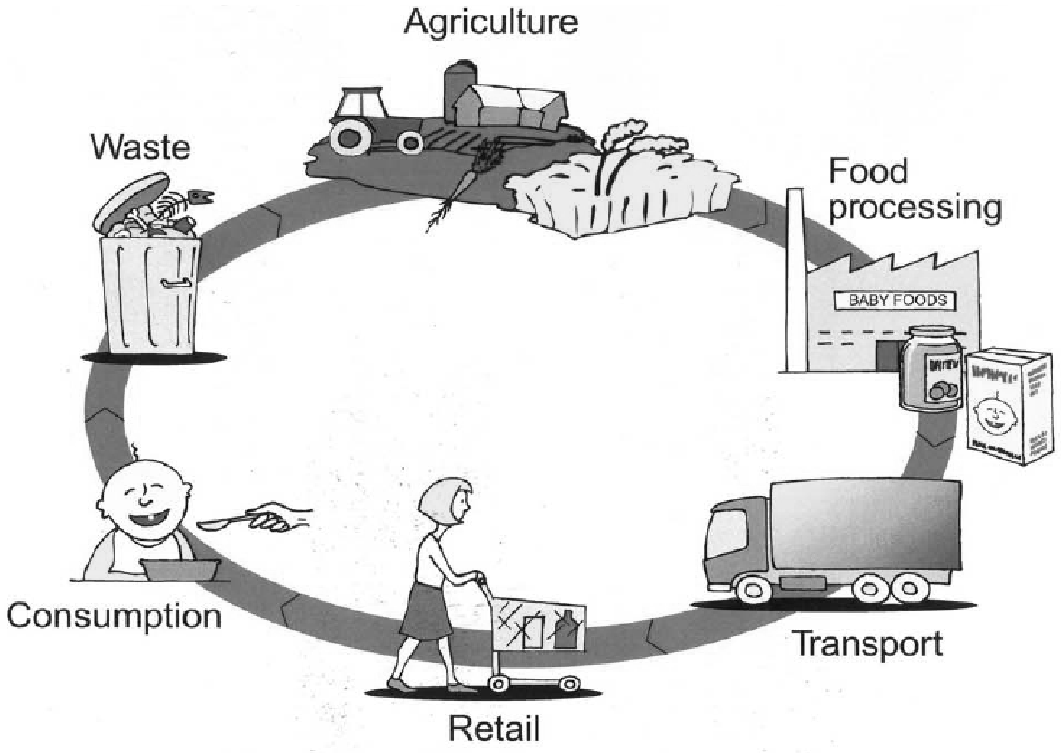


Figure 4: A typical product's life-cycle phases (Sonesson 2003)

In all activities involved during the life cycle of a product, resources are consumed from the environment and wastes are generated back into the environment. This creates an interesting relationship between all products and the environment as illustrated in figure 5.

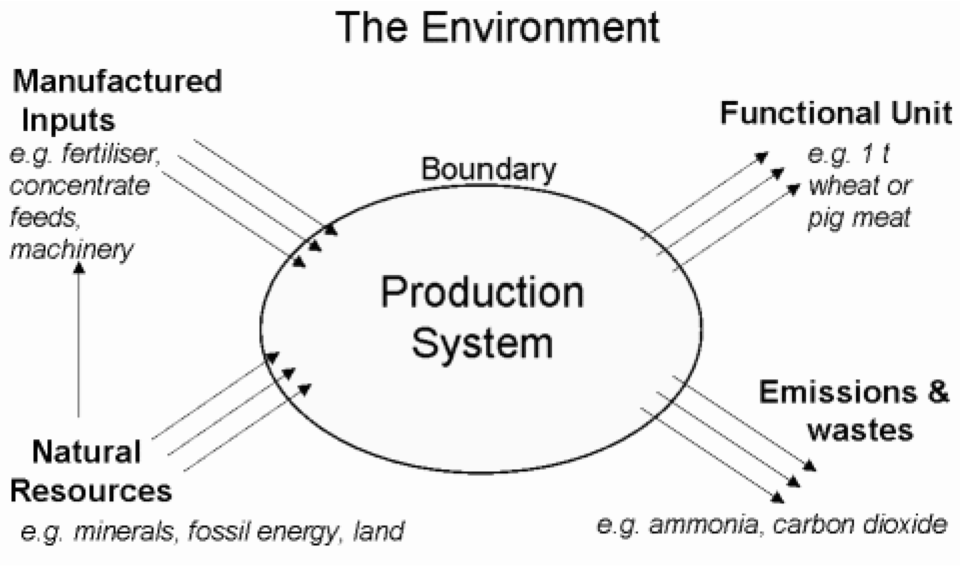


Figure 5: Schematic representation of the interaction between a product's life-cycle system and the environment (www.organicinform.org/newsitem.aspx?id=555)

Before we can enjoy a meal, the raw materials are first produced by agriculture; they are then processed by an industry, purchased from a retailer, and finally prepared for our consumption. Different modes of transportation have moved the food from one location to another. These activities affect the environment by the use of resources and by emissions to air, water and soil (Berlin, 2002). Whereas, in earlier times, consumers were more aware of environmental impacts of non-food products such as cars, they are now becoming inquisitive about environmental impacts of the food they eat. With this increased interest by consumers in the provenance of the food they eat (provenance includes the origin of food, its safety and nutritional value), and the environmental impacts of the production systems adopted in producing and delivering food (Berkel, 2002), there has been increasing pressure on food producers and processors to diminish environmental pollution caused by agricultural and food processing procedures. This pressure led to the idea of environmental protection. Sustainable environmental protection requires methods and tools to measure and compare the environmental impacts of human activities for the provision of goods and services (products) (Rebitzer,G. 2004). Earlier, end-of-pipe pollution abatement methods were adopted to meet government regulations and limits on emissions. However, in most cases, end-of-pipe strategy only shifted the problem from one domain to another. For instance, the wet limestone scrubbing process for the removal of SO_2 solved the problem of acidification, but created a problem of global warming associated with the life cycle of $CaCO_3$ required for the end-of-pipe solution (Hau, 2002).

Life Cycle Assessment (LCA) is one of the tools or techniques being developed to cope with the heightened awareness on the importance of environmental protection and possible impacts associated with products, and also the need to better comprehend and reduce these impacts. LCA has been termed as a tool or technique for the holistic evaluation of the environmental impacts associated with a product, process or activity during its life cycle from cradle to grave. This is accomplished by identifying and quantitatively or qualitatively describing its requirements for energy and material, and the emissions and waste released to the environment. The entire life cycle is included in the assessment, which means that the product under study is followed from the initial extracting and processing of raw materials through manufacturing, distribution and use, up to final disposal, including all transportation involved.

Besides identifying the environmental impact of the product or activity, LCA also identifies which activities in the product life cycle contribute most to these impacts (Berlin, 2002). LCA provides knowledge of a product and its related environmental impacts, such as global warming, acidification, eutrophication, photochemical smog formation, ozone depletion, land use area, or toxic impact. Over time, a number of different terms have been coined to describe the LCA processes. One of the first terms to be used was *Life Cycle Analysis*, but was later largely replaced by the two terms: *Life Cycle Inventory (LCI)* and *Life Cycle Assessment (LCA).* These terms seemed to better reflect the different stages of the process. Other terms, such as *Cradle to Grave Analysis*, *Eco-balancing*, *Well-to-Wheel analysis*, *Dust-to-dust Energy Cost* and *Material Flow Analysis,* were also used.

LCA has its roots in the 1960s, when the scientists who became concerned about the rapid depletion of fossil fuels developed it as an approach to understanding the impacts of energy consumption. A few years later, global-modelling studies predicted the effects of the world’s changing population on the demand for finite raw materials and energy resource supplies (Svoboda, 1995). The concept of environmental Life Cycle Assessment (LCA) was developed from the idea of comprehensive environmental assessments of products, which was conceived in Europe and in the USA in the late 1960’s and early 1970’s (Hunt, 1996). LCA is still a young and evolving application and has borrowed a lot from earlier research related to energy requirements in the 1960’s and the pollution prevention, which was formally initiated in the 1970’s (Rebitzer, *et al*, 2003).

Environmental management in general is also a young discipline. LCA is an internationally preferred method of compiling and evaluating the environmental impacts of products holistically, including direct and supply chain impacts (Suh *et al*, 2004). It is a relatively new and cutting-edge environmental decision support tool, as it provides quantitative environmental and energy data on products and processes (Berkel, 2002). Although still under development, LCA has been standardised by the International Standardisation Organisation (ISO) as an element in the ISO 14000 series.

The ISO began publishing the 14000 series of Environmental Management System (EMS) standards in 1996. Since then, the ISO 14000 series have rapidly been adopted globally, with more than 36,700 certifications awarded in 112 countries or economies. The ISO 14040 section on LCA is the most important element of the ISO 14000 series (Suh *et al.*, 2004). ISO 14040 presents the basic principles and framework to objectively evaluate the environmental aspects of a product, taking into account its whole life cycle. It provides a rationale for environmental labels and (Product Oriented Environmental Management Systems) POEMS among other programs (Ardente *et al.*, 2006). ISO 14041 describes the goal, scope and inventory analysis; ISO 14042 describes impact assessment, and ISO 14043 explains the process of life-cycle interpretation. Additionally, some examples of impact assessment also have been published as ISO 14047, documentation format as ISO 14048, and Examples of Inventory Analysis as ISO 14049 (Curran, 2004). LCA is based on rigorous mass and energy balances calculated by modelling and/or measuring the material and energy flows of the various processes in the system. The balances are used to evaluate the resource consumption and waste generation inventories of the product or process (Berkel, 2002). LCA is designed to assess a product, not from conventional standpoints like economics and convenience, but based on the degree of load put on the global environment by the product.

2.2 The key principles of LCA

Simply stated, the key principles of LCA involve the “compilation and evaluation of inputs and outputs and potential environmental impacts of a product system throughout its life” (Berlin, 2003). “Inputs” include all the efforts that go into producing the end product from its raw materials, and “outputs” include the product and all the waste that is generated during its processing and use. The LCA technique is structured along a framework involving a number of steps or activities in each stage of a product system. A *product system* is a collection of unit processes connected by flows of intermediate products that perform one or more defined functions. A product system description includes unit processes, elementary flows and product flows across the system boundaries (either into the system or out of the system), and intermediate product flows within the system. Essentially, a product system is characterised by its function and not solely by the final products (ISO 14040, 1997). A system boundary is what defines and limits the system under study. All unit processes within the system boundary must be studied. The boundaries may be set based on natural geographic, technical or time aspects as related to the unit processes within the product system under study.

A *functional unit* is defined as a quantified performance of a product system for use as a reference unit in an LCA study (ISO 14040, 1997). All data in the study are related to the functional unit--that is, all inputs and outputs--and it must therefore be defined and measurable.

A *reference flow* is a measure of the needed outputs from processes in a given product system required to fulfil the function expressed by the functional unit. LCA studies are conducted by developing models that describe the key elements of physical systems. It is often not practical to study all the relationships between all the unit processes in a product system, or all the relationships between a product system and the system environment. The choice of elements of the physical system to be modelled is dependent on the definition of the goal and scope of the study. The models used need to be described, and the assumptions underlying those choices identified.

2.2.1 Methodological framework of an LCA study

A traditional LCA consists of four stages: goal definition and scoping, inventory analysis, impact assessment and improvement analysis. It starts with a clear statement of the goal and scope of the study, the functional unit and allocation methods. The setting of system boundaries, statement of assumptions and limitations, and the impact categories also must be done. The functional unit as earlier stated must be quantitative and correspond to a reference flow to which all other flows in the LCA are related. Life Cycle Inventory (LCI) is an accounting of resources consumed, energy input, and wastes generated across all the stages. Some studies attempt to further describe the potential impacts that could result from these consumptions and emission activities-- a phase known as the Life Cycle Impact Assessment (LCIA) (Fava *et al.,* 1993, Vigen & Jensen, 1995). As typically conducted, LCAs are extremely data-intensive activities. The four LCA phases are usually linked as shown in figure 6.

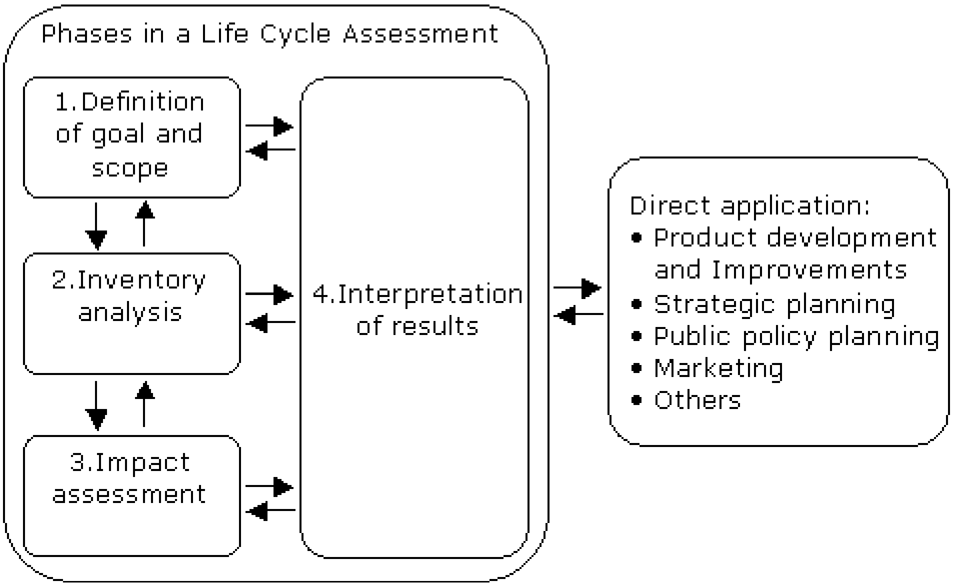


Figure 6: Life cycle assessment framework (Adopted from ISO 14040 1997)

2.2.2 Description of LCA phases

2.2.2.1 Goal and scope definition

Goal definition and scoping consist of defining the goals of the analysis, setting up the system boundaries, and validating the data. The goal of an LCA study must clearly define its objectives: the reasons for carrying out the study and the audience for whom the study is meant. The complexity of the study depends on these goals. Typical goals of LCA include:

- Comparing different products with the same function in order to determine which one consumes less energy and creates less stress to the environment;
- Demonstrating, for advertising or acceptance purposes, that a product is ecologically friendly, and
- Determining the emissions of many processes to have guidelines to make policies and set restrictions. This way, governments can set levels of emissions that are physically and monetarily achievable by the average company.

Scoping means defining the scope of the study and setting the limits of the study. In this step it is decided which processes will be included in the study to ensure that a feasible and realistic system is chosen. Larger systems are often more complex to study, especially during data collection. Gathering more information requires more time and money that may not necessarily be available. On the other side, excluding processes may result in oversimplified systems and underestimated results. Some guidelines suggest excluding processes where no data is available or whose contribution to emissions to the environment is negligible when compared to others. It is also during scoping that the functional unit is defined. All inputs and outputs referred to in this unit act as reference points for comparison of many products or product chains.

2.2.2.2 Life Cycle Inventory Analysis (LCI)

Inventory analysis includes the steps of recording and allocation. Recording involves collecting all data and information of each process included in the LCA study, refining the system boundaries, and validating the data. This step often requires the most effort because a lot of considerations have to be kept in mind. The data collected may either be site specific for a company or an area, or may be more general. Depending on the goal of the study, the data may be qualitative or quantitative. In this step, a flow model of the technical system is constructed using data about inputs and outputs of resources, energy requirements, transport, and emissions to air and water for all activities within the system's boundaries.

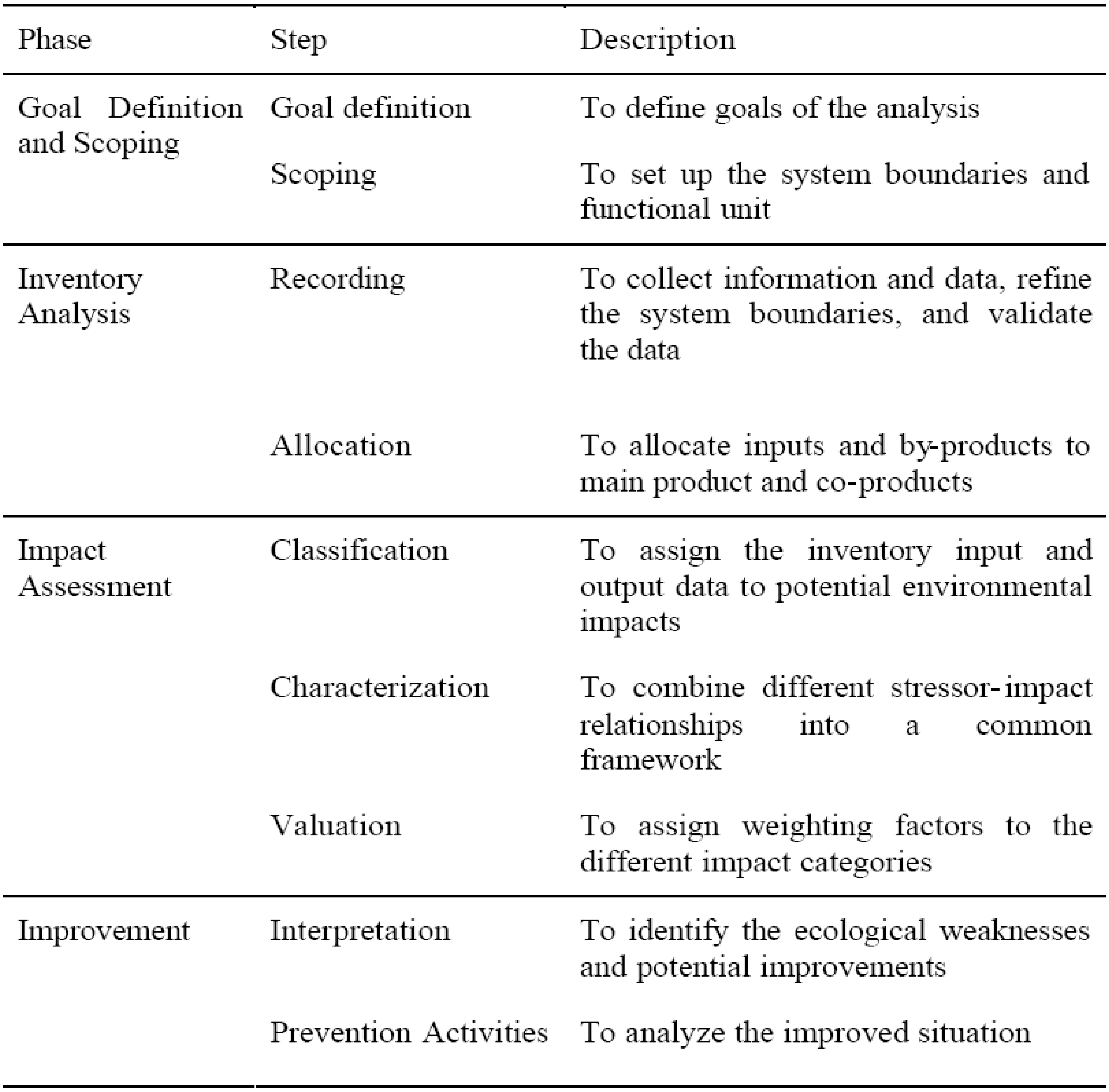
When there is more than an output, the main product refers to the specie or output of interest. Outputs different from the main product with a positive market value are called co-products. The outputs with negative or neutral market value are called by-products. For example, pollutants emitted to the environment and wastes are by-products. When there are co-products in a unit process, then inputs and by-products need to be allocated. Allocation involves assigning a fraction of inputs and by-products to the main product and co-product based on some rule as specified by ISO standards. Inventory analysis is the procedure used to determine the environmental load of the products or function of interest when several products or functions share the same process (Berlin, 2002).

2.2.2.3 Life Cycle Impact Assessment (LCIA)

LCIA follows the inventory analysis and includes the steps of classification, characterisation and valuation. The data are interpreted in terms of their environmental impact. In the **classification** stage, inventory input and output data are sorted and assigned to potential environmental impact categories. **Characterisation** is the process of combining the effect of different substances on the same category of environmental impact. For example, determining what the global warming potential impact of methane is in equivalents of CO_2. Thereafter, all parameters included in the impact category are added, and the result of the impact category is obtained. **Valuation** consists of assigning weighting factors to the different impact categories (ISO 14040, 1997). However, for many LCAs, characterisation is the last step. Moreover, the goal of some studies may involve the further step of **normalisation**, in which the results of the impact categories from the study are compared with the total impact in the region. During **weighting**, the different environmental impacts are weighted against each other to get one figure for the total environmental impact (Berlin, 2002).

2.2.2.4 Life Cycle Improvement Analysis

Improvement involves the steps of interpretation and prevention activities. Interpretation consists of identifying the ecological weaknesses and potential improvements. Prevention activities consist of analysing the improved situation. Generally, the interpretation and prevention activities systematically identify, qualify, check and evaluate information from the results of the inventory analysis and impact assessment. Figure 7 appropriately summarises the LCA methodological framework.



Phase	Step	Description
Goal Definition and Scoping	Goal definition	To define goals of the analysis
	Scoping	To set up the system boundaries and functional unit
Inventory Analysis	Recording	To collect information and data, refine the system boundaries, and validate the data
	Allocation	To allocate inputs and by-products to main product and co-products
Impact Assessment	Classification	To assign the inventory input and output data to potential environmental impacts
	Characterization	To combine different stressor-impact relationships into a common framework
	Valuation	To assign weighting factors to the different impact categories
Improvement	Interpretation	To identify the ecological weaknesses and potential improvements
	Prevention Activities	To analyze the improved situation

Figure 7: Outline and definition of the four major life-cycle assessment phases (Hau 2002)

2.2.3 Types of LCA studies

Two different LCA approaches have so far been identified and described as attributional LCA (ALCA) and consequential LCA (CLCA), depending on whether they are change-orientated (prospective) or descriptive (retrospective). ALCA describes the pollution and resource flows within a chosen system to the delivery of a specified amount of the functional unit (Rebitzer *et. al.*, 2004). These also have been termed as descriptive or accounting LCAs, as they seek to describe the chosen system as it actually was (or is, or would be) at a specific time. These are sometimes equated to environmental reports (Finnveden, 2008). In such studies, the system boundaries and appropriate data should reflect what was actually happening in the system. A CLCA, on the other hand, estimates how pollution and resource flows within a chosen system change in response to a change in output of the functional unit (Thomassen *et. al.,* 2008). These studies are change-orientated and analyse the consequences of a choice; ideally, the data used should reflect the actual changes taking place, and may depend on the scale of the change and the time over which it occurs. For a change-orientated prospective study, the ideal data are generally some type of marginal data reflecting the actual change. With regard to time, a distinction can be made between a time frame between LCAs that is very short (less than a year), short (years), long (decades), or very long (centuries).

2.2.4 Uses of LCAs

LCA has a wide range of application and can therefore be used in many different ways as summarised by Azapagic (1999) in his review of the different LCA uses:

- Identification of environmental improvement opportunities;
- Strategic planning or environmental strategy development;
- Product and process optimisation, design and innovation, and
- Environmental reporting and marketing.

2.2.5 Limitations of LCA

Some limitations of LCA studies were outlined in ISO (1997) as:

- The nature of choices and assumptions made in LCA (e. g. system boundary setting, selection of data sources and impact categories) may be subjective.
- Models used for inventory analysis or to assess environmental impacts are limited by their assumptions, and may not be available for all potential impacts or applications.
- Results of LCA studies focused on global and regional issues may not be appropriate for local applications, i.e., local conditions might not be adequately represented by regional or global conditions.
- The accuracy of LCA studies may be limited by accessibility or availability of relevant data or by data quality e. g. gaps and types of data: aggregate, average and site-specific.
- The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each impact category.
- There is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their life cycle.

- There is no single method for conducting LCA studies. Organisations should have flexibility to implement LCA practically as established in the ISO International Standards, based upon the specific application and the requirements of the user.

It is also important to note that the type of information provided, especially by LCIA, is merely an indicator and that:

- LCA should not be misunderstood as a comprehensive or a complete assessment;
- LCA is different and distinct in approach from other management tools; and
- LCA uses subjective judgement extensively, and the lack of scientific or technical data is sometimes obvious.

2.2.6 Advantages of applying LCA

Due to its subjectivity, a lot of versatility is afforded by the application of LCA methodology making it advantageous in several ways:

- Business and industry sectors can recognise the possibilities for saving natural resources and energy and in minimising pollution and waste using LCA.
- LCA is not only a tool to improve the environment, but also an instrument for industry-wide cost savings and competitive advantages.
- A wider set of options based on a complete picture may be available for decision making and the possibility of finding global optima (Hau, 2002).
- LCA sets different impacts in perspective, corrects misconceptions about impacts, and provides a valuable tool for both designer and manufacturer.
- LCA serves as a basis of comparison between similar products or dissimilar products with similar functions.
- LCA identifies the environmental impacts of all stages in a production cycle rather than focusing on a single source of an impact category (Biswas *et al.*, 2008)

2.2.7 Simplification or streamlining of an LCA study

The application of life-cycle studies falls along a spectrum from a complete spatial and temporal assessment of all the inputs and outputs due to the entire life cycle (which may never be accomplished in practice, both because of a lack of information and because it would require a tremendous amount of effort and expense) to an informal consideration of the environmental stresses that occur over a product or process life cycle. Life-cycle studies fall along a spectrum of difficulty and complexity, beginning with the use of life-cycle concepts and ending with complete life-cycle assessments as shown in figure 8 (Allen and Shonnard, 2001). The process of modifying an LCA in order to represent the goal and scope of the study may also be termed as streamlining or simplification.

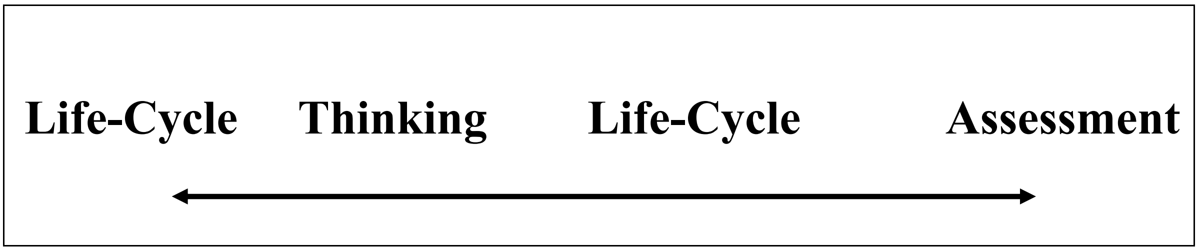


Figure 8: Spectrum showing increasing complexity of Life Cycle Assessment studies (Allen & Shonnard 2001)

An analysis that includes an inventory of all inputs and outputs and all life-cycle stages (including an assessment of which ones are significant enough to be included in the inventory), an impact assessment, and an improvement analysis is termed as a **Life Cycle Assessment,** while a study that falls to the left in the spectrum of complexity can be said to involve the use of **life-cycle concepts**. Studies in-between the two extremes may be called **streamlined life-cycle assessments**. Streamlined life-cycle assessments are conducted in order to find the most important life-cycle stages or type of inputs and outputs for more detailed study. They also can be used to identify where the most significant environmental issues occur.

There are many ways that a life-cycle assessment can be streamlined, usually by building extensively on previously completed life-cycle assessments. Similarly, data collected in previous studies may indicate that certain impact categories, or life-cycle inventory categories, can be safely neglected without a meaningful effect on the results of the study. Other approaches for making life-cycle studies easier to accomplish include omission of product components or materials. This omission can be based on whether the components or materials contribute significantly to the product's overall environmental impacts. The exclusion of any component that accounts for less than 1% of the total product weight has also been reported, although this could result in inadequate results, especially where toxic components are involved. Other ways to decide whether a component or material should be included or omitted in a life-cycle study are: economic value, toxicity and energy use (Allen & Shonnard, 2001; Masoni *et al*., 1998). Some environmental impact categories may sometimes be neglected in streamlined life-cycle studies. Similarly, a selected set of inputs or outputs might be chosen for inventorying. Another possibility of streamlining a life-cycle study would be to leave out life-cycle stages.

De Beaufort-Langeveld *et al.* (1997,) argue that streamlining efforts should ‘‘focus on the life-cycle inventory analysis, which is typically the most time-consuming phase and with the greatest potential for savings.’’ There are different strategies for the simplification of the inventory analysis, depending on the goal and scope of the study (the specific application and decision to be supported), the required level of detail (information on single technological processes or aggregated entities), the acceptable level of uncertainty, and the available resources (time, human resources, know-how and budget). They further elaborate three principal approaches of LCI/LCA simplification, with different strengths and weaknesses, namely: direct simplification of a process-oriented modelling, LCA based on economic input–output analysis, and the so-called hybrid method, which combines elements of process LCA with input–output approaches.

Some scientists have argued that a vertical cut, whereby data are collected for all relevant stages and stressors, but in lesser detail, is generally preferable to eliminating processes at any given stage. This implies that a screening, or pre-assessment, of the LCA is required prior to commencing a simplified inventory (Hunt *et al.*, 1998). The importance of this pre-assessment as a first step in simplification of LCA also was supported by De Beaufort-Langeveld *et al.*, (1997). Since the area of simplifying is still in its infancy, no general methods are recommended at present. However, there are certainly a variety of specific simplifying methods for specific applications based on experience and detailed LCAs (Hospido *et al.*, 2003)

It is not unusual for scientists to simplify LCAs, Fredriksson *et al.*, (20006), while evaluating energy balances and environmental loads of three possible fuels did not perform complete LCAs. When inventorying dairy processing plants Hospido *et. al.*, (2003), explain two methods that can be used to carry out the LCI: the simplified method or the detailed method. The simplified method considers all the production systems (farms and dairies, in this particular case) as a box and quantifies the flows corresponding to the inputs and outputs of the systems, that include global consumptions of additional activities. The detailed method allows specifying emissions, energy and water consumption for the different process steps (pasteurisation unit, sterilisation system, pumps, etc.) and requires a great effort (time and means) because it requires a very detailed collection of data. Due to data insufficiency on all the equipments and auxiliary devices, significant mistakes can be derived with the detailed method; hence, the simplified method was favoured in their study.

2.3 Energy use in food-processing chains

Energy is expended in a myriad of human activities. Energy sources based on fossil fuels, which are non-renewable resources, have become a concern because their use has escalated dramatically in the past three decades, especially in developed countries. This pressure is being felt not only in agricultural production but also in food processing and, in fact, at all stages of the food chain (Pimentel & Pimentel, 1985).

Prior to the industrial revolution, people depended primarily on renewable sources of energy: animal power, human labour, flowing water, solar energy, wind and biomass combustion. With the development of the steam engine at the birth of the industrial revolution, the use of coal, and eventually other fossil fuels, contributed to profound changes in production processes, farming and domestic activities. The use of fossil fuels has, however, generated environmental problems. At the local and regional level, fossil fuel energy consumption has caused air and water pollution; but it is the role of fossil fuel combustion in global climate change that has raised worldwide concern. Fossil fuel combustion is the biggest source of anthropogenic greenhouse gas (GHG) emissions that are changing the composition of the atmosphere and increasing the global mean surface temperature (Ramirez, 2005). Over the past half-century, energy consumption has risen steadily with rising economic growth. Since fossil fuels are the dominant form of primary energy in much of the developed world (and urban developing world), carbon dioxide (CO_2) emissions have risen as well, although not as rapidly as economic activity. These trends were interrupted by the oil crises of the 1970s and 1980s, which widened the gap between the rate of economic growth and that of primary energy or carbon emissions. But in the 1990s, emissions began rising with economic activity in most countries. Figure 9 diagrammatically presents a summary of the environmental impacts of burning fossil fuels.

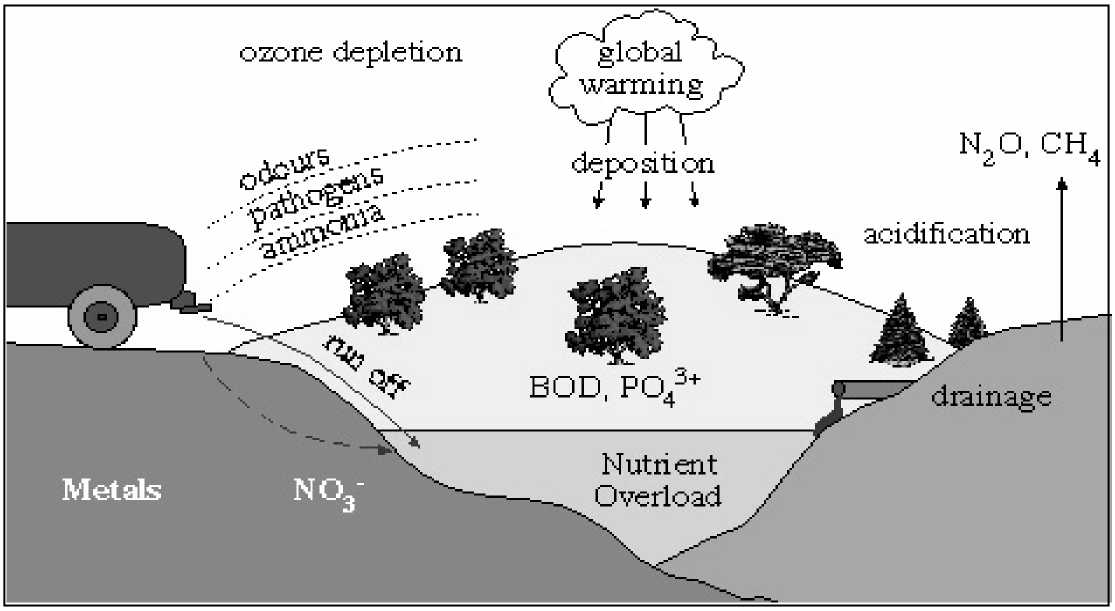


Figure 9: Effects of fossil fuel combustion on the environment

2.3.1 Energy balances

Energy balances are becoming increasingly useful as energy consumption throughout the world continues to contribute to pollution, environmental deterioration, and greenhouse gas (GHG) emissions. Increase in energy consumption is usually driven by population growth and economic development and tends to increase energy use per capita. Thus, the projected increase in population in the near future, and the economic development that is likely in many countries, is expected to have serious implications for the environment. Since the early 1980s the relationship between energy use and environmental impact has received attention, and a number of activities have focused on this topic. It was concluded that further political, economic and institutional changes from the standpoint of environmental impact appear to be necessary for future energy policies. To this end, energy efficiency improvements and renewable energy resources can play important roles in controlling and reducing these environmental impacts (Dincer & Rosen, 1998).

In energy balance studies, the processes within the life cycle and the associated material and energy flows, as well as other exchanges, are modelled to represent the product system and its total inputs and outputs from and to the natural environment, respectively. The results of a product system model and an inventory of environmental exchanges are then related to a functional unit (Hospido *et. al.,* 2003). This implies that it is possible to carry out energy balances under the LCA-methodology and then allocate the energy inputs to an appropriate functional unit of choice. Energy balances are used to examine various stages of a process over the whole process, and even extending over the total food production system from the farm to the consumer's plate. Since energy use affects global climate change and influences development and sustainability, the issue of energy use in industrial processes has lately received much more attention that ever before. Energy balances have been emphasised for use by enterprises in order to minimise the environmental impact of their products and save the accruing costs.

As a basis for setting up energy balances, the first law of thermodynamics is applied. It states that energy can neither be created nor destroyed, and based on this law it is possible to balance the incoming and outgoing energy for a system or a process. Energy balances involve taking into account all the internal energy of materials involved in a system and all energy efforts in the system as defined by the system boundaries. In this case, all the energy entering and leaving the system has to be accounted for, and any energy losses are also put into consideration. Energy balances are often complicated because forms of energy can be inter-converted, for example, mechanical energy to heat energy, but overall the quantities must balance.

2.3.1.1 Life-Cycle Energy Analysis

Life-cycle energy analysis (LCEA) is an approach in which all energy inputs to a product are accounted for, not only direct energy inputs during manufacture, but also all energy inputs needed to produce components, materials and services needed for the manufacturing process. An early expression used for this approach is “energy analysis.” In this approach, the energy analysis of the total life-cycle energy input is established. This analysis may also be referred to as “energy balance” and can be considered as a simplification of a complete LCA rather than a separate methodology.

In order to study operational efficiency of a food system, only the energy component of LCA is used as a standardised method. In this procedure, the complete energy efforts of the whole process are identified and allocated to the food item as a functional unit. Since energy balances are included as parts of a complete LCA, the primary energy and environmental impacts are usually calculated as in a compete LCA. In this process, the energy turnover of each process step from the very beginning up to the point-of-sale are investigated. These primary results are the basic empirical data that is then used to allocate the energy turnover to the food items as functional units. The specific energy turnover of global and regional systems or otherwise can then be compared. Business sizes also can be compared on this basis in order to establish energy use efficiency in food processing.

2.3.1.2 Some criticism of the Life-Cycle Energy Analysis (LCEA) approach

A criticism of the energy analysis approach is that it is an attempt to eliminate a monetary cost analysis, and as a result replace the currency by which economic decisions are made with an energy currency. Additionally, the problem of different energy forms (heat, electricity, chemical energy, etc.) having different quality and value even in natural sciences--as a consequence of the two main laws of thermodynamics--can not be resolved by the energy analysis method. A thermodynamic measure of the quality of energy is termed as “exergy.” According to the first law of thermodynamics, all energy inputs should be accounted with equal weight, whereas by the second law, diverse energy forms should be accounted by different values. Thus the conflict is resolved in one of the following ways:

- Ignoring the value difference between energy inputs;
- Assigning arbitrary value ratios, e.g., a joule of electricity is 2.6 times more valuable than a joule of heat or fuel input; or
- Supplementing the analysis with an economic (monetary) cost analysis.

2.4 Application of energy balance to the Kenyan dairy chain

Agricultural activity in Kenya accounts for 16.3% of the GDP, and a lot of the country’s energy is spent on agricultural production (which includes processing, delivery and consumption). While it may seem a small percentage, agricultural processes contribute a significant amount of GHG in the atmosphere. And energy use in the dairy industry is estimated to contribute up to 15% of a dairy farm’s total GHG emissions. One way of reducing emissions of GHGs from the energy system is to reduce the use of fossil fuels. In many countries, discussions are currently ongoing on how to reduce the use of fossil fuels and increase the use of renewable fuels. Waste is sometimes regarded as a renewable fuel (Finnveden *et al.,* 2005). Energy requirements are usually included in other impact categories, such as together with the emissions released during the extraction and production of energy. However, to increase the understanding of energy consumption, and the amount and sources of energy required for each activity, energy requirements are sometimes presented separately (Berlin, 2002).

2.5 LCA State-of-the-art

LCA is a very versatile methodology that has been adopted, modified and applied to a wide range of product chains. Applying LCA to assess energy use in food systems has become more necessary as the systems that produce the world's food supply are heavily dependent on fossil fuels. Vast amounts of oil and gas are used as raw materials and energy in the manufacture of fertilisers and pesticides, and as cheap and readily available energy at all stages of food production: from planting, irrigation, feeding and harvesting, to processing, packaging and distribution. In addition, fossil fuels are essential in the construction and repair of equipment and infrastructure needed to facilitate this industry: farm machinery, processing facilities, storage, ships, trucks and roads. The industrial food supply system is one of the biggest consumers of fossil fuels and one of the greatest producers of GHGs.

Ironically, the food industry is at serious risk from global warming caused by these GHGs through the disruption of the predictable climatic cycles on which agriculture depends. Global warming can have the more pronounced and immediate effect of exacerbating existing environmental threats to agriculture, many of which are caused by industrial agriculture itself. Environmental degradation, water shortages, salination, soil erosion, pests, disease and desertification all pose serious threats to our food supply, and are made worse by climate change. But many of the conventional ways used to overcome these environmental problems further increase the consumption of finite oil and gas reserves; thus the cycle of oil dependence and environmental degradation continues. In order to find a tangible solution to this vicious cycle, the issue of operational efficiency concerning energy use can play a major role in minimising the use of fossil fuel and eventual production on GHGs. The idea of "ecology of scale" is therefore worth exploring as has been demonstrated by Schlich & Fleissner, (2005) to be useful in minimising emissions from particular studied food chains. They found global food chains operating under ecology of scale to be emitting less CO_2 than regional food chains not operating under the same. However, they advise that this only be applied to the studied food chains. For making conclusions about another food process chain, a specific survey needs to be carried out, for example the Kenyan fluid milk chain.

2.5.1 Ecology of scale

The ecology of scale theory basically suggests that operational efficiency in energy use is more important than transportation distances involved in food chains, therefore posing a key to minimising CO_2 emissions of food processing chains. Ecology of scale supports the setting up of larger business sizes to favour lower emissions to the environment, and borrows from the long-time economic concept of "economy of scale" (also "economies of scale"), which economists have used to describe the declining dependency of average production costs per unit on increasing number of units produced.

This scientific theory supports that the energetic turnover and ecological impact of a food supply chain at the point of sale depends on business size in inverse ratio, regardless of the distance between primary production and point-of-sale (Schlich, 2004). The cases of beef, pork, lamb, apples and wine analysed by Herdtert (2008), Krause (2008), Schroeder (2007), Schlich (2004) and Fleissne (2001). Their findings have articulately approved the hypothesis that businesses of sufficient size can--from an energetic point of view--operate more efficiently than small businesses; regardless of whether they are operating regionally or globally. Their findings are opposed to frequent assumptions that shorter transport distances with in food process chains are obviously more ecologically friendly by emitting less GHGs since they consume less energy.

In economics, economies of scale generally refer to the benefits or economic efficiencies resulting from producing on a large scale. The resulting operational or economic efficiencies are usually expressed in terms of the reduction in incurred cost per unit produced as production volumes increase. It is argued that economies of scale are accomplished because the cost of producing each additional unit decreases with increasing production volumes, since the capital costs remain unaltered. As a result, larger businesses are often able to perform at lower costs than smaller ones, with other factors being constant. It is suggested that after a certain volume of production, this fall in costs will be halted as diseconomies of scale begin to set in--but this will happen only at very high levels of production, if at all (Geography Dictionary). This idea has been borrowed and applied to the study of the environmental soundness of food and other material production chains.

The production, processing and use of food and other materials consume resources and energy from the environment and produce wastes to the environment as earlier illustrated in figure 5.

The cost of production has been compared to the use of resources and energy from the environment to produce desired goods. It is argued that, as influenced by the scale of business, process chains will either achieve operational efficiencies resulting in less resource use and waste generation into the environment, or result in more wastage of resources and waste generation. This then can be related to the ecological efficiency of process chains. Smaller businesses use up a lot of resources and energy from the environment to produce small volumes of product, and this is detrimental to the environment. As the world's non-renewable resources continue to get depleted, it has been suggested that larger business sizes can be beneficial to the environment by utilising less resources and energy to produce a larger volume of desired goods as they benefit from operational efficiencies. This is the backbone behind the idea of "ecology of scale" described by Schlich (2008).

This hypothesis suggests that smaller businesses are less ecologically friendly than larger businesses in the same process chain. This is because they utilise more energy and other resources to produce less product units, as compared to their larger counterparts that produce larger volumes with less requirements of energy and other resources per unit article produced in the same process chain. Schlich went further to describe a "minimum business size" also termed as the "break-even-point": the optimum business size in a particular product chain where the benefits of "ecology of scale" begin to be observed. However, it must be noted that the increase in business sizes based on the same capital costs is not unlimited as diseconomies of scale may begin to set in at some point. This relationship can be represented mathematically in the equation $y = a/x + b$, where y is the economy of per unit costs. In this case it may be specific delivered energy, and x stands for the number of units produced comparable to the business size. This relationship utilises power laws to define a dependent variable (y) in terms of an independent variable (x), resulting in a hyperbolic shape when graphically represented. The diagram in figure 10 illustrates the relationship on a linear scale on the x-axis.

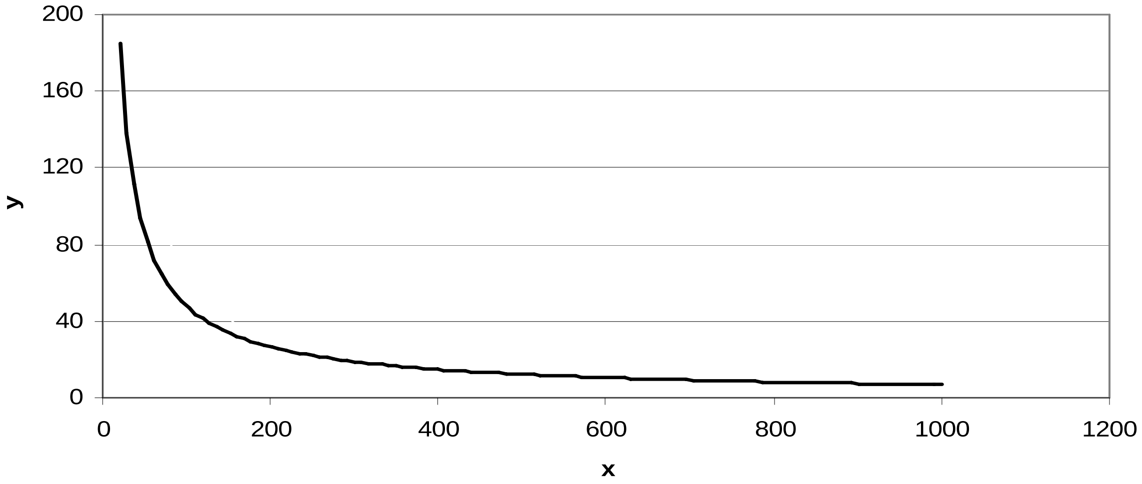


Figure 10: Graph demonstrating the economies of scale on a linear scale on the x-axis (Schlich, 2008)

The graph on figure 10 also can be plotted using the same coordinates, but on a logarithmic scale on the x-axis, so as to cover large differences in the independent variable as shown on the graph in figure 11.

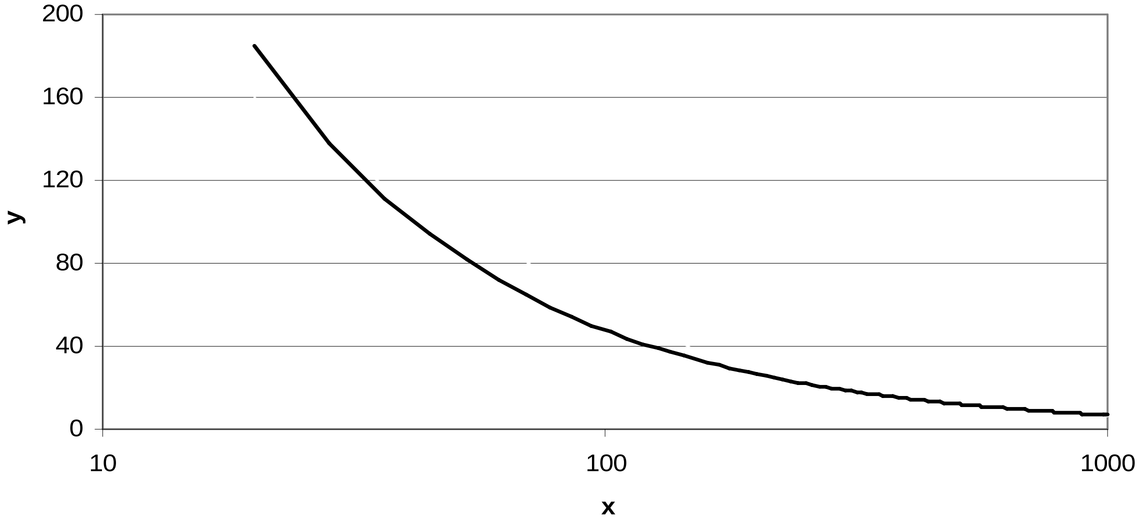


Figure 11: Graph showing economies of scale on a logarithmic scale on the x-axis (Schlich, 2008)

The two graphs illustrate the marginal case (borderline case). In the first case, as the y-value approaches infinitive, the independent variable *x* approaches zero. In the other case, the graph approaches the x-axis asymptotically if the independent variable *x* takes on values tending towards y=*b*. In both graphs, the values of the dependent variable *y* increases with decreasing product volumes, meaning that, as business size increases, the specific accruing costs of producing each extra unit decrease (Schlich, 2008).

Energy use in food production and processing chains can be compared to the accruing costs of producing food products as it leads to production of gases, such as CO_2 that can harm the environment--commonly expressed in terms of Global Warming Potential (GWP) and Ozone Depletion Potential (ODP). Other by-products of fossil fuel combustion include sulphur oxides and nitrogen oxides, both of which contribute to acid rain formation and hydrocarbons, which can react with nitrogen oxides to form smog. Additionally, the by-products of burning fossil fuels, such as nitrogenous gases, sulphur dioxide and other fine dusts, may have harmful effects to health (Schlich, 2008). For example, nitrogen oxides irritate the lungs; particulate matter such as soot and dust contribute to respiratory illnesses and cardiac problems, including arrhythmias and heart attacks, and noise production by the production engines also can be considered a negative environmental effect.

These effects tend to decrease with decreasing energy use and thus support the idea that larger businesses that produce larger product volumes using lower amounts of energy per unit product are more environmentally friendly and, hence, enjoy the benefits of "ecology of scale." In this case, the distance of consumer from the place of production is of little or no significance. This hypothesis has received attention in the past decade with some scientists supporting the idea of "ecology of scale," with others refuting it and suggesting that the distance of the consumer from the place of production is of more importance than production efficiencies enjoyed by larger business sizes in a product chain. There is yet another school of thought that supports the idea that smaller business sizes are less harmful to the environment as they utilise less energy and resources from the environment and also generate less waste back to the environment, making them more ecologically friendly.

2.5.2 Research evidence on "ecology of scale"

The idea of size and resource use has been explored in different industries yielding interesting findings. In the building industry for example, Wilson and Boehland's (2005) findings support that smaller houses are more environmentally friendly because an increase in house sizes increases resource use in buildings and occupies more land; larger buildings are therefore less advantageous to the environment. They also compared the energy performance of compact (small) and large single-family houses. They found small houses built to only moderate energy-performance standards use substantially less energy for heating and cooling than a large house built to very high energy-performance standards.

A study on firm size and national environmental policy was carried out in Greece to present evidence on the relationship between firm size and electricity consumption in the Greek manufacturing industry. The results suggested that, contrary to the average cost disadvantage of small firms, their cost of electricity consumption is lower than the one corresponding to large firms; thus indicating that small firms are less burdening to the environment (Papadogonas *et al*., 2005). Although it is noteworthy that these studies did not apply LCA methodology, and the environmental benefits of smaller business sizes reported might be off-set by negative environmental effects incurred at other stages of the same process chains.

While applying the energy balances as part of LCAs to explore the importance of transport distances and the idea of "ecology of scale," Schlich *et al.,* (2006) researched the empirical energy data, looking at all steps of the (system) in the case of a food chain, including farming, transporting, and distributing for beef, pork and wine. They then allocated the energy efforts to the functional units, so as to assign to the business size in addition to calculating the primary energy and the CO_2 –released. The results of case studies comparing wine from South Africa, Hungary and Germany, and pork from Hungary and Germany, demonstrated a digressive relation of specific energy turnover and the business size in terms of energy, and the question of regional origin was rather insignificant. The data also indicated a minimum business size as the "break-even-point" in the studied product supply chain. They conclude in support of the idea of "ecology of scale," giving no indication of blame to global food chains as energy wasting process chains.

Fleissner *et al.,* (2004) also applied a similar method in assessing energy use comparing regional and national food processing chains using the example of fruit juice production and distribution. They wanted to establish the connection existing between the location of a particular food producing process and the energy input per litre of the end product. The results showed that for small firms the energy throughput per unit end product was much higher than for bigger firms. It also showed that the end product related energy used for fruit juice production; processing and transportation did not depend on the distance of the point of production location from the market. Instead, a clear logarithmic digression in relation to firm size was observed. This digression is comparable with a declining relationship between unit costs and the number of units produced, as well known in economics. Their results clearly indicate that ecological quality is mainly influenced by operational efficiency and not by the distance from the market. They recommend the establishment of minimum firm sizes for regional firms in order to optimise energy use.

A further survey investigated regional orange juice producers by establishing the energy turnover per year for processing, transportation and distribution of orange juice in Germany. Juice diluting companies and concentrating facilities were also investigated. For comparison purposes, the global orange juice chain of orange juice from Brazil to Germany was also investigated. The investigation started with farming, pressing and concentration of the juice in Brazil, and the dilution and packaging done in Germany. The transportation of juice concentrates by ship was also carefully investigated. While applying the LCA energy balances method, allocation problems were handled by collecting all the necessary details on transportation information in place, i.e., the sizes of the vessels, the exact amounts transported, and the road transport from the seaport to the diluting plant. Personal visits and interviews with all the contact partners (including farmers, vessel engineers and at the ports in Brazil and Germany) were carried out to ensure high-quality primary data was collected (Schlich & Fleissner, 2004).

The primary data of energy sources used was then converted into energy values using appropriate specific heat values and the results allocated to the functional unit--in this case a litre of fruit juice at the point-of-sale (POS). The specific energy turnover in kWh/l was then plotted as a function of the yearly throughput of the squeezing facility in tons/year, on a logarithmic scale covering a wide range of the investigated companies. The results showed that small companies with up to 100 tons of fruit squeezing per year were disadvantaged with high energy turnovers. Even after adding transport costs to the production costs in global systems, no disadvantage was observed in larger global companies; thus falsifying the belief that transport costs raise global systems energy needs as compared to regional systems. A strong relation between specific energy turnover and the business size was observed. They concluded that sea transport, when carried out under Hazard Analysis and Critical Control Points (HACCP), in the long term takes less energy than local distribution efforts (Schlich & Fleissner, 2004).

Schlich & Fleissner (2005) evaluated the ecology of scale by assessing regional energy turnover and comparing it with global food using energy balances as part of LCA. They found a strong digressive relation between the specific energy turnover and business size. They further noted an obvious coincidence of economic and ecological facts: in ecology, as in economics, the strong digressive relation between production costs/ecological impacts and the number of produced items support the idea of "ecology of scale." They investigated the energy turnover from the beginning of the process up to the POS for lamb meat and orange juice.

Gwehenberger *et al.*, (2007) found a strong influence of the size of the plant on environmental pressure exerted by bio-ethanol production, therefore supporting the idea of ecology of scale by stating that increased efficiency of larger plants usually reduces not only the costs but also the ecological impacts. However, logistical factors were found to become increasingly important and sometimes leading to situations where the economy of scale and ecology of scale are in contradiction. Although a different methodology was applied to study the ecology of scale versus economy of scale for bio-ethanol production, the results found are in agreement with the idea of ecology of scale.

On the contrary, however, the findings reported by Schlich and Fleissner (2004) were refuted by another German survey set up to investigate and compare energy balances for locally grown apples with apples imported to Germany from New Zealand (Blanke & Burdick, 2005). They used energy balances in their investigation to compare the primary energy needed to import apples of a particular cultivar from New Zealand with the energy required for storage of locally (in Germany) grown apples of the same variety. They wanted to establish whether several months of storage in Germany for the local apples compensated for the energy required for shipment of apples from overseas. The energy requirement was calculated employing the same system boundaries from crop cultivation to end user. The primary energy requirement for cultivation, i.e., the first system boundary, was adopted from European data but reduced by 25% to cater for the 2.5-fold larger yields in New Zealand. The results showed a great discrepancy to those reported by Schlich *et al.*, (2003) and Schlich & Fleissner (2004) of up to 8-fold larger energy requirements for juice from locally grown apples versus imported apple juice. They found that imported apples of the studied cultivar required 27 percent more energy than growing, harvesting and storing locally produced apples. They conclude by cautioning that such comparative calculations rely on the settings of the system boundaries and that the use of primary energy is also not the only approach; other approaches may yield different results. They suggest the consideration of other factors, such as quality assurance and social factors, in comparing regional goods versus global food chains (Blanke & Burdick, 2005).

A case study of white bread has been done with the purpose of comparing different scales of production to their potential environmental effects, which reported no support for the theory of ecology of scale. The scales compared were home baking, a local bakery and two industrial bakeries with distribution areas of different sizes. Data was collected from the three bakeries and their suppliers. The systems investigated included agricultural production, milling, baking, packaging, transportation, consumption and waste management. Energy use and emissions were quantified, and the potential contributions to global warming, acidification, eutrophication and photo-oxidant formation were assessed (Andersson and Ohlsson; 1999). The main conclusion was that LCA is very valuable for incorporating environmental aspects in the evolution of more sustainable systems for production and consumption of foods. For bread, the results showed that the environmental performance of the specifically studied systems of home baking, the local bakery and the small industrial bakery were similar. The large industrial bakery was found to require more energy and to contribute more to global warming, acidification, eutrophication and photo-oxidant formation (Andersson, 2002). The researcher notes that great scarcity of environmental data was one of the major problems encountered when applying the LCA methodology to food systems. Data collection and modelling were time consuming and, therefore, ended up producing results with relatively large uncertainties. Each individual LCA study contributes to the generation of new data as well as the identification of data gaps. Further research and development are required to improve both databases and models so that the uncertainties can be reduced. Until high-quality environmental data are accessible, there is a need for simplified methods that can be used as a compass to show the direction toward sustainability (Andersson, 2002).

2.5.3 Food process and supply chain length

Concerning the issue of the length of food process chains, i.e., the influence of transport distances between producers and consumers, different and sometimes contradicting findings have been presented by different scientists. To this effect, several product-based environmental indicators for assessing the environmental impacts of food product chains--and especially the importance of transport in today's food process chains--have been developed and used. Among such indicators are "food miles" and "carbon footprint." These are product-based environmental indicators that build on life-cycle thinking (Smith *et al.*, 2005; Wiedmann & Minx, 2007). However, these methods have been criticised for exclusively focussing on global warming and only including fossil CO_2 emissions and no other of the two important greenhouse gases: methane and nitrous oxide.

"Food miles" is a term that refers to the distance food travels from the farm to the consumer (Smith *et al.,* 2005) and is used as an environmental indicator for food products. It has gained much attention in the environmental debate, especially in Great Britain (Smith *et al.,* 2005). Food miles is used not only as an indicator of environmental sustainability, but also of economic and social sustainability (Smith *et al.,* 2005). But it remains unknown to what extent reduction in food miles will increase the environmental sustainability. Food miles is a concept that cannot stand alone as an indicator of environmental impact from food production, especially for food chains in which transport plays an insignificant role (Dalgaard *et al.,* 2007). Moreover, food miles has been said to be misleading at times because it ignores production energy and often excludes the transport mode (ship, aircraft or lorry) in the calculations. For example, transport by lorry emits considerably more CO_2 than transport by ship (EcoInvent Centre, 2004). If the attention is to reduce the GHG emissions in food chains where transport is not significant, focus should not be set on reduction of food miles, but on more significant environmental hotspots of that particular food chain (Dalgaard, 2007).

"Carbon footprint" is another environmental indicator that is used in various forms (Wiedmann & Minx, 2007), and it must be used with care if applied to food products. A footprint is a measure of the impact of a system, practice or product on one or more environmental factors from a point of reference. Carbon footprint specifically focuses on CO_2 and/or other gases measured in CO_2 equivalents. When applying this procedure, one must remember that if nitrous oxides and methane are not included in the calculation, the food product's impact on global warming will be underestimated and comparison of products might give a misleading result. This procedure also has been accused of only considering the negative aspects: CO_2 emission and no positive effect of a product. However, these environmental indicators "food miles" and "carbon footprint" have one large advantage: they are much easier to communicate to people who have no knowledge of environmental issues. Thus they remain applicable in certain cases where LCA is seen to be too complicated for communication (Dalgaard *et al.,* 2007). In support of LCA, Dalgaard (2007) reports of an important quality of LCA in that it offers the opportunity of assessing several types of environmental impacts (acidification, global warming, etc.) for a product. This makes it easier to assess whether mitigation of one type of emission implies an increase in other types of emission.

A study in Sweden found no support for shorter food processing chains in terms of energy use using LCA methodology. The energy requirements for food transport to a farmers' market by the farmers themselves with energy requirements for transport in the conventional food system were compared. The study found no significant differences in amounts of energy used for transport in either food system. The farmers' market was investigated through data sampling from on-site investigations. The conventional food system was studied with the aid of life-cycle assessments reported in the literature. However, considerable potential to increase energy efficiency in local food systems by organising the selling in new ways and by using more energy-efficient vehicles was reported (Wallgren, 2006). Support for short transport distances in food production has also been supported by Erzinger *et al.,* (2003) in their LCA study of animal products from different housing systems and its relevance on energy use. Although their study had different aims, goal and scope, they used the LCA methodology and suggest that short transport distances in food production can be adopted as possible measures to lower emissions.

In a study seeking to explore the environmental impacts associated with fresh produce supply chains, aimed at understanding the relative significance of transport as compared to other supply chain activities, Sim *et al.*, (2007) used the LCA method to estimate the potential environmental impacts of some supply chains. Three fresh produce items sourced from six countries and sold in Marks and Spencer stores were studied: Royal Gala apples from Brazil, Chile, Italy and the UK; runner beans from Kenya (and extrapolated for Guatemala and the UK); and watercress from the UK and USA (and extrapolated for Portugal). The study concluded that transport (the distance between production and consumption) was an important factor in determining the sustainability of food supply chains (although they reported a significant distinction between air-freight and shipping for long-distance haulage).

2.6 Application of LCA to assess milk chains

The LCA methods have been applied to assess dairy farming (Berlin, 2002; de Boer, 2003; Cedeberg & Stadig, 2003; Casey *et al.,* 2005). Others who also have applied it to the dairy industry are Verge *et al*.; (2007) when they quantified GHG emission of the Canadian dairy industry, and Thomassen *et al*.; (2008) who carried out an LCA of conventional and organic milk production in the Netherlands. However, as noted by Biswas *et al*., (2008) and Schlich & Fleissner, (2004), the results of a particular LCA are usually best applicable for policy change and environmental performance improvements--specifically to the studied or similar system--due to differences in certain critical factors. This finding means that in order to effectively identify and quantify the environmental impacts of a particular system, a LCA specific to the objectives of the researcher needs to be carried out for that particular system.

Most of the reported LCA of dairy chains have been carried out in more developed countries and are not very applicable in determining the major environmental contributors. These also do not help in improving developing dairy chains where limited financial resources must be used to achieve the best possible outcomes. This has made it necessary to apply the LCA methodology to developing an economy's food supply chain, in order to establish the major environmental impact contributors that should be targeted for policy and organisational changes that would significantly improve the environmental performance of these systems. The present study seeks to identify the major environmental processes in the environmental impact category of energy use in the dairy chain in Kenya by applying energy balances as an integral part of the standardised LCA methodology.

Life Cycle Assessment (LCA) was applied to milk production and processing in a study of the Norwegian dairy industry. The potential environmental impact of milk production extending from the origin of the inputs, to the agricultural step, to the consumer phase and the waste management of the packaging, to the processing stage were assessed. The overall objective of the work was to establish a scientific basis for environmental improvements in the Norwegian dairy industry in the future. The specific objectives were to find any "hot spots" in the life cycle of milk and to determine the influence of transport. The main goals were to identify possibilities for improvements, to work out ways to apply the LCA methodology to milk processing, and to investigate the influence of three key aspects in the dairy industry: the size of the dairy, the degree of automation of the dairy, and the transport distances (Eide, 2002).

The whole life cycle of milk production and processing at three dairies was investigated. The agricultural phase was found to be the main hot spot in the life cycle of milk for almost all the environmental themes studied. Transport to dairies and to retailers was not found to have a major influence. However, the consumer phase was important, due both to transport and to loss of milk. The smallest dairy was found to have a greater environmental impact than the middle- and larger-sized dairies. The lowest level of automation had the least influence on eutrophication. Transport did not have any major influence. Milk packaging and cleaning of dairies were investigated in detail. Packaging was found to be of some importance, but the assumptions regarding packaging waste management were found to be more important (Eide, 2002).

A Swedish study was carried out to analyse the environmental impact of future supply chains for dairy products. A scenario technique was chosen to yield information about the environmental consequences of certain lines of action or developments in the system. A mathematical model of the milk supply chain was constructed and used to simulate possible scenarios, in order to quantify the effects of future systems. The model was based mainly on LCA methodology. The results showed that any consideration of the environmental effects of the milk supply chain must consider the entire chain. The amount of packaging materials used was an important factor, as was the transportation of the dairy products to households (Sonesson and Berlin, 2003). The findings on the consumer transport phase were in agreement with those presented by Eide (2002) in Norway.

The importance of the dairy, retailer and household stages in the Swedish post-farm milk chain was demonstrated by Berlin *et al.*,(2008) in their study of product chain actors potential for greening the product life cycle of the Swedish post-farm milk chain using the LCA methodology. They also suggest less energy use as the most efficient improvement for retailers of milk products.

While studying the environmental effectiveness of the beverage sector in Norway in a factor 10 perspective, Hanssen *et al.*, (2007) limited the environmental impact indicators in their study, for practical reasons, to total energy consumption and global warming potential. They also reported difficulties in obtaining other types of data for all studied products (tap water, coffee, milk, soft drinks, beer, squash, juice and bottled water). Additionally, the production of raw materials was found to be the most important part of the life cycle of most drinking products with respect to energy consumption and emissions that can contribute to global warming.

An environmental LCA was performed to investigate the environmental consequences of the life cycle of Hushållsost, a semi-hard cheese. The assessment identified those activities that contribute most to the cheese's environmental impact throughout its life cycle from extraction of ingredients to waste management. Milk production at the farm was identified as having the greatest environmental impact, followed by cheese making at the dairy, retailing, and the production of plastic wrapping (Berlin, 2002). de Boer (2003) applied the LCA methodology to compare organic and conventional milk production and concluded that results from LCAs of different case studies at the time could not be compared directly. She concluded that such a comparison would require further international standardisation of the LCA method. A within-case-study comparison of LCAs of conventional and organic production, however, proved suitable to gain knowledge and to track down main differences in potential environmental impact.

Noteworthy is that all through literature there is no reported work on the application of LCA, or energy balance as part of LCA, to assess the fluid milk chain of any developing economy, especially from Africa. Considering that the environmental effects are global, any actions to combat ecological degradation related with energy use need to be applied globally to have any significant effect. This means that every country needs to make its contribution to this end, no matter how small a contribution. The current study seeks to fill in the empirical data gap for milk production and processing in Kenya in an effort toward greener food production, processing and transportation in this economy.

Materials and Methods

3.1 Methodology

Although it borrows a lot from the methodology of LCA, it must be noted that this survey was not a complete LCA--it is as a simplified LCA study based on energy balances. Not all the four steps of defining the goal and scope of the study as in a complete LCA were carried out: making a model of the product life cycle with all inflows and outflows, understanding the environmental relevance of all the inflows and outflows, and interpretation of the study. The study was organised as a qualitative case study that included inventorying all energy efforts such as gas, fuels and electric power required for producing milk, including farming and transport of milk to the dairy processors. All energy efforts of processing, transport and distribution to the point of retailing were inventoried as the primary data and allocated to an appropriate functional unit. The specific turnovers of energy versus business size were then compared. The data was collected in Kenya in 2007 using carefully prepared questionnaires personally administered during visits to all inventoried premises carried out by the author (see Appendices).

The main technique used in LCA is that of modelling. In the inventory phase, a model is made of the complex technical system that is used to produce, transport, use and dispose of a product. This generates a flow sheet or process tree with all the relevant processes. For each process, all the relevant inflows and the outflows are inventoried. The result is usually a very long list of inflows and outflows that is often difficult to interpret. In the life-cycle impact assessment phase, a completely different model is used to describe the relevance of the inflows and outflows identified during the inventory phase. For this, a model of an environmental mechanism is used. For example, an emission of sulphur dioxide (SO_2) could result in increased soil acidity, and increased soil acidity can cause changes in the soil that result in the death of trees. By using several environmental mechanisms, the LCI result can be translated into a number of impact categories such as acidification, climate change, etc. The issue of weighting the impact categories is usually highly controversial because it is a highly subjective issue (Goedkoop *et al.,* 2006).

Three spheres are involved in an LCA: the technosphere, the ecosphere and the valuesphere. The **technosphere** involves modelling technical systems, such as production and transport processes, and usually has uncertainties of a factor not greater than two (2), since almost all measurements are verifiable and repeatable. The **ecosphere** involves modelling the environmental mechanisms ("what happens with an emission") and often has uncertainties ranging between 1-3 orders of magnitude because verification is often difficult or impossible. For example, one cannot test-run climate change and repeat this several times to get a good measurement. The **valuesphere** deals with subjective choices of weighting impact categories and allocation procedures. It is typically a social science discipline and one cannot speak of uncertainties, as a single "truth" does not exist (Goedkoop *et al.,* 2006). With that consideration, this study attempted to set achievable goals and scope within limited time and resources by only carrying out the energy balance as part of LCA as applied by Schlich & Fleissner, (2004) and simplifying the study in terms of system boundaries and data quality by excluding some product life-cycle stages.

3.2 Case studies

The history of case study research is marked by periods of intense use and periods of disuse. The earliest use of this form of research can be traced back to Europe, predominantly to France (Tellis, 1997). The Oxford English dictionary defines a case study as a detailed study of the development of a particular person, group or situation over a period of time or a particular instance used to illustrate a thesis or principle. On the other hand, the dictionary of sociology defines it as a detailed examination of a single example of a class of phenomena. A case study cannot provide reliable information about the broader class, but it may be useful in the preliminary stages of an investigation because it provides hypotheses, which may be tested systematically with a larger number of cases (Abercrombie, Hill & Turner, 2000). More recently however, some scientists have disputed the second definition, citing that while it is correct that a case study is a "detailed examination of a single example," it is not true that a case study "cannot provide reliable information about the broader class." It is also correct that a case study can be used "in the preliminary stages of an investigation" to generate hypotheses, but it is misleading to say a case study is a pilot method to be used only in preparing "the real study's larger surveys," systematic hypotheses testing, and theory building (Flyvbjerg, 2006).

The field of sociology is associated most strongly with case study research, and during the period leading up to 1935, several problems were raised by researchers in other fields. This coincided with a movement within sociology to make it more scientific. This meant providing some quantitative measurements to the research design and analysis. Case studies have been classified into exploratory, explanatory and descriptive. Of these three approaches, single or multiple-case designs have been identified. A multiple-case study design follows a replication rather than sampling logic, resulting in replicatory cases rather than sampled cases as described by Yin (1993). When no other cases are available for replication, the researcher is limited to single-case designs. The unit of analysis is a critical factor in a case study; typically a system of action rather than an individual or group of individuals is the unit of analysis. Case studies tend to be selective, focusing on one or two issues that are fundamental to understanding the system being examined. Therefore, case selection must be done so as to maximise what can be learned in the period of time available for the study.

Single cases may be used to confirm or challenge a theory, or to represent a unique or extreme case (Yin, 1994). Single-case studies are also ideal for revelatory cases where an observer may have access to a phenomenon that was previously inaccessible. Single-case designs require careful investigation to avoid misrepresentation and to maximise the investigator's access to the evidence. Single-case studies can either be holistic or embedded: the latter occurring when the same case study involves more than one unit of analysis. Multiple-case studies follow replication logic. This is not to be confused with sampling logic where a selection is made out of a population for inclusion in the study. This type of sample selection is improper in a case study. Each individual case study consists of a "whole" study, in which facts are gathered from various sources and conclusions drawn based on those facts. Yin (1994) pointed out that generalisation of results, from either single or multiple designs, is made to theory and not to populations. However, multiple cases strengthen the results by replicating the pattern-matching, thus increasing confidence in the robustness of the theory.

3.2.1 Types of case studies

3.2.1.1 Exploratory case studies

In exploratory case studies, fieldwork and data collection may be undertaken prior to definition of the research questions and hypotheses. This type of study has been considered a prelude to some social research. However, a framework of the study must be created ahead of time. Pilot projects are very useful in determining the final protocols that will be used. Survey questions may be dropped or added based on the outcome of the pilot study. Selecting cases is a difficult process, but it is recommended that the selection should offer the opportunity to maximise what can be learned, knowing that time is limited. Thus, the cases that are selected should be easy and willing subjects. A good instrumental case does not have to defend its typicality.

3.2.1.2 Explanatory case studies

Explanatory case studies are suitable for doing causal studies. In very complex and multivariate cases, the analysis may make use of pattern-matching techniques.

3.2.1.3 Descriptive cases

Decscriptive cases require the investigator to either begin with a descriptive theory or face the possibility that problems will occur during the project. In this type of study, the formation of hypotheses of cause-effect relationships is of importance, thus the descriptive theory must cover the depth and scope of the case under study. The selection of cases and the unit of analysis are developed in the same manner as the other types of case studies (Tellis, 1997).

3.2.2 General advantages of case studies

The general advantages of case studies are:

- case studies give a picture close enough to the real situation as it were;
- case studies usually give details of the studied case that may not be obtained by a representative or comparative study;
- case studies are useful in generating context-dependent knowledge (Flyvbjerg, 2006), and
- case study evaluations can cover both process and outcomes because they can include both quantitative and qualitative data (Tellis, 1997).

3.3 Organisation of the present Study

The entire investigation was designed as an embedded multiple-case study because it involved surveying more than one unit of analysis. The whole study was organised in such a way that it included several studies put together in order to complete the whole life cycle of the Kenyan dairy industry; each study (analysis) focussed on a particular life-cycle stage or unit process in the milk production and process chain. The four (4) multiple-case studies that were included are namely:

1. Production of milk at the farm;
2. Bulking and cooling of milk at cooling stations;
3. Milk processing, packaging, and
4. Distribution of processed, packaged milk from the dairy.

For each of these stage or unit processes, a multiple-case study was mounted to help collect information about the use of energy. In each of these multiple-case studies, a replication logic was followed, which differs from the kind of sampling logic where a selection is made out of a population, for inclusion in the study. In this type of sample selection, each individual case study consists of a "whole" study in which facts are gathered from various sources and conclusions drawn based on those facts. As Yin (1994) pointed out that generalisation of results, from either single- or multiple-case study designs, is made to theory and not to populations.

This choice of cases to include was made based on the fact that multiple cases strengthen the results by replicating the pattern-matching, thus increasing confidence in the robustness of the theory. To this effect, several cases were carefully selected in each of the above-named life-cycle stages and inventoried so that they may act as replicates from which means of data obtained will be calculated to represent the particular life-cycle stage. This, therefore, meant that several dairy farms, bulking stations and dairies would be included. However, the investigator was very cautious during the investigation as to avoid misrepresentation and to maximise on the information provided.

3.4 Case selection

This study also may be termed as a descriptive case study, since it has earlier been described as not being causal but rather an “attributional” LCA study that sought to establish the *status quo* of energy utilisation in the Kenyan milk supply chain; therefore, case selection was a relatively difficult process. However, the selection of cases offered the opportunity to maximise what could be learned, knowing that time and funds were limited. Hence, selected cases were mostly accessible and willing subjects attainable within limited resources.

Strategic case selection has been reported to increase the generalisability of case studies (Flyvberg, 2006) and it was therefore taken seriously in this study. As Flyvberg (2006) put it, “when the objective of a study is to achieve the greatest possible amount of information on a given problem or phenomenon (as is the case here), a representative case or a random sample may not be the most appropriate strategy. This is because the typical or average case is often not the richest in information. Atypical or extreme cases often reveal more information because they activate more actors and more basic mechanisms in the situation studied and are as a result better.”

This study identified a few cases for study based on their validity rather than their representativeness that is emphasised by random sampling techniques. In other words, case selection was "information-oriented" to include the cases that would give the most information on the subject of interest at the lowest cost within the shortest period of time. This also included some extreme cases and maximum-variation cases for comparison purposes.

3.5 Goal and scope definition of this study

The first step of an LCA is defining the goal and scope of the analysis. The system boundaries are set and the functional unit is also defined in this step. The functional unit is a reference to which all other materials (and associated environmental loads) in the LCA are related (Ogino *et al.*; 2007). The product in this case is fresh milk pasteurised, homogenised and packaged in a paperboard package ready for sale. The functional unit (FU) was defined as 1 kg of fresh processed milk in a distribution depot ready for wholesaling or retailing. The retailing stage was left out due to its complexity and difficulty in obtaining accurate data within a limited budget and time. In the Life Cycle Inventory analysis (LCI), only the delivered (metered) energy requirements for milk handling were considered from the farm level, through the transportation of milk to bulking and cooling stations, cooling at bulking stations, transportation to the processing plants, actual processing and packaging, to the distribution stage. The study was therefore to be a typical second order LCA where all processes during the life cycle of milk in Kenya, and one step before the actual inputs, are included, but the capital costs left out to simplify the study. The Life Cycle Impact assessment (LCIA), in this case, only included Global Warming Potential (GWP $_{(100)}$) resulting from energy use in the Kenyan dairy chain up to the point of distribution. Global Warming Potential is the contribution of GHG to global warming in a medium time scale of 100 years (GWP $_{(100)}$). Retailing was excluded from this survey due to difficulty in obtaining data at the time of running the survey. In LCIA only interpretation of the findings was done.

The main goal of the study was defined as only providing information about energy use in the chosen food system. In order to establish the baseline information on this milk chain, given current or previous practices in the manufacture, use and disposal of the milk, the study was set up as an "attributional" rather than "consequential" LCA, sought to document the *status quo* of energy used in the Kenyan milk supply chain. This baseline will consist of the empirical data on energy requirements and the environmental loadings from the milk process system. The baseline information will be valuable for initiating improvement analysis by applying specific changes to this baseline system.

3.5.1 Data quality

Data quality goals provide a framework for balancing the available time and resources against the quality of data required to make a decision regarding the overall environmental or health impacts (Jensen *et al.*, 1997). For this study, data quality goals were set as follows:

1) To obtain site-specific data on energy inputs for most unit processes in the whole chain--from the dairy farm up to the point of retailing;
2) To consider approximate data values adequate for the transport energy data category, and
3) To account for a minimum of 95% of all energy inputs during the LCI.

Data quality indicators are benchmarks to which the collected data can be measured to determine if the data quality requirements have been met. This study identified consistency, reproducibility, precision and completeness as its main data quality indicators. The **data sources** for the LCI were meter readings from equipment, industry data reports, laboratory test results, equipment and process specifications, and best engineering judgement. Reference books also came in handy as data sources, especially where data was missing. **Data types** included metered data, sampled data, non-site specific and non-LCI data, i.e., data not intended for LCI purposes. For production data, well-characterised industry data for milk processing was utilised. The inventory included data for the year 2006/2007 for a period of 12 months.

3.5.2 Setting of system boundaries

A principal flow chart is a flow diagram used to define the principal flow and a system boundary of the processes to be evaluated. **Figure 12** illustrates the principal flow chart for this study. The unit processes used to determine the principal flow of energy resources through the product system for the Kenyan dairy chain were: farm level production of milk, bulking and cooling of milk at cooling stations, and the actual processing, packaging and distribution of processed, packaged milk at the dairy. All the transport efforts involved in between were also included.

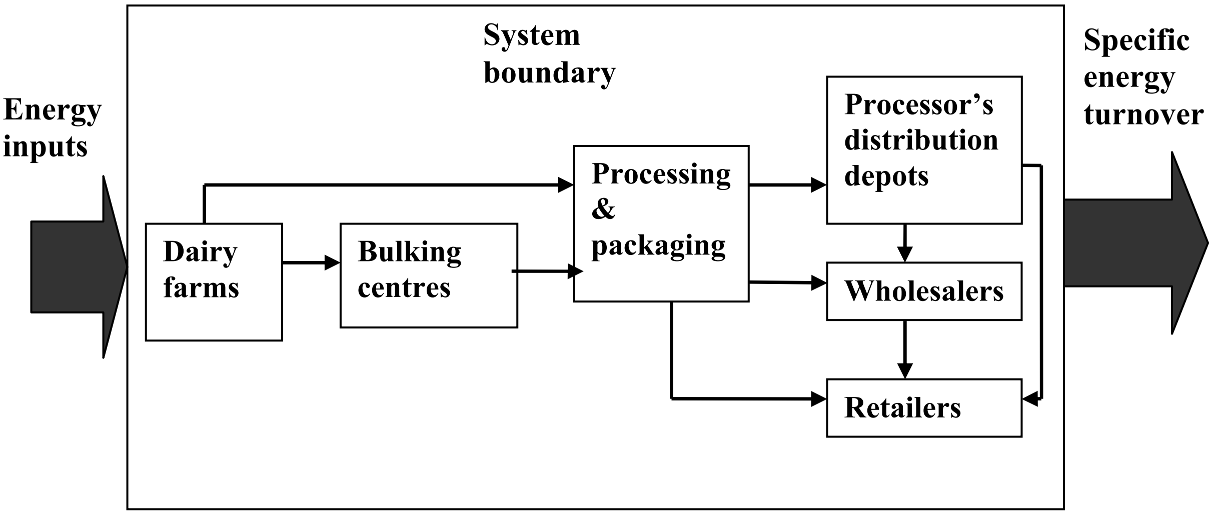


Figure 12: Diagram of the principal flow and system boundary considered for the study

3.5.3 System description

The dairy industry is one example of a system characterised by the association of different production systems: agriculture, livestock, dairy farming, dairy packaging and product distribution. These systems are closely related, as the final product quality is highly dependent on the appropriate combination among the mentioned systems (Hospido *et al.*, 2003).

This survey was divided into four stages, namely: milk production at dairy farms, bulking of milk at collection centres, processing and packaging of milk at the dairy plant, and the distribution of milk from the factory to the large regional company depots. All transport efforts in between were also considered. The diagram on figure 13 shows the life-cycle inventory activities included in this study.

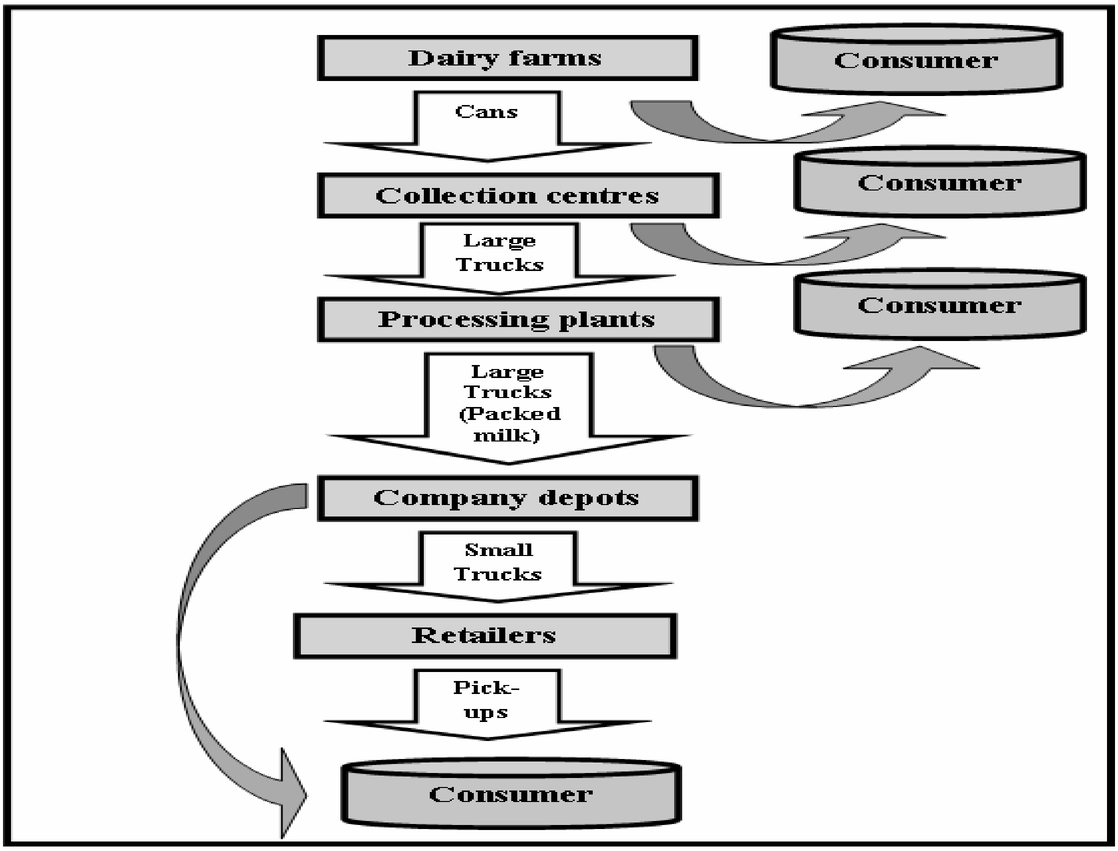


Figure 13: Diagram showing the flow of milk in the chain and all transportation in between

3.6 Life Cycle Inventory Analysis

The Life Cycle Inventory Analysis step started by preparing the data collection tools (questionnaires) to be used in gathering information about energy inputs used in the production, transportation, processing and distribution of processed milk in Kenya. A questionnaire is a research instrument consisting of a series of questions and other prompts for the purpose of gathering information from the respondents. After identifying the unit processes to be studied, the important material flows to be inventoried were identified in order to evaluate the energy consumption through these flows.

Next, the energy inputs and outputs of all the unit processes included were listed to establish their measurability in terms of units of acquisition. Questions were then carefully formulated to capture the information in the best possible way. Information on the use of delivered energy (metered energy) was then collected including the use of electricity, biomass and petroleum-based fuel sources. In the case of electricity, the primary energy was also inventoried as biomass and petroleum-based fuel sources. The energy used to transport the energy sources and other resources from the point of acquisition to the point of use within each sub-system and in between the sub-systems was also inventoried. Direct energy is the energy supplied directly in the form of fuels and electricity. Indirect is the energy used in the manufacture of fertilisers, agrichemicals, seeds, and animal feed supplements. Capital energy is the energy used to manufacture items included in capital equipment such as farm vehicles, machinery, buildings, fences and methods of irrigation. In this case, only direct energy was inventoried.

3.6.1 Pre-testing of questionnaires

The necessary questionnaires were composed with the help of several experienced questionnaire writers who went through them and made useful corrections. Time was then spent pre-testing the questionnaires to identify any misunderstandings and bottlenecks that could arise during the actual data collection process. This process involved identifying potential recipients to each category of the questionnaires and asking them to go through it, or carrying out mock interviews with them. The main aim was to find out if the questions in the questionnaire made sense to the interviewees and if the required information could actually be captured by use of those questions. In an effort to determine the most effective method for collecting the desired data, some questionnaires were sent to potential respondents by post and some telephone interviews were conducted.

After the pre-test, it was concluded that sending the questionnaires by post was an unreliable method of administering questionnaires under the specific circumstances. Apart from being a slow process, finding the current postal addresses of some enterprises was very difficult since most directories were outdated. Additionally, the response rate was the poorest with this method, since most people found it bothersome to reply, and with no one to encourage them to fill in the questionnaires, most questionnaires were not returned. Unique to this case, some respondents were illiterate and could not respond to questionnaires without assistance from an interviewer. Administering questionnaires by telephone was also found to be fairly ineffective, as most landline telephone lines were either out-of-service or too busy to get a response. In most cases, it was very difficult to connect to the right people in the enterprise that could answer the questions and, therefore, no useful information could be obtained. The use of mobile phones was more reliable but extremely expensive, and as a result impossible to accomplish within limited financial resources.

The best method of questionnaire administration was that of structured interview. Despite being extremely expensive as a result of transport and accommodation costs, it gave the best responses and one could visit several enterprises within the same area, even in those areas where telephone connection was poor. Personal visits were also seen to be important because they allowed the interviewer to see the premises before administering the questionnaires: a clearer understanding of the premises and its operations was found to be useful in improving the quality of the data collected.

3.6.2 Questionnaire administration

At this very important stage, all relevant data were collected and organised providing a basis to evaluate associated environmental impacts or potential improvements. The level of accuracy and detail of the data collected at this stage is usually reflected throughout the remaining parts of the LCA process and must, therefore, be carried out carefully. An inventory analysis produces a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed.

A data collection plan was drawn, based on the observations of the questionnaire pre-testing stage, to maximise on the limited resources available for carrying out the inventory of those unit processes. Then the actual data collection on the selected unit processes followed. The information on energy inputs was collected with the help of questionnaires. Personal interviews were carried out with farm managers or farmers at the farms, managers of collection centres, operation managers or supervisors of dairy processing plants, and marketing managers of milk processing companies. However, before commencing with this activity, it was important to first establish contacts by way of personal visits, especially for the three (3) largest dairy companies whose head offices are in Nairobi, the capital city of Kenya, even though they own several dairy farms, cooling and bulking stations and milk processing plants in the countryside. The official permission and goodwill of the main administration in Nairobi was sought before travelling to the hinterland for inventory analysis at the dairy enterprises. These three milk processing companies handle over 70% of the Kenyan processed milk and, therefore, represent an important part of the data needed. Confidentiality issues arose as companies’ proprietary data was required for this study, and all participants were reassured that a high level of confidentiality would be maintained for all proprietary data given. Additionally, it was agreed that all participating companies’ identity would not be revealed. Table 1 shows the number of inventoried dairy enterprises: each represents an independent case study.

Table 1: Table showing the number of inventoried dairy enterprises

Dairy enterprises	Total number inventoried
Dairy farms	6
Bulking/cooling stations	6
Dairy processing factories	9
Distribution centres	9

3.6.2.1 Dairy farms

Only on-farm activities were investigated for their energy inputs, while all pre-farm activities were excluded. For example, off-farm feed production was excluded although on-farm feed preparation was included, as well as feed transport into the farm. Carbon dioxide uptake from crop growth was not considered because much of the plant material was retained on-site following harvest and it was assumed that the absorbed CO_2 would be re-released with time. Soil carbon-sequestration also was not considered because it was not deemed significant during a 12-month period. Emissions of CO_2 from cattle respiration and composting of the cattle waste were offset by carbon fixation through photosynthesis from the atmosphere into forage crops (Ogino *et al.,* 2007).

3.6.2.2 Milk bulking/collection centres

Energy inputs to run the collection centres, such as electricity and fuels, were inventoried in addition to all transport efforts of utilities into the bulking centres. These include the transport of detergents and other utilities, cooling, and storage of milk energy inputs. In relevant cases, the energy inputs for the transport of milk from the farmers were also inventoried.

3.6.2.3 Processing and packaging at dairy plants

Among the energy inputs inventoried at this stage were the energy for transport of detergent and packaging, energy for the transport, and energy for the transport of different fuel sources, such as diesel, fuel oil and wood, to the premises. Energy inputs, such as electricity and wood, were also included. Allocation of energy used for fluid milk processing was carried out based on mass of fluid milk produced by the processor in comparison with other products (ISO, 1997).

3.6.2.4 Distribution of processed packaged milk to depots and large-scale retailers

Here, all the energy inputs related to the transport and storage of milk to the processing company's large country-wide milk depots were inventoried. The actual retailing energy inputs were not included in this study. Figure 14 summarises the inventory analysis activities included in this study.

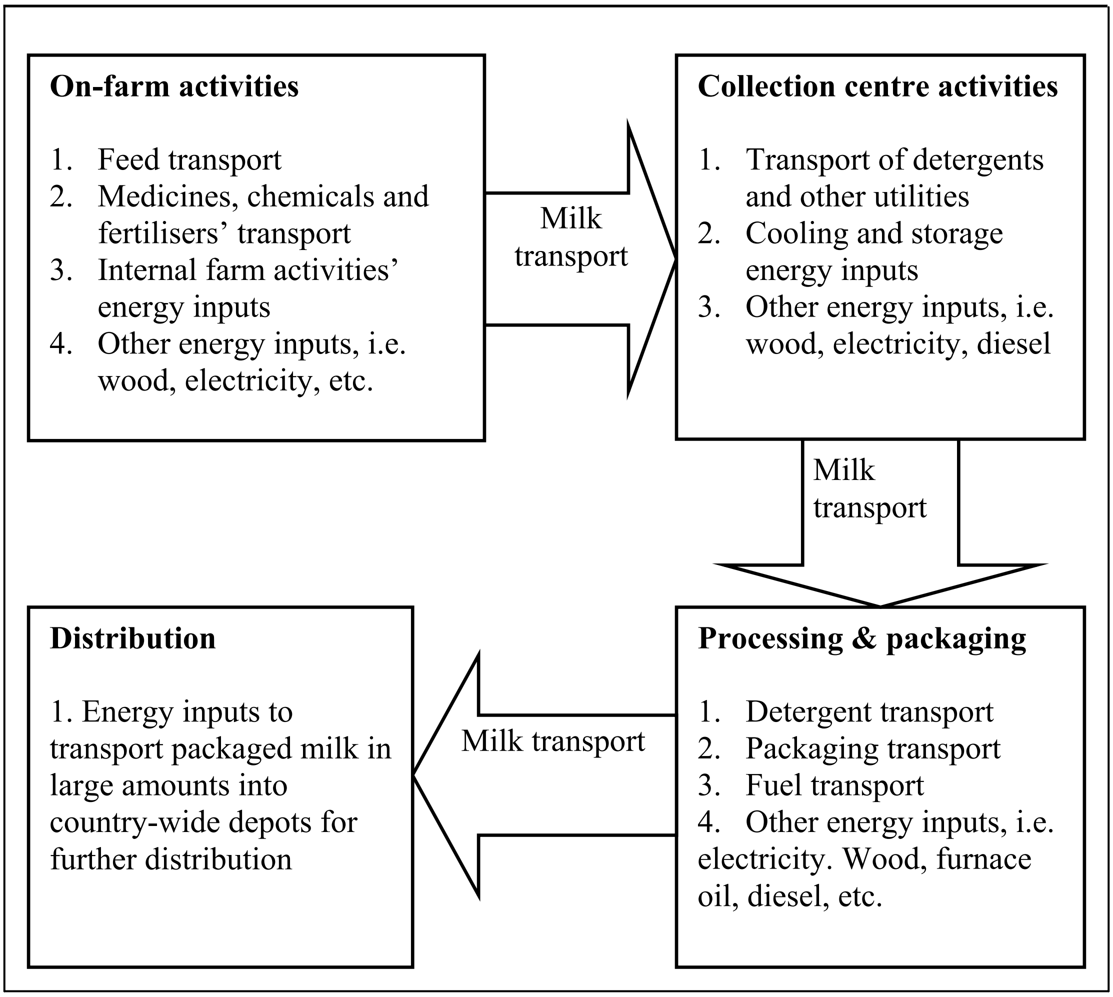


Figure 14: Life-cycle inventory of all energy inputs of the surveyed milk process chain

3.6.3 Data categories

This study included several **data categories** both disaggregated and aggregated in the inventory, namely,

- Individual process data: data from a particular operation within a given facility not combined in any way.
- Composite data: data from the same operation or activity combined across locations.
- Aggregated data: data combining more than one process operation.
- Industry average: data derived from a representative sample of locations and believed to statistically describe the typical operation across technologies.
- Generic data: data whose representativeness may be unknown but which are qualitatively descriptive of a process or technology.

3.6.4 Data sources

The sources of information and evidence collected during data collection included: documents, archival records, interviews, direct observation, participant observation and physical artefacts. Out of all these sources, interviews were by far the most important sources of study information, since most enterprises were uncomfortable about giving copies of their archival records, and any physical artefacts collected at the site of study as part of the field visit, such as taking photographs, was completely prohibited.

3.7 Life-Cycle Impact Assessment (LCIA)

The Life-Cycle Impact Assessment (LCIA) step is aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. The potential environmental effects, especially of greenhouse gases (GHGs) from fossil fuel combustion, were assessed using the primary data collected during LCI. The environmental impact categories considered were energy use Global Warming Potential (GWP) presented as the estimated CO_2 emissions. Global Warming Potential is the contribution of GHG to global warming in a medium time scale of 100 years (GWP $_{(100)}$). According to the IPPC, water vapour is the most important GHG, contributing 36-70% to global warming; CO_2 and methane contribute 9-26% and 4-9% respectively, while ozone contributes 3-7%. As related to fossil fuel combustion, CO_2, methane and nitrous oxide are the most important GHGs.

Greenhouse gases are like a blanket around the earth. They absorb the heat from the earth, and re-radiate it: about half gets sent out to space, and the other half goes right back to the earth's surface. The most important GHGs are water vapour and CO_2, but there are many others, some artificial and some naturally occurring. Overall, the greenhouse effect is a good thing. It is a cold universe out there (on average, only a few degrees above absolute zero). Without GHGs, the earth would be a frozen, lifeless ball as the temperatures would be unbearably low and unable to support any form of life.

The problem with GHGs is that over the last few hundred years (since the industrial revolution), the concentration of GHGs in the atmosphere, especially CO_2, have greatly increased. This is because we are burning lots of fossil fuel to make power, to run our cars and heat our homes, and to operate industrial equipment. When you burn fossil fuel, you make CO_2, and the CO_2 then makes a thick blanket around the earth that makes the atmosphere too warm. It doesn't take a lot of change in the earth's temperature to make a difference in our weather. This is because differences in temperature in the atmosphere and in the ocean control the wind and ocean currents. Sometimes it only takes a few degrees to alter circulation patterns.

In order to estimate GWP in this study, preliminary calculations proved that for fossil fuel combustion, the amount of methane and nitrous oxide produced is very small. Such estimations of CO_2 emissions provide a sufficient estimation for the corresponding GWP; therefore, further estimations for the mentioned GHGs were left out during the impact analysis. However, the results presented give a good estimate of GWP produced by utilising the inventoried energy inputs.

3.7.1 Calculations for Delivered Energy Turnover: $W_{(DE)}$

The primary data (inventory) was collected as litres [L] of petrol and diesel, kilograms [kg] of wood and kilowatts hours [kWh] of electricity. The volumes of petrol and diesel used were then converted into m^3 by multiplying by a factor of 0.001 and the product used to calculate the energy turnover. Energy turnover calculated in kWh using calorific and density values of fuel sources uses the formula:

$$W_{DE\ (fuel)} = V_{(fuel)} * \rho_{(fuel)} * H_{u\ (fuel)} * f$$

(Equation 1)

Where:

$W_{DE\ (fuel)}$	**[kWh]**	Delivered energy turnover from a particular fuel source
$V_{(fuel)}$	**[m^3]**	Volume of fuel (petrol, diesel or industrial diesel)

$\rho_{(fuel)}$ **[kg/m^3]** Fuel density

$H_{u\,(fuel)}$ **[kJ/kg]** Fuel-calorific value

f **[kWh/kJ]** Conversion factor 3600^{-1}

In the case of firewood, the density values were not used because the primary energy source was reported in kilograms. The total energy turnover per enterprise was established by summing up all energy turnovers resulting from all fuel sources used by the enterprise in kWh.

Table 2: Table showing the values used in the above calculation (* Schlich, 2008:104; # www.IEA.org)

Fuel source	Units of sale (delivery)	Fuel density (**ρ**)	Calorific Value (**H_u**)	Conversion factor from unit of sale to kWh
S.I. Units		**kg/m^3**	**kJ/kg**	
Diesel	L	832.5 *	42960 *	9.94
Petrol	L	747.5 *	44000 #	9.14
Fuel oil	L	933.3 #	40473 #	10.49
LPG	kg	774.1 #	46680 #	12.97
Heavy oil	kg	933.3 #	40473	11.24
Wood	kg	-	15300 *	4.25
Electricity	kWh	-	-	1.00

The values on the final column of the table were directly multiplied by the volume or mass of fuel inventoried during the survey in order to obtain the energy turnover from each fuel source used at the dairy enterprises. The total delivered energy turnover per factory was calculated by cumulatively adding all the energy turnovers from all fuel sources applied.

$$W_{DE(case)} = \sum_{i=1}^{n} W_{DE(fuel)} \qquad \text{(Equation 2)}$$

Where:

n is the number of different fuel forms of delivered energy

$W_{DE(case)}$ **[kWh]** is the total delivered energy turnover per case

$W_{DE(fuel)}$ **[kwh]** is the delivered energy turnover by each form in a business

As an allocation procedure in the milk processing stage, only the proportion of energy used for fresh milk production as calculated by mass was included in the calculation, since most processing plants not only processed fresh packaged milk but had it as one of several products they were producing out of the same raw material. These plants processed several products on the same premises.

3.7.2 Specific Delivered Energy Turnover $W_{(SDET)}$

The Specific Delivered Energy Turnover (SDET) for each case was then calculated by dividing the total energy turnover $[W_{DE(case)}]$ by the allocated amount of milk processed into fresh milk per year as denoted by (m). The results were obtained in **kWh/kg milk**, with one (1) kilogram (kg) of milk being the functional unit in the study, as it was found to be the preferred unit of measurement in the process chain and thus easier to work with.

$$W_{SDET(case)} = W_{DE(case)} / m \qquad \text{(Equation 3)}$$

Where:

$W_{SDET(case)}$	**[kWh]**	is the specific delivered energy turnover per case
$W_{DE(case)}$	**[kWh]**	is the total delivered energy turnover per case
m	**[kg]**	is the mass of milk handled per year

To obtain the total specific energy turnover (SDET) for the complete chain, procedures were developed to determine the cases that would be included in the complete chain calculation, since each stage in this embedded study included more than one case. The respective $W_{SDET\ (case)}$ of the cases selected to represent a stage, calculated using equation 3, were simply summed up as shown in equation 4:

$$W_{Total\ SDET\ (chain)} = \sum_{i=1}^{n} W_{SDET\ (stage)} \qquad \text{(Equation 4)}$$

Where:

$W_{Total\ SDET\ (chain)}$	**[kWh]**	is the total specific delivered energy turnover for the complete chain
n		is the number stages
$W_{SDET\ (stage)}$	**[kWh]**	is the $\mathbf{W}_{SDET\ (case)}$ of the case selected to represent a stage
$W_{SDET\ (stage)}$	**[kWh]**	is the specific delivered energy turnover for the stage

3.7.3 Estimation of primary energy turnover $W_{(PE)}$ from delivered energy turnover $W_{(DE)}$

This was done by dividing by specific factors applied as the efficiency of the delivered energy production process. The symbol η is used to depict this factor.

3.7.3.1 Electricity

All the primary energy sources needed for a country to produce a year's supply of electricity were enumerated, and the actual amount of electricity produced in that year recorded. In this case, data from the year 2005 as reported by the International Energy Agency (IEA) statistics website (2008). The efficiency of electricity production in Kenya was calculated as done by Krause (2008):

$$\eta_{\text{elec-Ken}} = W_{\text{out- elec}} / W_{\text{in-elec}}$$

(Equation 5)

Where:

$\eta_{\text{elec-Ken}}$		is the efficiency of electricity production in Kenya
η_{elec}		is the efficiency of electricity generation
$W_{\text{out- elec}}$	**[kWh]**	is the delivered energy in Kenya produced as electricity
$W_{\text{in-elec}}$	**[kWh]**	is the primary energy used for producing electricity in Kenya

The value of $\eta_{\text{elec-Ken}}$ was found to be **24.68%.**

The delivered energy inputs in this milk chain were then converted back to their primary energy inputs with the help of the following equation:

$$W_{\text{PE-elec}} = W_{\text{DE-elec}} / \eta_{\text{elec}}$$

Where:

(Equation 6)

$W_{\text{PE-elec}}$	**[kWh]**	is the primary energy from electricity
$W_{\text{DE-elec}}$	**[kWh]**	is the delivered energy used as electricity
η_{elec}		is the efficiency of electric production

3.7.3.2 Fossil fuel sources

The conversion of delivered energy from fossil fuel sources into primary energy was achieved by use of specific country data on the efficiency of petroleum refineries in Kenya. Country-specific micro-data was required in order to successfully establish η_{ref}, which was then used in the conversion of fossil fuel from $W_{DE(fuel)}$ back into $W_{PE(fuel)}$ in [kWh].

$$\eta_{\text{ref}} = W_{\text{out ref}} / W_{\text{in-ref}}$$

Where: (Equation 7)

η_{ref}		is the efficiency of petroleum refining
$W_{\text{out ref}}$	**[kWh]**	is the output of the refinery
$W_{\text{in-ref}}$	**[kWh]**	is the input into the refinery

To convert the values of $W_{DE(fuel)}$ for petroleum fuel sources into $W_{PE(fuel)}$, the following equation was applied:

$$W_{\text{PE-fuel}} = W_{\text{DE-fuel}} / \eta_{\text{ref}}$$

Where: (Equation 8)

$W_{\text{PE-fuel}}$	**[kWh]**	is the primary energy from a fuel
$W_{\text{DE-fuel}}$	**[kWh]**	is the delivered energy of the same fuel source
η_{ref}		is the efficiency of the petroleum refinery

The IEA statistics website provided the micro statistics on the Kenyan crude oil import, and fuel production through refinery were employed in the above calculation. By use of the given IEA net calorific values of the petroleum refinery products, the energy in kWh was calculated and found to be **85.0%**. This value compares very well with the German efficiency of petroleum refinery reported as **88.3%** (Krause, 2008).

The only forms of delivered energy used at the surveyed dairy enterprises were electricity and fossil fuel; no other form of delivered energy was used in this milk chain. Wood fuel was inventoried, but this is a special case since wood is a primary energy form as well as a delivered energy form. Therefore, no conversion factors are required to convert delivered energy obtained from wood into primary energy obtained form wood [kWh] since:

$$W_{DE(wood)} = W_{PE(wood)}$$

(Equation 9)

Where:

$W_{DE(wood)}$	**[kWh]**	is the delivered energy turnover from wood
$W_{PE(wood)}$	**[kWh]**	is the primary energy turnover from wood

3.7.4 Specific Primary Energy Turnover $W_{(SPET)}$

For each stage and enterprise surveyed, the total PE used was obtained by using the following equation of summation and divided by the amount of milk handled to obtain the specific PE per kg milk:

$$W_{SPET(case)} = (W_{\text{PE-el}} + W_{\text{PE-fuel}} + W_{\text{PE(DE)-wood}}) / m_{(case)}$$

(Equation 10)

Where:

$W_{SPET\,(case)}$	**[kWh/kg]**	is the primary energy per kg milk for each stage
$W_{PE\text{-}el}$	**[kWh]**	is the primary energy of inventoried electric energy
$W_{PE\text{-}fuel}$	**[kWh]**	is the primary energy of surveyed fossil fuel energy
$W_{PE\text{-}wood}$	**[kWh]**	is the primary energy of surveyed wood energy
$m_{(case)}$	**[kg]**	is the mass of milk handled per year

For the complete chain, all the primary energy values obtained were summed up as follows:

$$W_{TotalSPET(chain)} = \sum_{i=1}^{n} W_{(PE\text{-}stage)}$$

(Equation 11)

Where:

$W_{Total\ SPET(\,chain)}$	**[kWh/kg]**	is the total specific primary energy for the chain
$W_{SPET(stage)}$	**[kWh/kg]**	is the specific primary energy per stage
n		is the number of stages in the chain

3.7.5 Estimation of CO_2 –emission from energy inputs

To estimate emissions from fuel combustion, the Intergovernmental Panel on Climate Change (IPCC) methodology for the calculation of emissions from fuel combustion was adopted. In this method, the quantity of fuel combusted is multiplied by the emission factor per physical unit of fuel to give the emissions. For CO_2 emissions, the delivered energy fuel units were converted into CO_2 emissions by multiplying the W_{SDET} in [kWh] energy from each fuel by the specific CO_2-emission factor of that particular fuel [gCO_2/kWh]. Equation 12 shows how the estimations were calculated:

$$m_{CE(fuel)} = W_{DE(fuel)} * f_{SCE(fuel)}$$

(Equation12)

Where:

$m_{CE(fuel)}$	**[kg]**	is the CO_2 emission associated with a fuel
$W_{DE(fuel)}$	**[kWh]**	is the delivered energy turnover from a particular fuel source
$f_{SCE(fuel)}$	**[kg/kWh]**	is the specific carbon emission factor of the fuel

Table 3 shows the specific CO_2 emissions of the inventoried energy inputs adopted from Schlich, (2008: 09). The values used in the actual calculations were those on the last column obtained from the Department of Environment "*Umweltbundesamt*" (UBA).

Table 3: Table showing the selling units and specific carbon emission of different fuels

Fuel source	Selling units	Specific CO_2 –emission in g CO_2/kWh energy $f_{(sce)}$	
Diesel	Litre [L]	265	266[^]
Petrol	Litre [L]	252	259[^]
Fuel oil	Litre [L]	260	281[^]
Heavy oil	Tonne [t]	260	281[^]
Wood	Kilogram [kg]	0[#]	
LPG	Kilogram [kg]	234[^]	
Electricity	Kilowatt-hour [kWh]	380*	

* Own calculation from Kenyan electricity mix based on Kenyan energy data from IEA

[#] because wood is a renewable energy source that takes up CO_2 during formation and gives the same amount when combusted

[^] from Umweltbundesamt; Gichtgas: KFA Jülich

The methods used to derive the factors are based on the carbon contents of the fuels and the typical fraction of carbon oxidized during combustion. Both the hydrocarbons and particulate matter formed during combustion are accounted for to some extent: Carbon monoxide (CO) emissions are included in the estimates of CO_2 emissions. It is assumed that CO in the atmosphere undergoes complete oxidation to CO_2 shortly after combustion: within 5-20 weeks of its release (IPCC/OECD/IEA, 1997).

3.7.5.1 Specific carbon dioxide emission factor ($f_{SCE(elec)}$) for the Kenyan electricity mix

The Kenyan electricity mix shown on table 4 was used to calculate the CO_2 emission factor. Equation 10 was used to estimate the CO_2 contribution of electricity generation according to the IPCC guidelines. The CO_2 emissions were then added and divided by the total quantity of electricity consumed in the same year to give the value **0.38** kgCO_2/ kWh. Similar calculations were applied to estimate methane and nitrous oxide emission factors for this electricity mix.

$$m_{CE(elec)} = \quad W_{DE(elec)} * f_{SCE(elec)}$$

(Equation13)

Where:

$m_{CE(elec)}$	**[kg]**	is the mass of CO_2 emission associated electricity input
$W_{DE(elec)}$	**[kWh]**	is the delivered energy turnover from electricity
$f_{SCE(elec)}$	**[kg/kWh]**	is the specific carbon emission factor of electricity per kWh

Table 4: Showing the Kenyan electricity mix in 2005 (IEA 2008)

Primary energy source	**% Contribution**
Hydropower	50
Oil	30
Geothermal	15
Biomass	5
Total	**100**

The specific CO_2 emissions, $m_{SCE(case,)}$ for cases were calculated by adding the carbon emissions from all energy inputs and dividing them by the mass of milk handled using equation 14. The CO_2 emission of wood was considered to be zero.

$$m_{SCE\ (case)} = \{m_{CE\ (elec)} + m_{CE\ (fuel)}\} / m_{(case)}$$

(Equation 14)

Where:

$m_{SCE\ (case)}$	**[kg/kg]**	is the specific mass of CO_2 emission per kg milk for the case
$m_{CE\ (elec)}$	**[kg]**	is the mass of CO_2 emission of inventoried electric energy (from equation 13)
$m_{CE\ (fuel)}$	**[kg]**	is the mass of CO_2 emission of surveyed fossil fuel energy
$m_{(case)}$	**[kg]**	is the mass of milk handled per year in the specific case

In order to obtain a total specific CO_2 emission for the complete chain, the specific CO_2 emission for the selected cases $m_{CE\ (case)}$ to be included in the sum of total chain CO_2 emission were added up, similar to the case of delivered and primary energy to obtain $m_{Total\ SCE(chain)}$.

$$m_{Total\ SCE(\ chain)} = \sum_{i=1}^{n} m_{(SCE\text{-}stage)}$$

(Equation 16)

Where:

$m_{Total\ SCE(\ chain)}$	**[kg/kg]**	is the total specific mass carbon emission for the chain
$W_{SCE(stage)}$	**[kg/kg]**	is the specific mass of CO_2 emission per stage
n		is the number of stages in the chain

3.8 Representativeness of the study

The study was very representative of the complete picture of the Kenyan dairy industry as it included 9 of the 15 operational fresh milk processors, which together have more than 70% of the market share. Although the active milk processors produce a wide range of products, including yoghurt and long-life milk in many flavours, fresh milk is still the predominant product; therefore, the choice of product to inventory was relevant. All the stages included in the study were shown to contribute 88% of the revenue in the value chain, making it significant for the study of the whole chain. Table 5 shows the findings of a study of the Kenyan dairy chain by *Technoserve* in 2005.

Table 5: Revenue share of life-cycle stages of the Kenyan dairy value chain (Technoserve 2005)

	Farm	**Transport**	**Bulking and cooling**	**Transport**	**Processing and packaging**	**Distribution**	**Retail**	**Total**
Revenue share(%)	27	4	4	4	41	8	12	**100**
Kshs/litre	**13.5**	**2.0**	**2.0**	**2.0**	**20.3**	**4.0**	**5.7**	**49.5**

3.9 Validation of data

Since this was a qualitative study, it was impractical to validate the data using quantitative statistical methods available. Each inventoried dairy enterprise was comprised of a complete case study within the larger system chain case study. Therefore, the findings characterised qualitative findings that could only be compared to each other and industry means, but not by using quantitative statistical methods.

Results

4.1 Delivered Energy Turnover at different stages of Kenyan milk chain

4.1.1 Farms

Six dairy farms were surveyed and among them were two (2) large-scale commercial farms with 200 and 500 milked cows respectively. The rest comprised mainly of small-scale milk producers with less than 10 milked cows. The large farms were owned by large milk processing companies and are fairly more mechanised than the small-scale farms. The small holders were free to choose where to sell their milk. Some of these farmers sent their milk directly to the processors, while others sold it to the bulking centres belonging to large processing companies. The issue of transport distance and the arising costs was not very straight forward. This is because some farmers chose to send their milk to distances as far as 50 km to preferred bulking or cooling stations, despite having a bulking centre closer by. This was because the closer centre belonged to a company they did not prefer to sell their milk to. This pattern, of course, had direct implications on the energy turnover arising from milk transportation of this unique milk chain.

Table 6: Table showing results on energy sources used at surveyed dairy farms

Energy source	***W* [kWh/a]**					
	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6
Diesel	547640	839092	1524	34973	8096	1814
Electricity	31108	36000	4200	756	1390	1668
Wood	127500	2975000	8500	8500	4654	7756
Petrol	731348	68316	1280	0	0	789
LPG	0	20228	0	0	0	0
Total	**1437596**	**3938636**	**15504**	**44229**	**14140**	**12027**

The main sources of energy at the dairy farms were: diesel, electricity, petrol and wood (biomass); liquefied petroleum gas (LPG) was also used at one of the large-scale farms. Table 6 clearly demonstrates the findings on the different types of fuel used for dairy farming in Kenya. Although each farm had a unique fuel mix, diesel and wood appeared to be the most important energy sources used in all farms in substantial amounts. Electricity also was used at all farms, although to a lesser extent in comparison to diesel. Petrol was not very popular, although it was in use at most farms. A complete synopsis of the percent contribution of each energy source of the farms' total delivered energy turnover is shown in Figure 15: a closer look at the individual fuel mixes for all the surveyed farms are given in figures 16-21.

Farm 2 was the largest of all surveyed farms and had the highest total delivered energy turnover (***W**$_{DE\ (case)}$*); while Farm 6 had the lowest ***W**$_{DE\ (case)}$*. Farm 2 is also the only one of all surveyed farms that was found to utilise forms of delivered energy that were encountered. The normal situation for most household dairy farmers appears to be the use of diesel, electricity and wood.

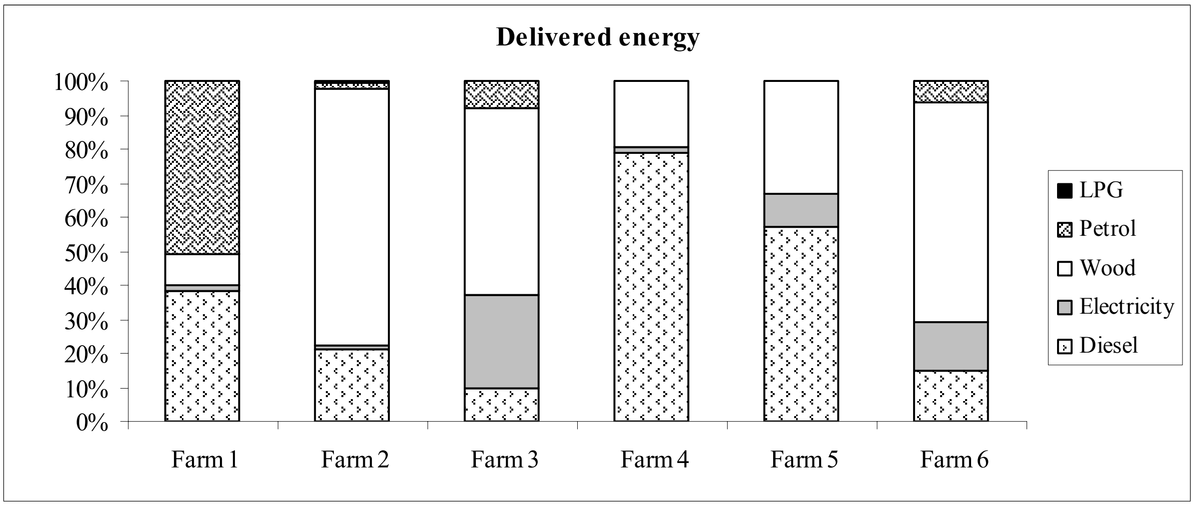


Figure 15: Chart showing the proportions of different energy sources at surveyed farms

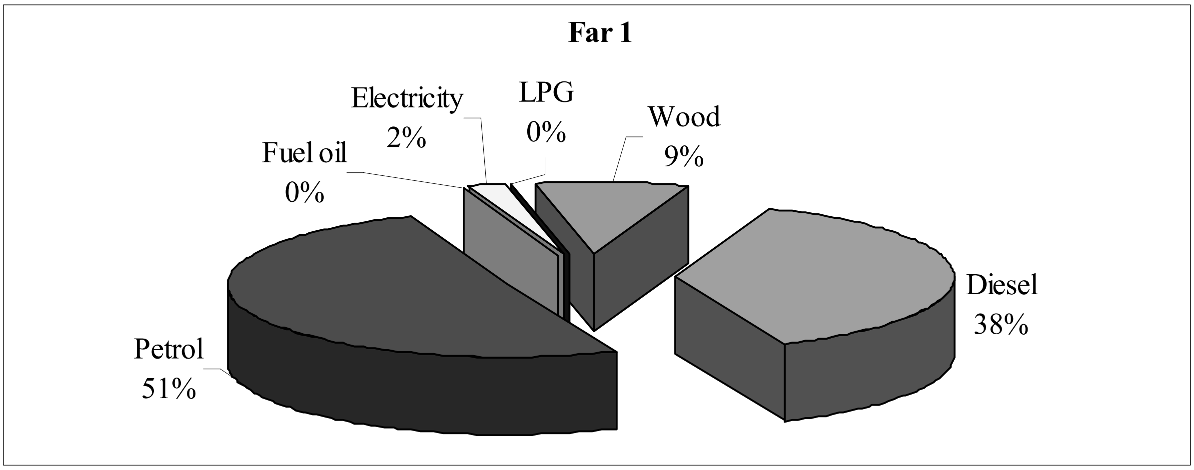


Figure 16: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 1

At Farm 1 shown in figure 16, petrol was the most important fuel as it contributed 51% to the total delivered energy turnover. Contributing 38% is diesel, followed by wood that contributed 9%. Of small significance was electricity as it only contributed 2%. At Farm 2, depicted in figure 17, wood made up the largest percent share in the total delivered energy turnover as it contributed 75%; diesel contributed 21%, and petrol commanded a humble 2% share. LPG and electricity provided only 1% each of the energy utilised at this farm.

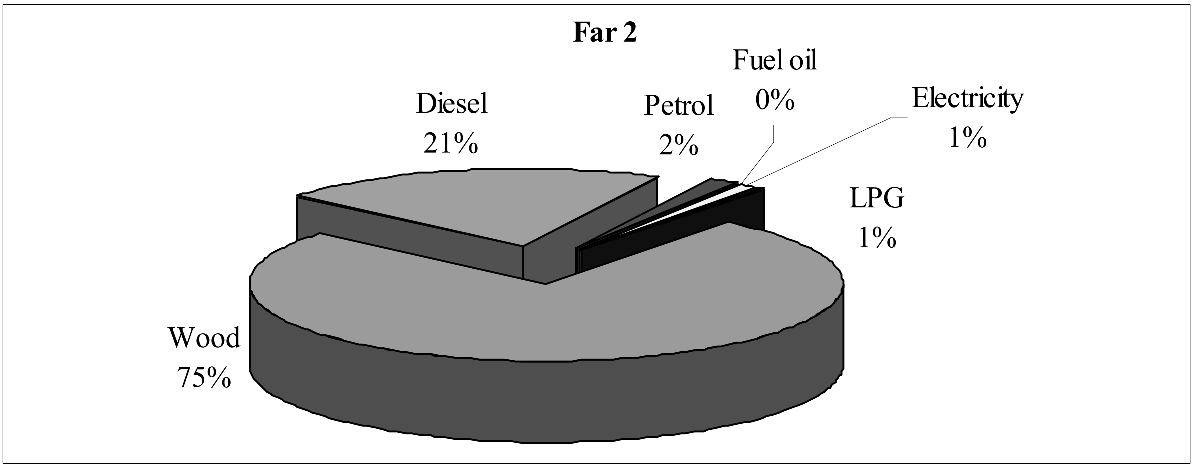


Figure 17: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 2

At Farm 3, figure 18, wood again took the lead, contributing 55%, followed by electricity at 27%. Diesel and petrol contributed 10% and 8% respectively, to the total delivered energy turnover at this farm.

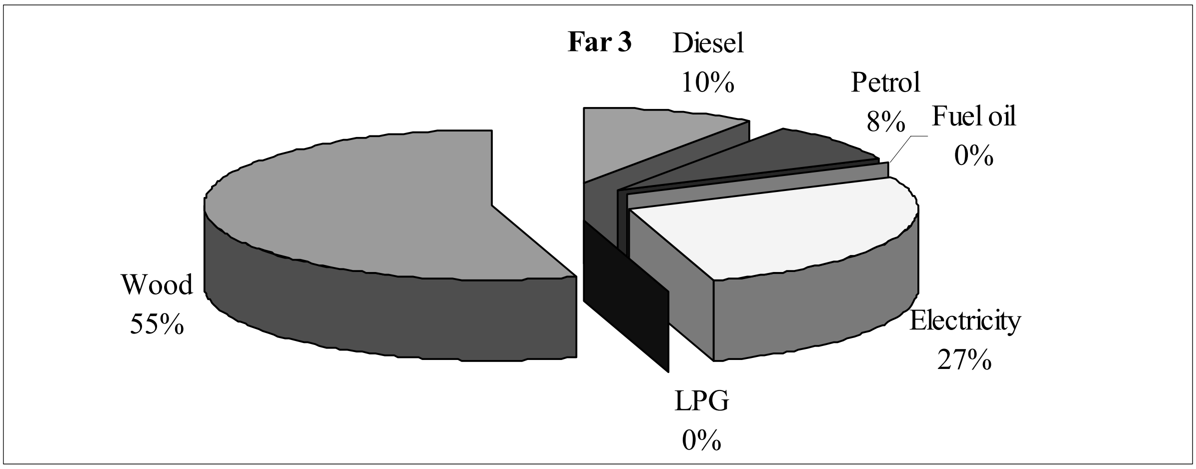


Figure 18: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 3

At Farm 4, figure 19, diesel was the most significant fuel and had the highest percent share contribution of 79% among all farms. Wood came in second, with only a 19% contribution, and electricity provided a mere 2%. Other fuel sources were reported not to be in use at this farm. At Farm 5, diesel was the highest contributor to the total delivered energy turnover at 57%; wood followed at 33% and electricity contributed 10% to the total delivered energy turnover.

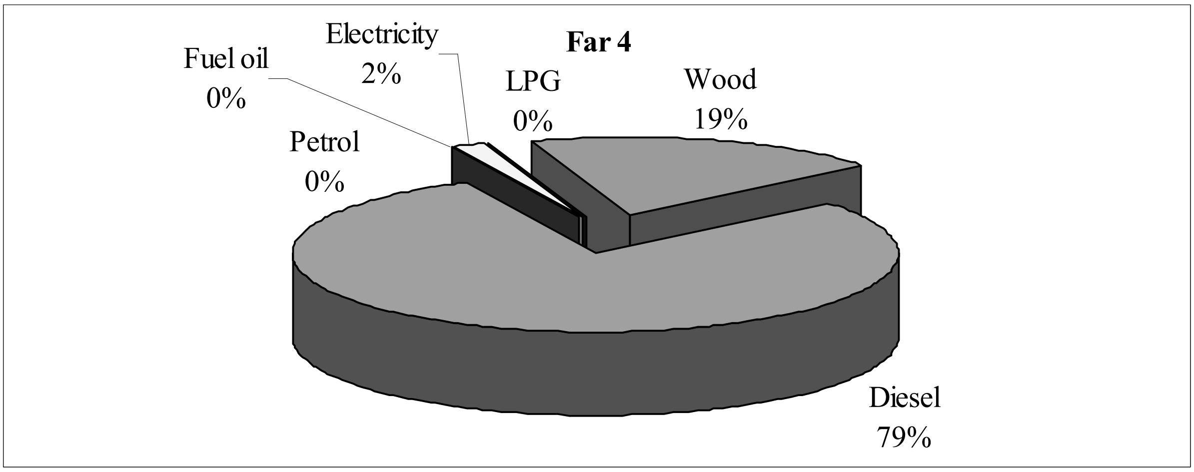


Figure 19: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 4

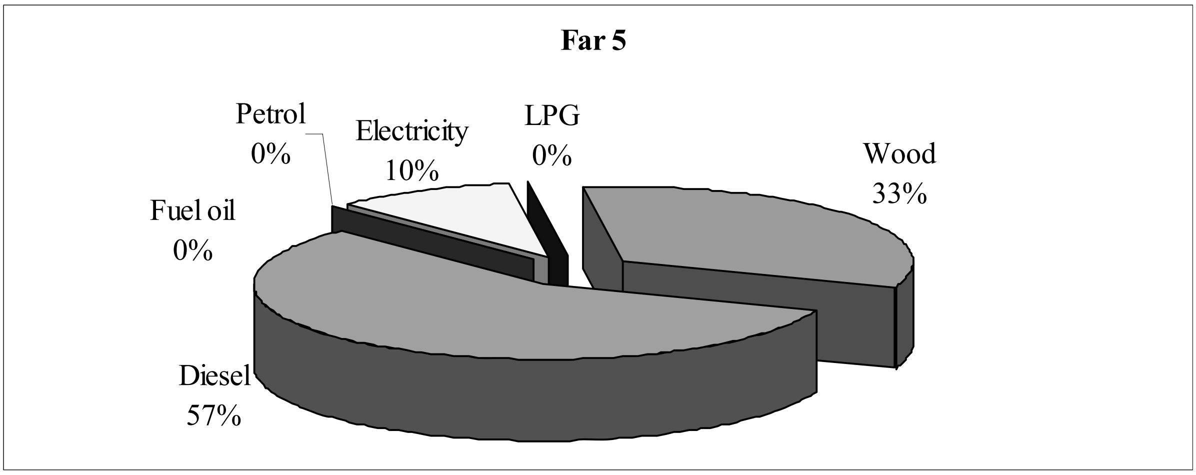


Figure 20: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 5

Farm 5, in figure 20, shows diesel contributed 57%, wood 33 %, and electricity 10% to the total delivered energy turnover. In figure 21 wood fuel is again seen to contribute the highest percent share of the total delivered energy turnover at Farm 6 with 64%. Second to wood was diesel at 15% and electricity at 14% .The least important energy source at this farm was petrol with 7%; no other form of delivered energy was reported to be utilised at this farm.

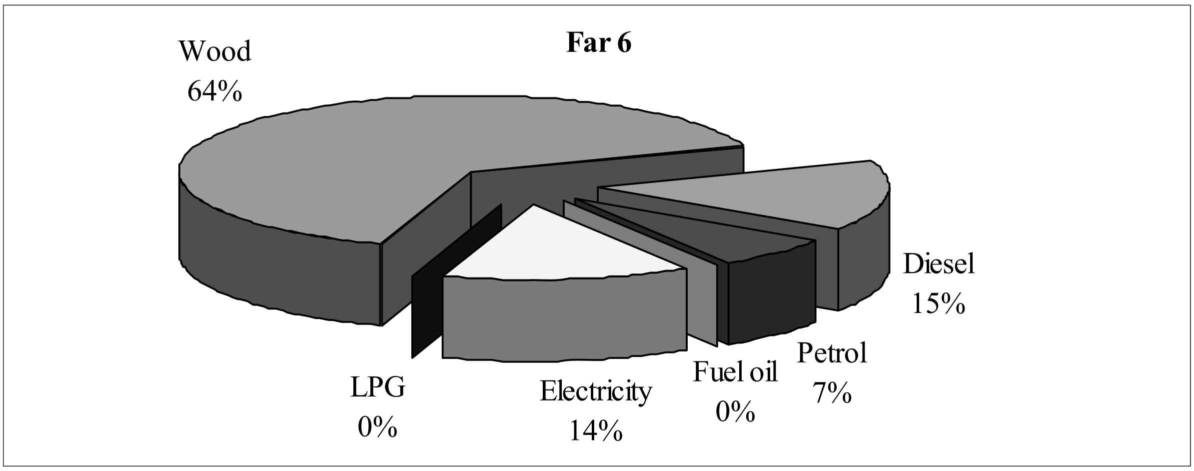


Figure 21: Pie chart showing the percent contribution of each fuel to total energy turnover at Farm 6

The results of specific delivered energy turnover ($W_{SDET\ (case)}$) in kWh/kg milk produced at the six (6) farms are given in table 7. Farm 6 required the least amount of energy: **0.8** kWh; while Farm 4 required the most energy: **4.3** kWh (5 times more energy) to produce 1 kg of milk for processing.

Table 7: Table showing total delivered and specific energy turnover and milk produced per year

Farm code	*m* *[kg/a]*	$W_{DE(case)}$ *[kWh/a]*	$W_{SDET(case)}$ *[kWh/kg]*
Farm 1	1 404 428	1 437 596	1.0236
Farm 2	1 600 500	3 938 636	2.4609
Farm 3	5 475	15 504	2.8318
Farm 4	10 080	44 229	4.3878
Farm 5	8 640	14 140	1.6366
Farm 6	14 400	12 027	0.8352

A scatter plot of the SDET values against farm sizes presented as the volumes of milk produced per year was prepared on a logarithmic scale and is hereby presented in figure 22.

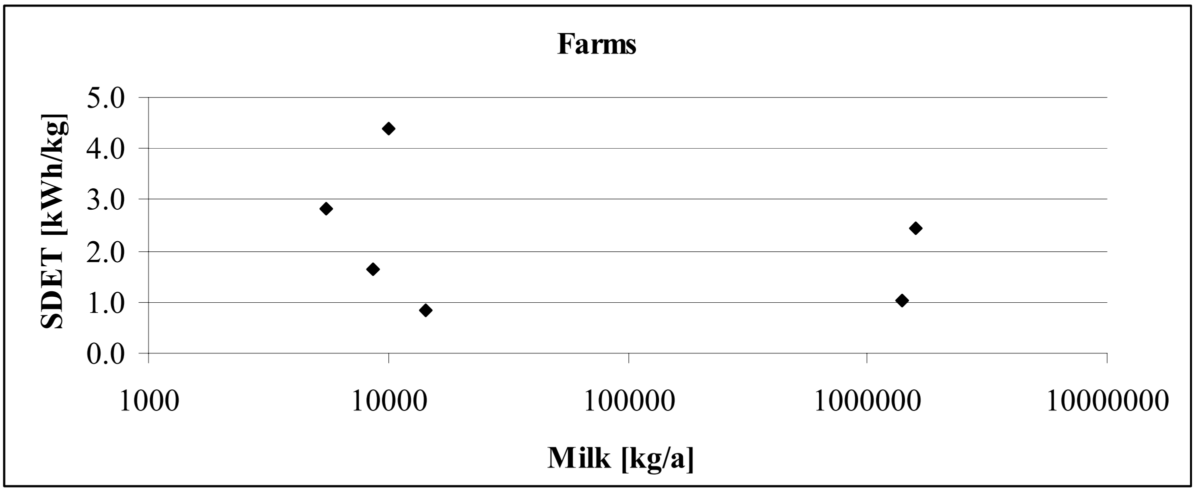


Figure 22: Scatter plot of SDET against milk produced by farms on a logarithmic scale

The surveyed farms clearly lie within two classes: those producing around 10 tonnes of milk per year and those producing (100 fold more) around 1000 tonnes per year. The $W_{SDET\ (case)}$ values lie between **0.5** and **4.5** kWh/kg milk.

4.1.2 Bulking / collection centres

Six bulking stations were surveyed: four belonged to the two (2) major milk processors in the country and are situated between 200 to 400 Km away from the processing plant. The bulking centres--also referred to as collection centres--always send their milk to the processing company that owns them, no matter how far they are situated from it. At the surveyed centres, milk was pooled, cooled and temporarily stored, awaiting collection and transportation to the processing plants. The centres surveyed collected between 250,000 and 20 million kg of milk per year.

In the stage of milk collection from farmers, some bulking stations owned vehicles that were usually sent to the farms to collect milk, and the cost was deducted from the farmers' milk returns. Other farmers choose to send their milk directly to the bulking station at their own expense. In the latter case, varied transport modes were employed: ranging from carriers carrying milk cans physically on the head, animals pulling carts, bicycles, to using motorcycles and small pick-up vehicles. Passenger vehicles were also sometimes utilised for this purpose. The results obtained from the energy survey of milk collection centres are presented in table 8.

Table 8: Table showing the energy sources used at surveyed milk bulking centres

Collection centre	***W* [kWh/a]**					
	Diesel	**Petrol**	**Electricity**	**Wood**	**Fuel oil**	**Total turnover**
col 1	544 926	0	120 000	0	50 365	715 290
col 2	1 097 040	0	233 346	255 000	0	1 585 386
col 3	2 549 959	0	2 160 000	612 000	0	5 321 959
col 4	5 235 812	0	420 000	0	0	5 655 812
col 5	14 5160	0	53 630	0	0	198 789
col 6	155 528	350 422	9 730	170 000	0	685 680

At this stage of this product chain, the most important energy sources of energy were found to be diesel and electricity. Wood also proved to be fairly popular depending on availability and seasonality. Petrol and fuel oil were found to be the least popular fuels at this stage. Col 4 used the most energy among all the surveyed bulking centres and used only diesel and electricity to power its activities: a practice also observed in Col 5, which utilised the least energy recorded at this stage. Col 6 was the only one of the surveyed centres that used petrol; while Col 1 was the only centre reported to utilise fuel oil to power its operations.

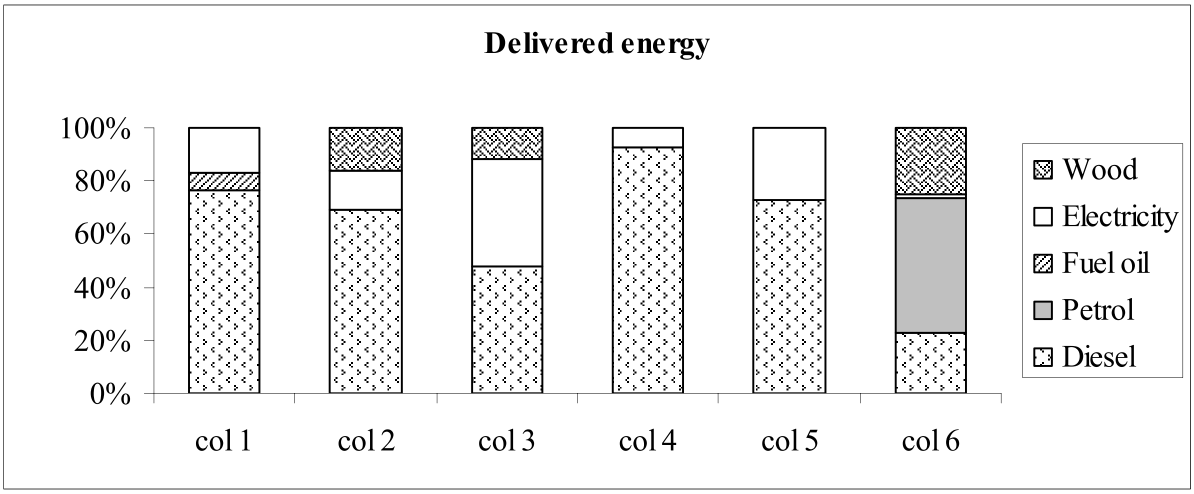


Figure 23: Chart showing the proportions of different energy sources at collection centres

Figures 24 to 29 show in detail the total energy turnover $W_{DE\ (case)}$ and the contribution of each fuel to the total energy at each surveyed collection centre.

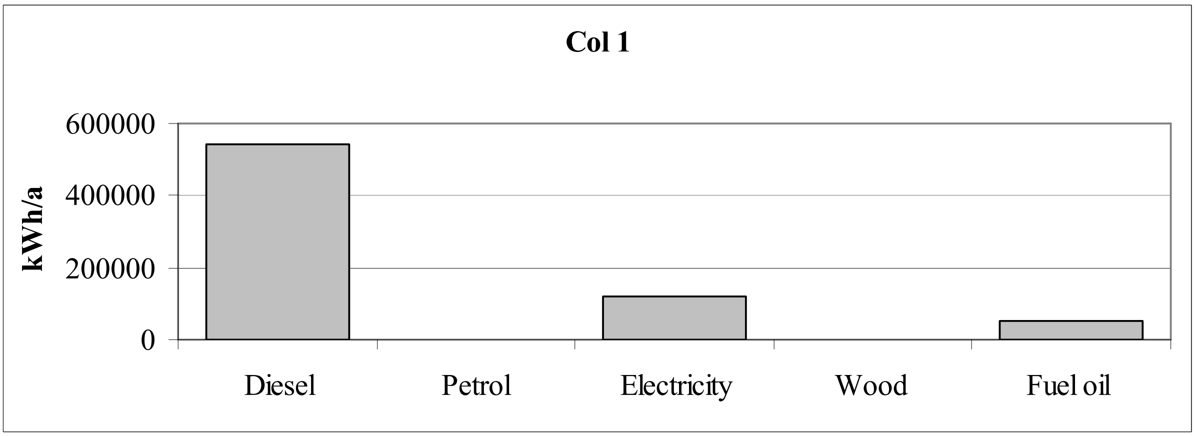


Figure 24: Graph showing energy turnover from different sources at Col 1 milk collection centre

Collection centre (Col) 1 is situated some 250 kilometres from the processing plant where it delivered milk for processing and packaging. It did not own any vehicle for collecting milk from farmers, meaning the milk was delivered at the cost of the farmers by using many different means of transport. Milk was collected every other day from this centre for processing. Electric coolers were used to cool the milk and to store it at chilled temperatures until it was collected for transportation to the processing plant.

As shown in figure 24, diesel was the most important energy source, contributing over 70% of the $\boldsymbol{W_{DE(case)}}$ at Col 1; electricity followed by contributing slightly above 15% and finally fuel oil. Col 1 was the only collection centre that utilised fuel oil for steam production; this centre utilised no other energy source. Col 2, shown in figure 25, shows diesel was also here the most important energy source, accounting for 70% of total delivered energy turnover; electricity and wood contributed almost 15% each. Petrol and fuel oil were reported not to be in use at this station.

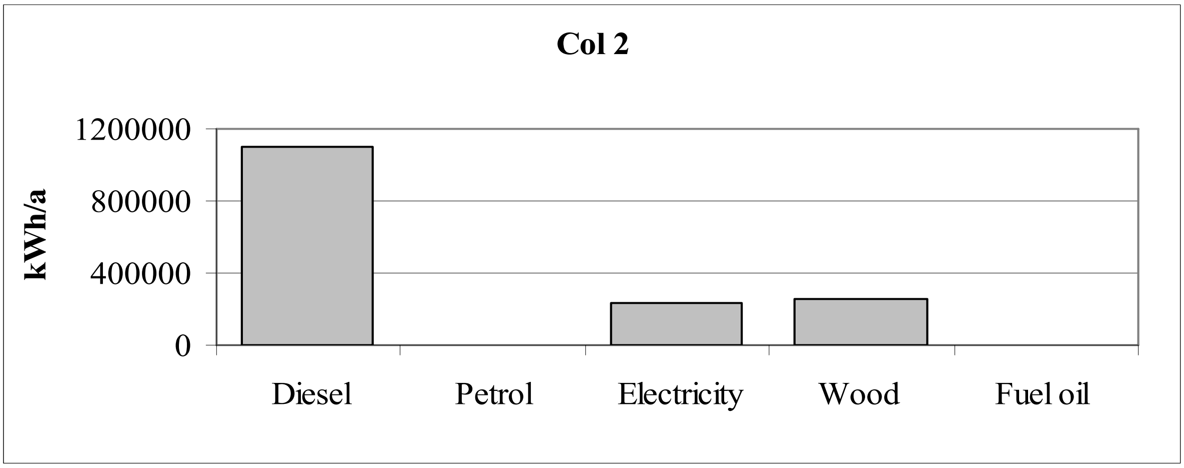


Figure 25: Graph showing energy turnover from different sources at Col 2 milk collection centre

Col 2 is situated about 200 kilometres from the processing plant. The centre hired about eight (8) vehicles, with carrying capacities ranging from 5 to 10 tonnes, to daily collect milk from farmers. Most of the diesel used here was for this purpose. Some farmers in this case also supplied their milk using their own transport means. Milk was collected daily for processing. Electricity was used to run the plant and for cooling milk during the short periods of storage. Wood fuel was utilised at the centre because it was situated in a woody area.

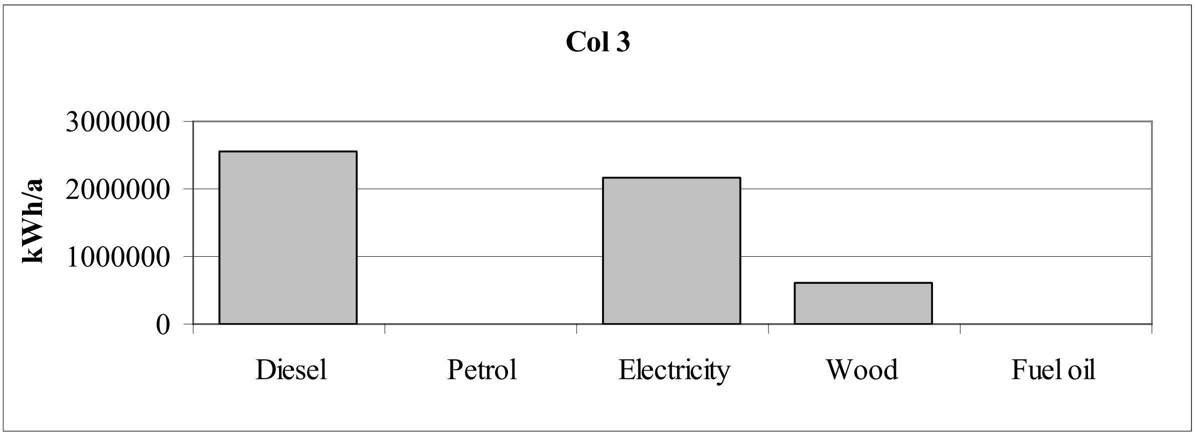


Figure 26: Graph showing energy turnover from different sources at Col 3 milk collection centre

Col 3 was the largest collection centre among those surveyed, although it utilised less energy than Col 4, which was smaller. Col 3 also collected most of its milk from the farmers. In this case as well, milk was collected daily for processing, and the use of wood as a fuel was moderate. The processing plant is situated some 400 kilometres away from this centre. Out of the reported total delivered energy turnover at Col 3, diesel was still leading in its contribution, being the largest share slightly before 50%; however, electricity followed closely with around 40%. The remaining energy was contributed by burning firewood.

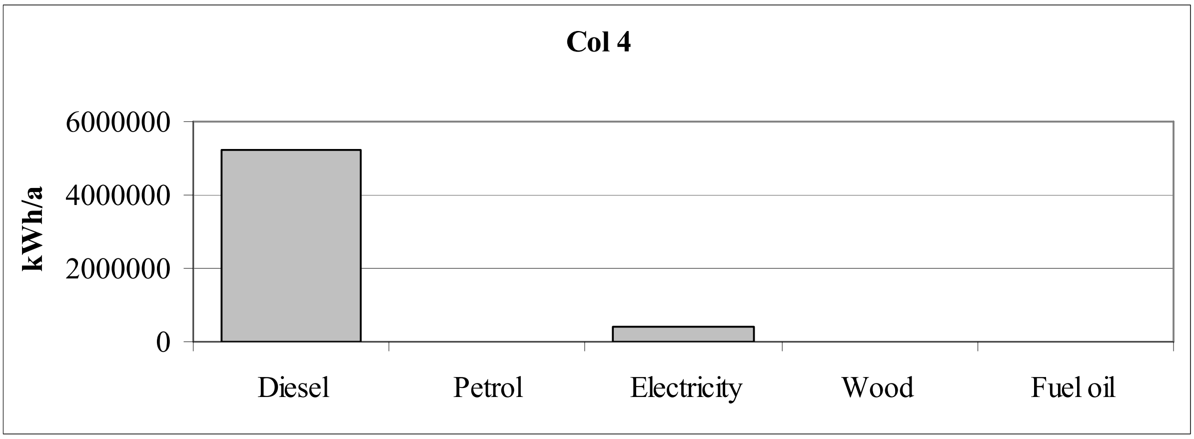


Figure 27: Graph showing energy turnover from different sources at Col 4 milk collection centre

Col 4 stands some 160 kilometres away from the processing plant. This centre was fairly large in size and hired a number of medium-sized trucks to collect most of the milk from farmers. No wood fuel was utilised at this centre. Diesel dominated among the forms of delivered energy used at this centre by contributing over 90% of this station's energy needs. Electricity provided the remainder of energy requirements at Col 4.

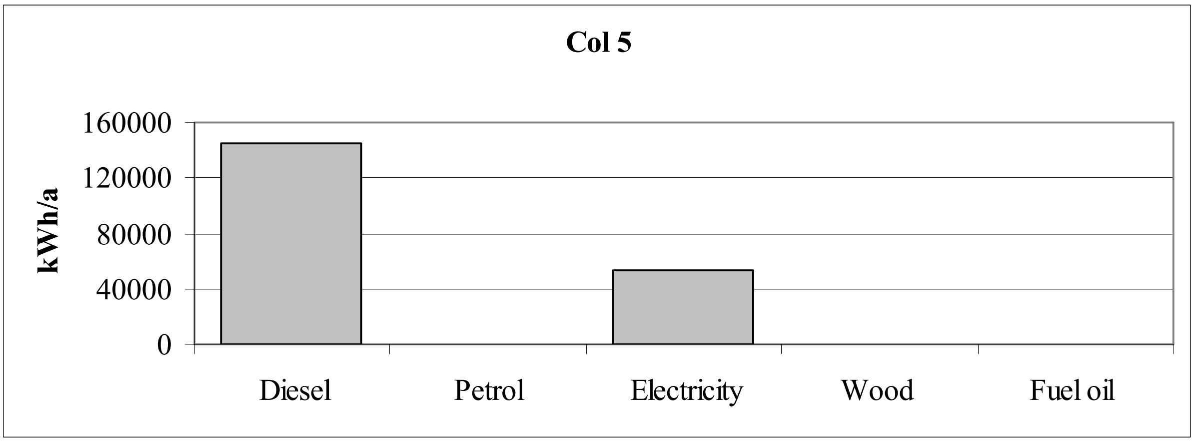


Figure 28: Graph showing energy turnover from different sources at Col 5 milk collection centre

Col 5 was a small collection centre situated in the suburbs of a large city and is about 50 kilometres from the processing plant. Again, diesel provided more than 70% of its energy needs, and electricity provided the remainder of its energy requirements. No wood fuel was utilised and no vehicles were sent out to collect milk from farmers. Most of the diesel was used for cooling milk and for running a stand-by generator to supply electricity in case of power blackouts.

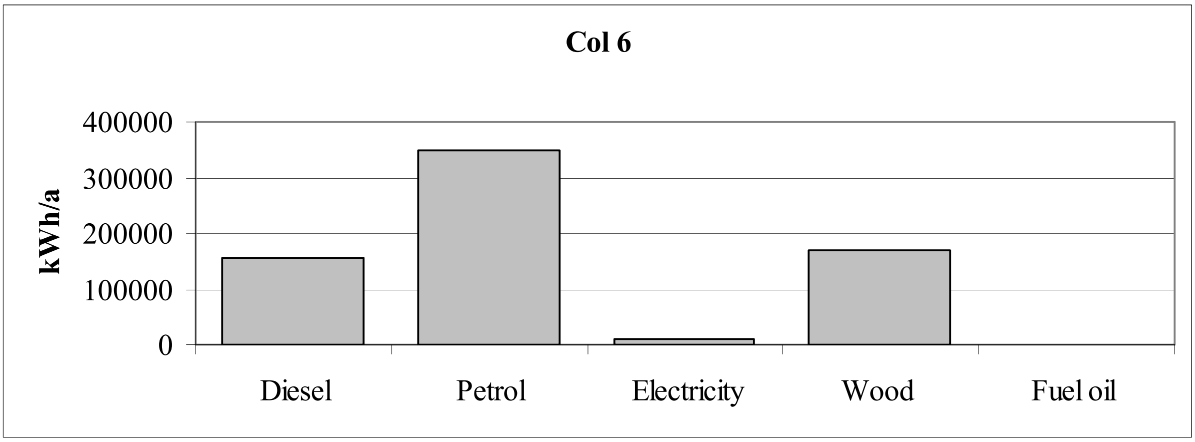


Figure 29: Graph showing energy turnovers from different sources at Col 6 collection centre

Collection centre, Col 6 presents an interesting trend where petrol was the most utilised fuel. The station only collected milk supplied by farmers using different means of transport. The centre was owned by a small co-operative or small-scale farmer’s self-help group and usually sent its milk to different processing companies depending on the price offered for their milk. Petrol was mainly used for transporting milk for processing and for running small vehicles used for administrative purposes; hence a lot of the petrol used accounted for about 50% of the total energy requirements. Diesel was used for cooling milk and running a stand-by generator and accounted for only around 20% of the station’s energy needs. The centre drew 25% of its energy needs from firewood; electricity claimed a very small share.

Table 9: Table showing the total and specific delivered energy turnover for collection centres

Centre code	***m***	$W_{DE(case)}$	$W_{SDET(case)}$
	[kg/a]	[kWh/a]	[kWh/kg]
Col 1	2 190 000	715 290	0.3266
Col 2	20 415 088	1 585 386	0.0777
Col 3	14 400 000	5 321 959	0.3696
Col 4	16 790 000	5 655 812	0.3369
Col 5	270 000	198 789	0.7363
Col 6	648 000	685 680	1.0581

The $W_{DE\ (case)}$ and $W_{SDET\ (case)}$ for the collection centres is shown in table 9. A closer look at the $W_{SDET\ (case)}$ values revealed that Col 6 presented the highest and Col 2 presented the smallest. The bulking stations required between **0.78** kWh to **1.06** kWh to collect 1 kg of milk and dispatch it for processing

Figure 30 shows the scatter plots of the SDET values plotted against the size of the centres in terms of volumes of milk collected per year on a logarithmic scale. Two clusters of collection centres emerged from the scatter plot: those collecting milk below 5000 tonnes and those collecting milk around 15000 and 20000 tonnes per year.

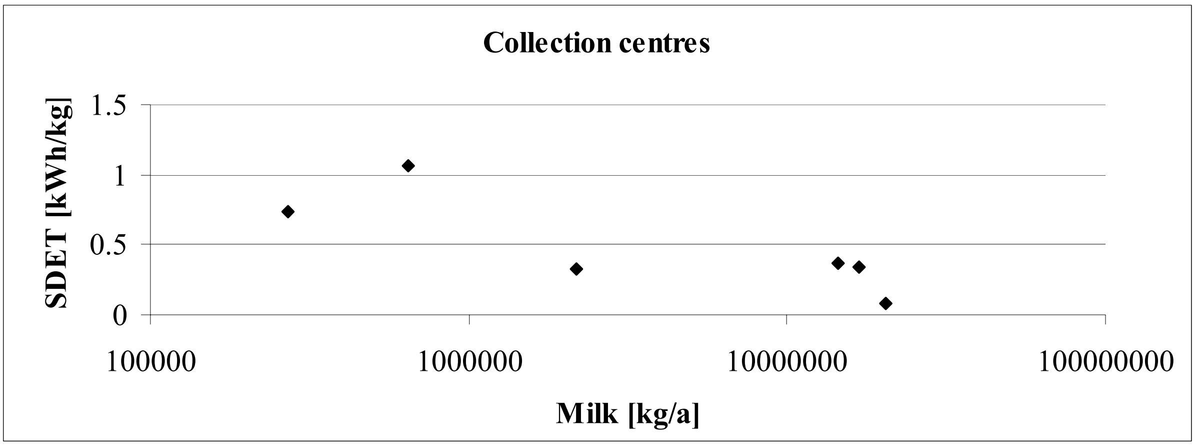


Figure 30: Scatter plot of WSDET(case) against milk collected at collection centres on a logarithmic scale

4.1.3 Processing plants

All the eight (8) processing plants surveyed collected certain portions of their milk directly from farmers. All the small companies collected a hundred percent (100%) of their milk for processing directly from farmers. Some of the milk from independent collection centres was collected by company-owned specialised milk tankers and transported to the factory for processing, while other collection centres chose to transport it to the factory at their own cost. The larger companies owned bulking centres from which they received large volumes of milk for processing, in addition to the milk directly collected from farmers.

Most processing plants undertook most of the procedures illustrated in figure 31; although the surveyed milk processors produced a wide range of products, including yoghurt and long-life milk in many flavours. Fresh milk was still the predominant product. Most plants produced well over 50% of their products as fresh milk. This milk was usually standardised, pasteurised, homogenised and packaged in tetra-pak paperboard laminate packages of different sizes. All the factories had varying total energy turnovers, as their sizes greatly varied judged by the mass of milk handled in one year ($\boldsymbol{m}$) in kg.

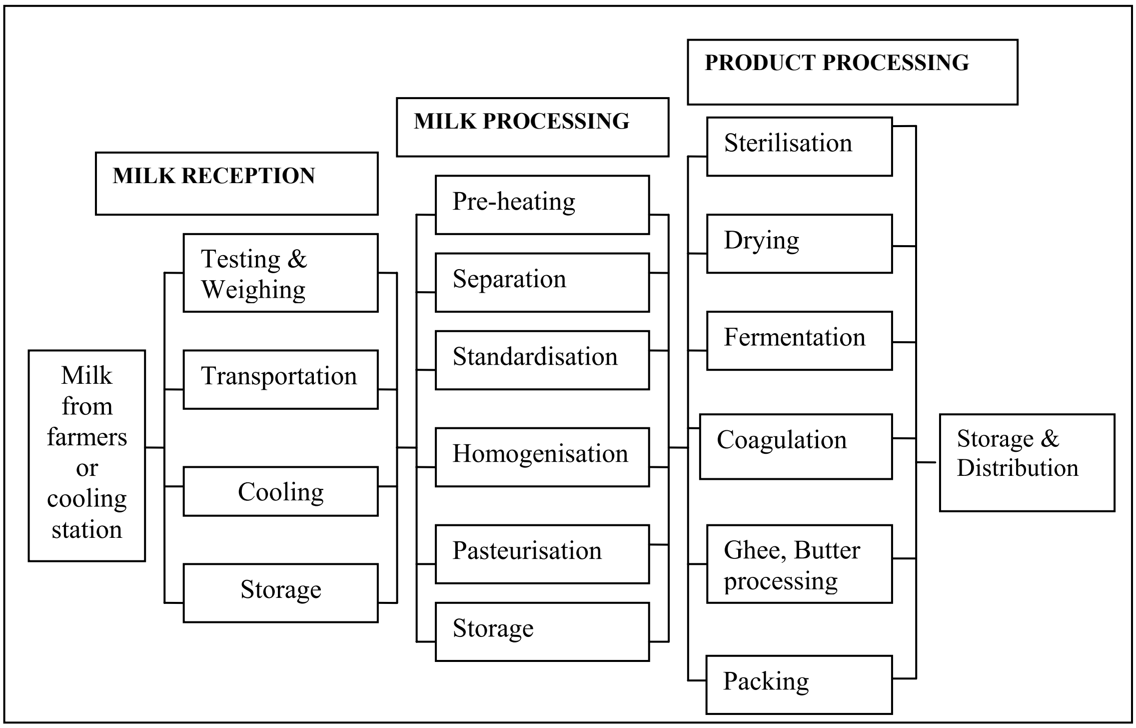


Figure 31: A description of typical milk processing plant operations

Processing plant (Pro) 9 had the highest energy demand of above 3 terawatts per year; while Pro 5 had the lowest energy demand of about a half of that required by Pro 9. Diesel and electricity were the two energy sources utilised by all the surveyed processing plants. Only two plants utilised LPG as a fuel, while only one processing plant made use of firewood to satisfy some of its energy needs. At this stage of this milk process chain, fuel oil proved to be an important form of delivered energy being used by at least six of the surveyed plants. This represented 75% of all the surveyed milk processing plants: popularity was not observed at the other stages.

Table 10: Table showing the energy sources used at surveyed milk processing plants

Energy source	$W_{DE(case)}$ **[kWh/a]**							
	Pro1	**Pro 2**	**Pro 3**	**Pro 4**	**Pro 5**	**Pro 6**	**Pro 8**	**Pro 9**
Diesel	**3163522**	**830414**	**1856772**	**526099**	**504927**	**1362097**	**12971292**	**25914947**
Petrol	**0**	**124876**	**0**	**2304**	**0**	**0**	**9**	**696838**
Fuel oil	**0**	**1352290**	**1133204**	**94437**	**0**	**6917074**	**10**	**6629083**
Electricity	**429037**	**29190**	**594000**	**100800**	**1171200**	**635363**	**2654034**	**3436920**
LPG	**6224**	**0**	**0**	**0**	**0**	**0**	**0**	**17038**
Wood	**0**	**0**	**0**	**6426000**	**0**	**0**	**0**	**0**
Total	**3598783**	**2336769**	**3583975**	**7149640**	**1676127**	**8914533**	**15625345**	**36694827**

The inventoried energy sources used by each factory for their day-to-day activities are presented in terms of proportion used in relation to the total energy turnover of the processing plants in figure 32.

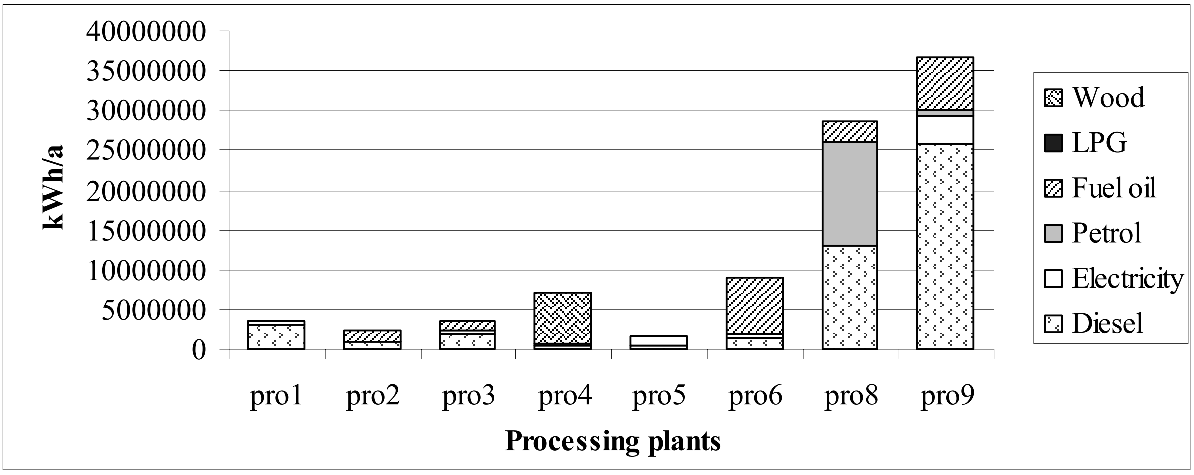


Figure 32: Graph showing the total delivered energy turnovers from different fuels at surveyed processing plants

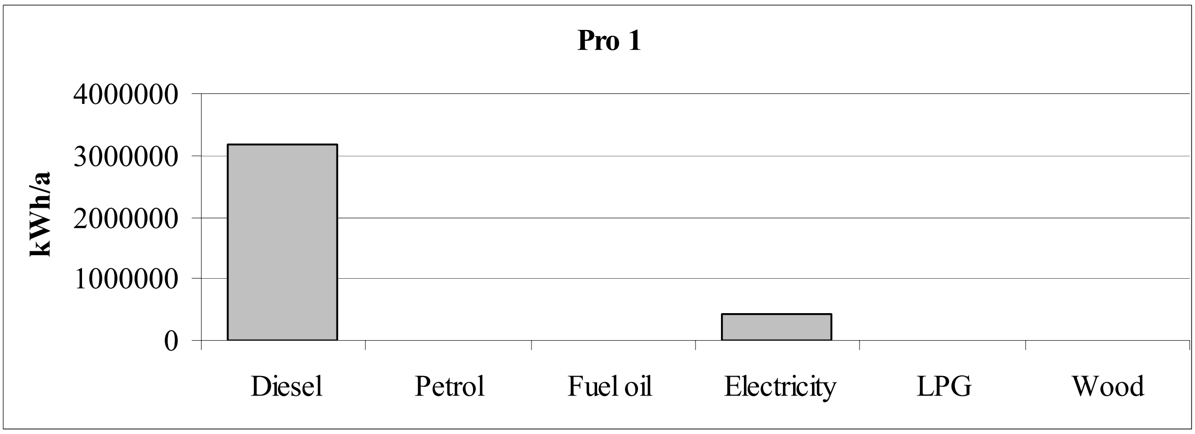


Figure 33: Graph showing energy turnovers from different sources at Pro 1 processing plant

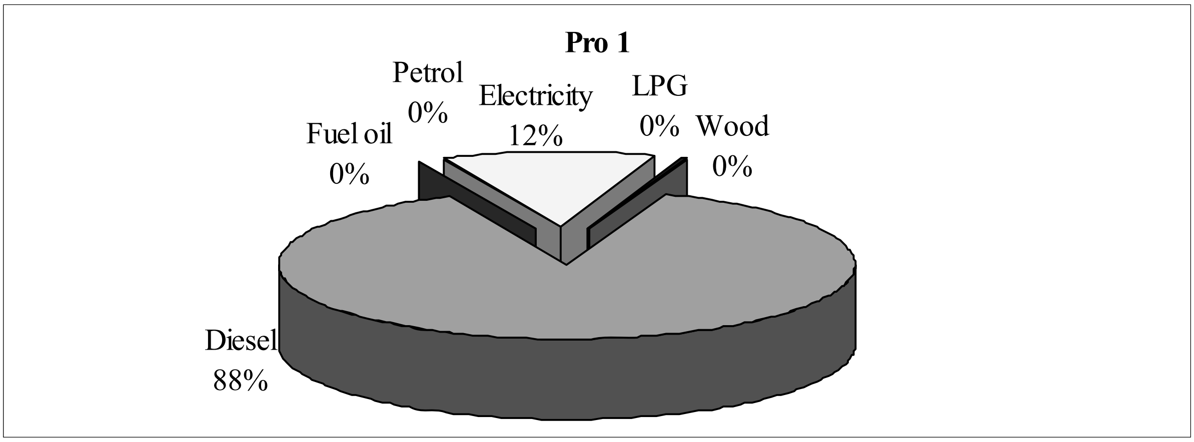


Figure 34: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 1

At Pro 1, diesel was the predominant form of delivered energy, contributing 88% to the total energy turnover. Wood, petrol and fuel oil were not in use at this plant, and electricity was a significant energy source.

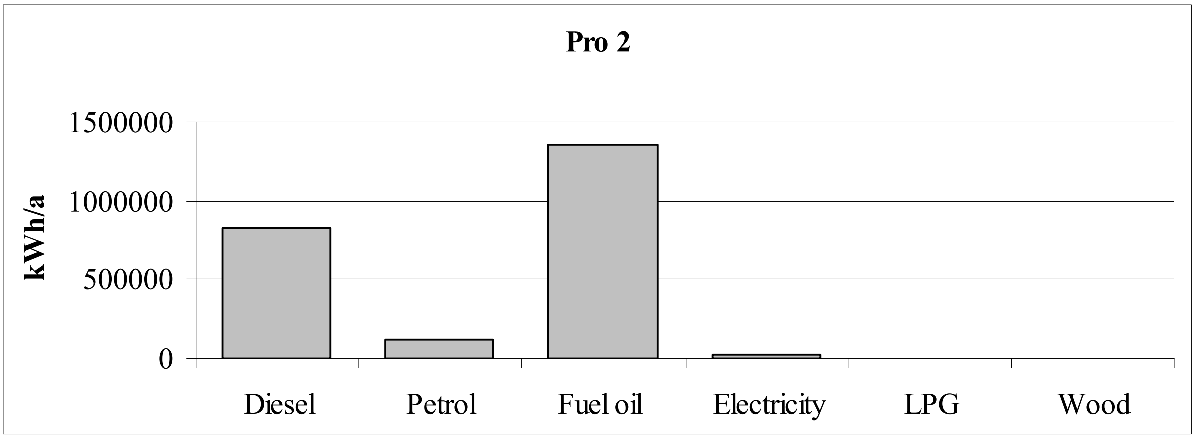


Figure 35: Graph showing energy turnovers from different sources at Pro 2 processing plant

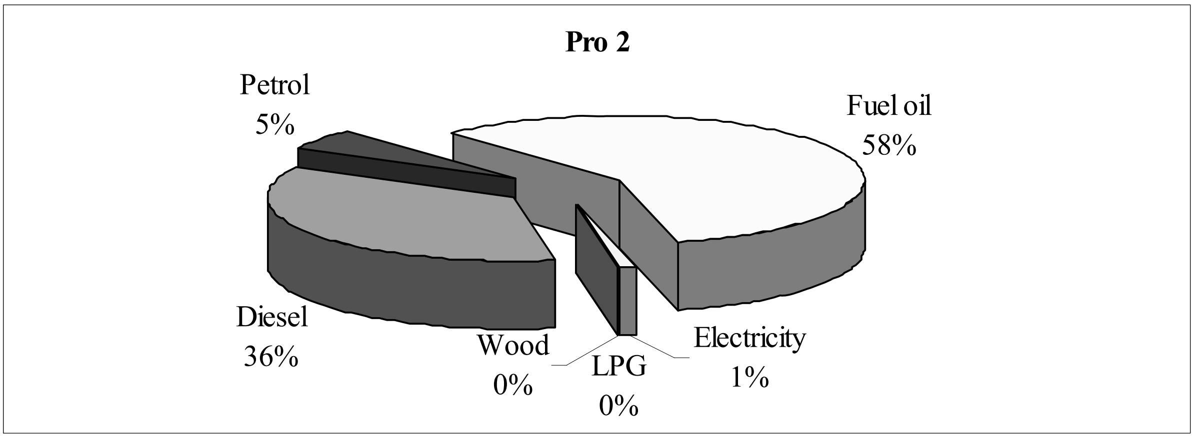


Figure 36: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 2

At Pro 2, the case was different, with fuel oil being the predominant fuel supplying 58% of the total energy turnover. Although diesel was still very important: contributing 36% and petrol 5%; electricity was not very significant here, contributing only 1%.

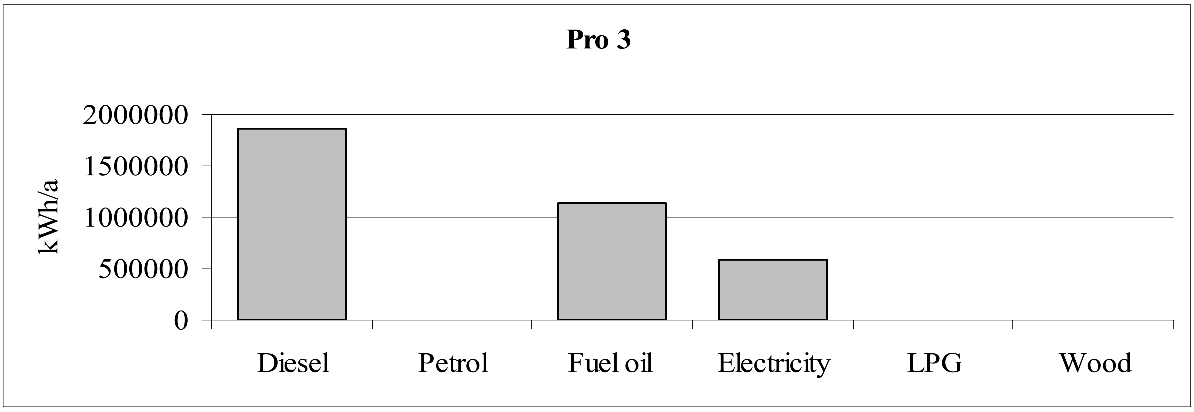


Figure 37: Graph showing energy turnovers from different sources at Pro 3 processing plant

At Pro 3, fuel oil emerged as an important form of delivered energy as it supplied 32% to the total turnover and was only second to diesel that contributed 51%. Electricity was, in this case, more important as it provided 17% to the total turnover. Figures 37 and 38 illustrate these findings.

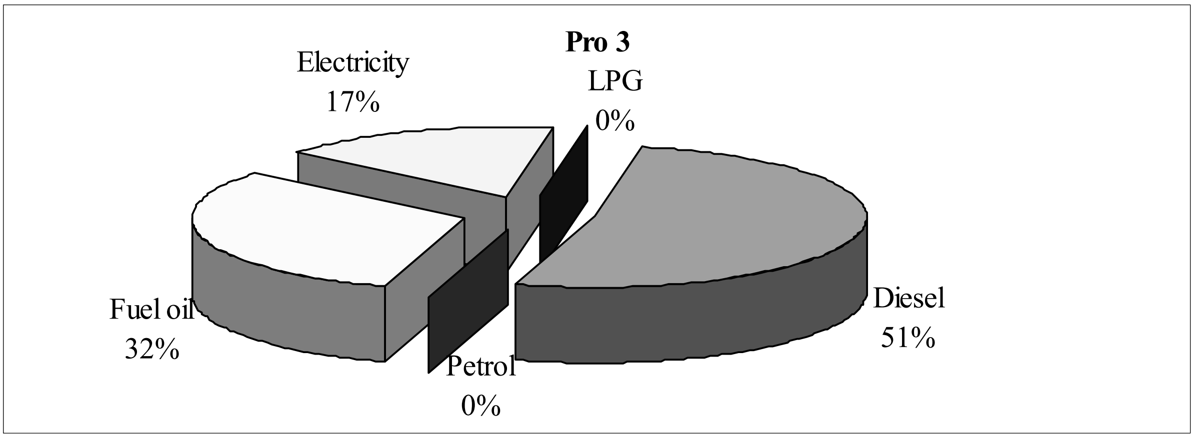


Figure 38: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 3

In the case of Pro 4, a completely different fuel supplied the largest share of the total delivered energy; wood contributed a good 91% to the total energy turnover. Far behind, was diesel that contributed a humble 7%. Fuel oil and electricity were not very significant energy sources here, contributing a mere 1% each. Petrol was used only to a minimal extent, while LPG was not in use at this processing plant, as seen in figures 39 and 40.

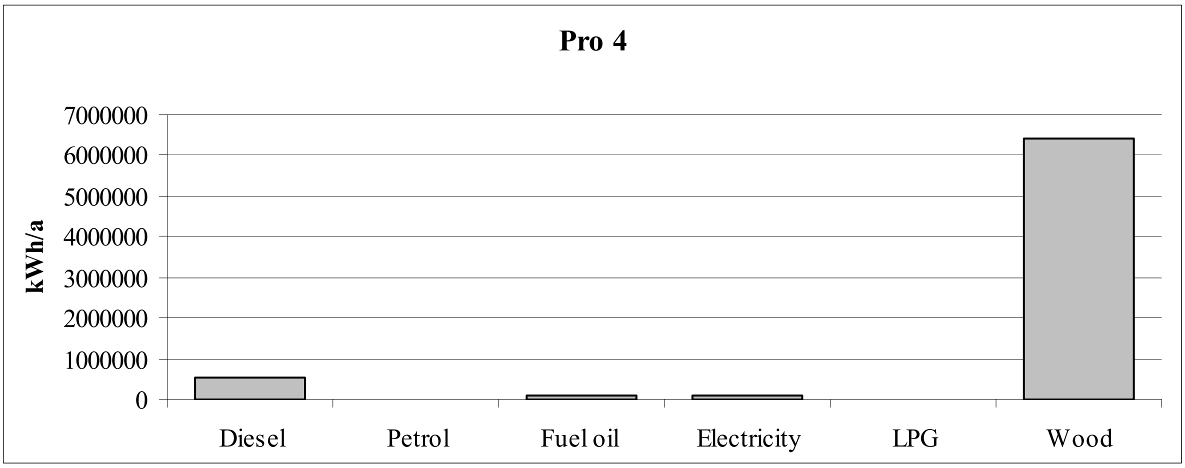


Figure 39: Graph showing energy turnovers from different sources at Pro 4 processing plant

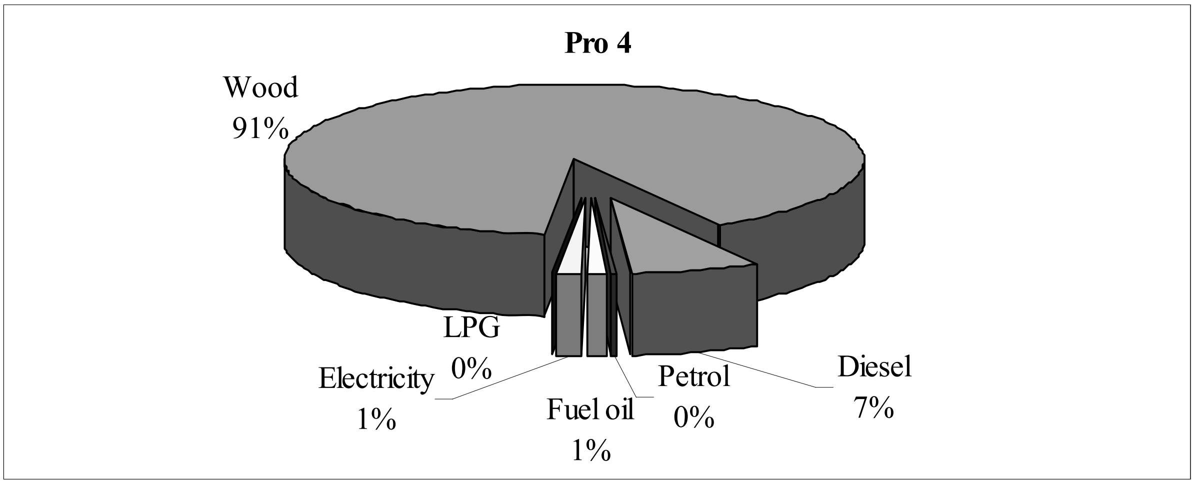


Figure 40: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 4

Pro 5 marked the first instance among the studied cases that electricity was the most important energy source, supplying 70% of the total energy turnover. Diesel was the only other delivered energy form in use here, contributing 30%; the other fuel sources were not in use at this factory, as clearly shown in figures 41 and 42.

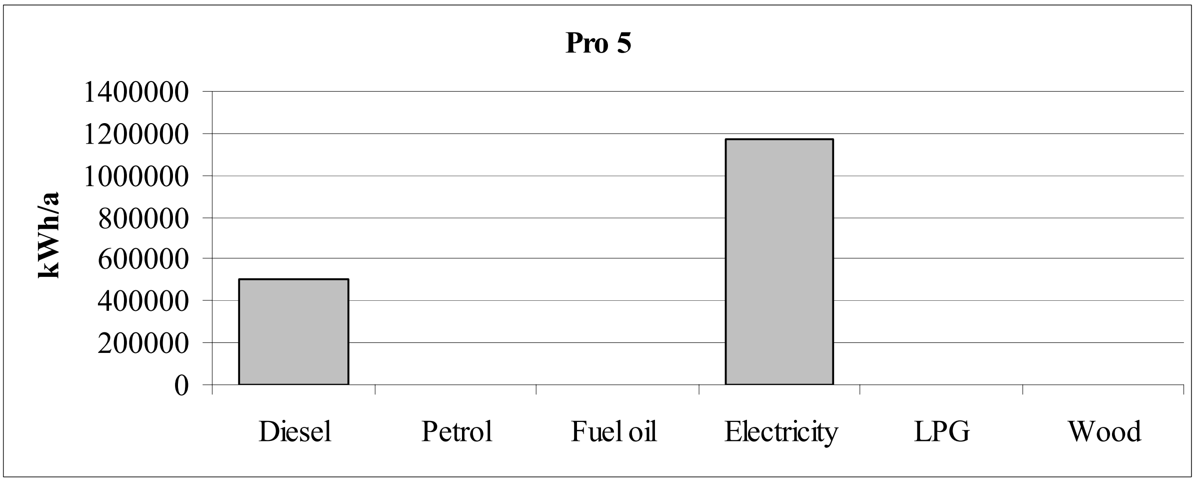


Figure 41: Graph showing energy turnovers from different sources at Pro 5 processing plant

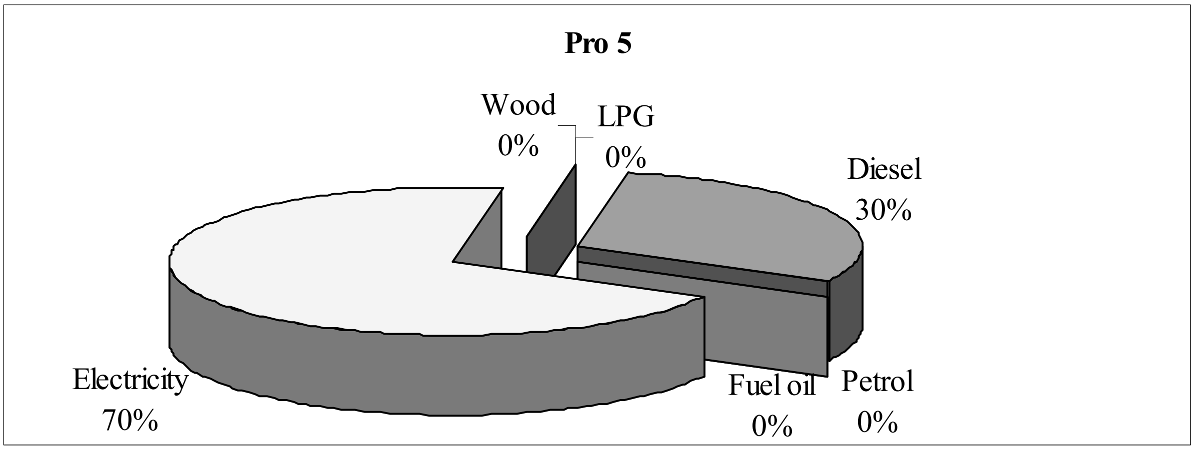


Figure 42: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 5

At Pro 6, as was the case in Pro2, fuel oil led the other forms of delivered energy as it contributed the most to the total energy turnover: 78%. It was followed by diesel at 15%, and then electricity at 7%.

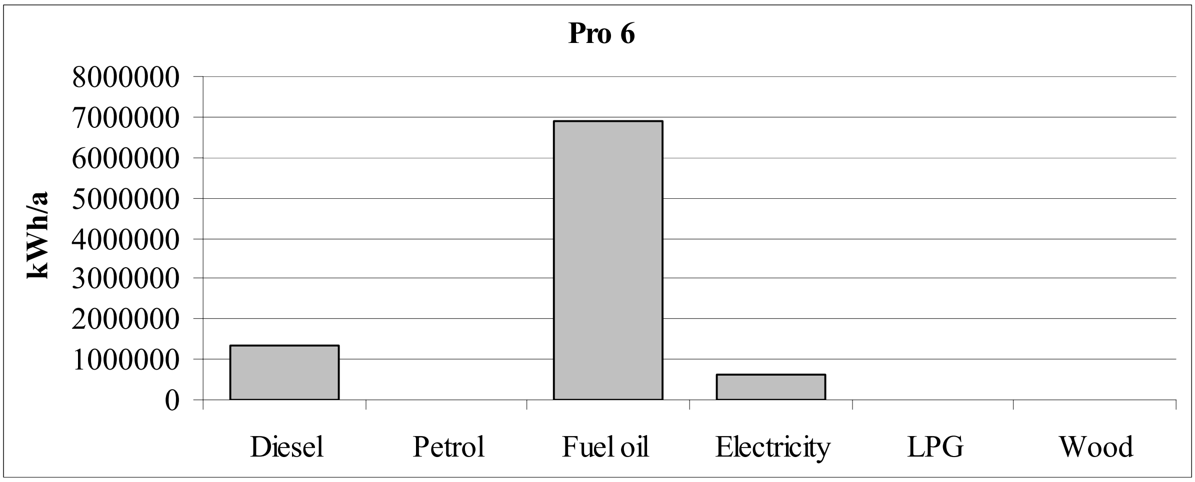


Figure 43: Graph showing energy turnovers from different sources at Pro 6 processing plant

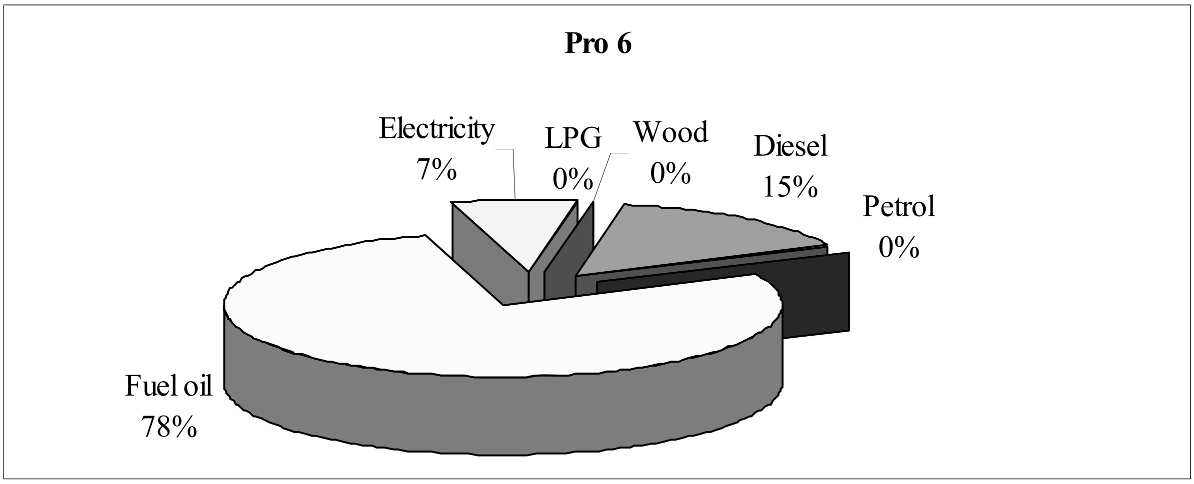


Figure 44: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 6

In addition, the case of Pro 6 was the only one where fuel oil supplied such a large percentage of the total delivered energy turnover among all the surveyed plants. It was 66 percent ahead of the second most important energy source, as shown in figures 40 and 41.

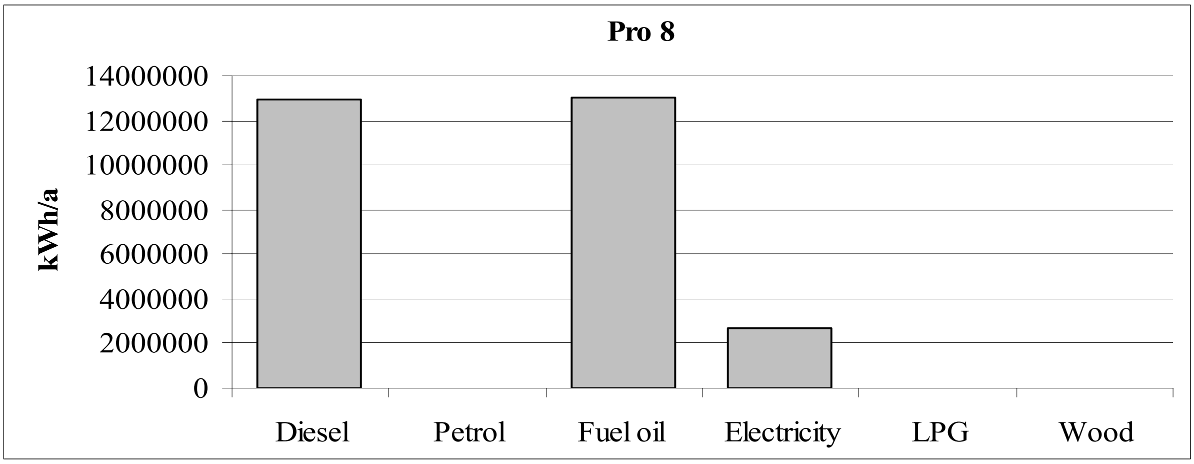


Figure 45: Graph showing energy turnovers from different sources at Pro 8 processing plant

Pro 8 gave a completely new picture where diesel and fuel oil were used in almost equal amounts; each contributing 46% and 45% respectively to the total energy turnover. Electricity contributed only 9%, while wood and LPG were completely unused in this milk processing plant. Figures 44 and 45 clearly illustrate these findings.

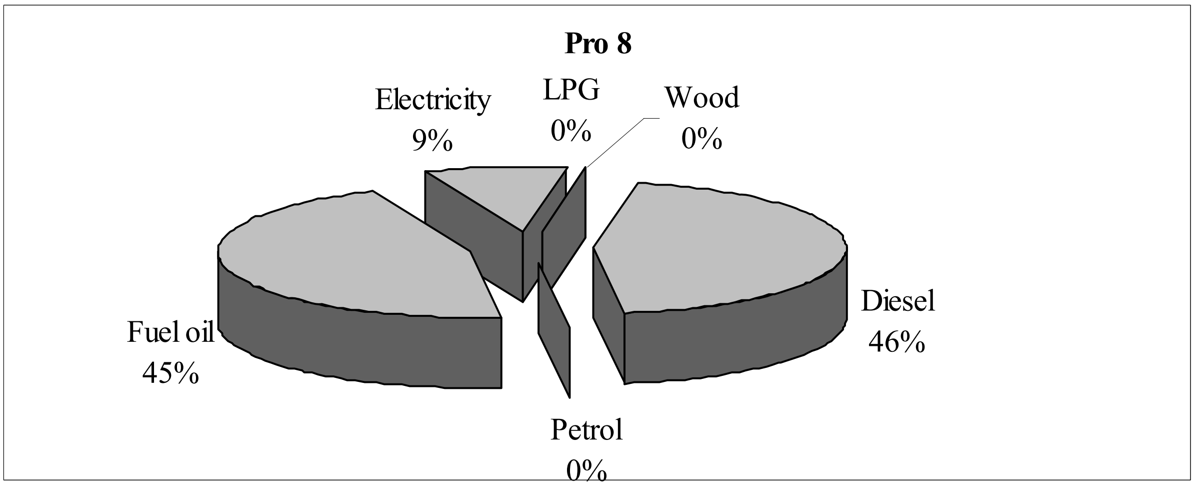


Figure 46: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 8

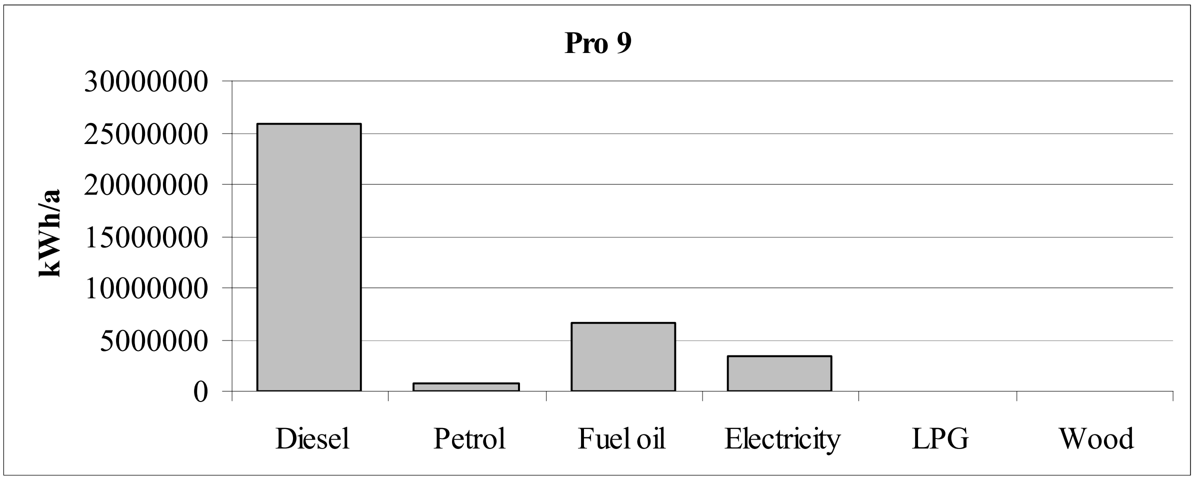


Figure 47: Graph showing energy turnovers from different sources at Pro 9 processing plant

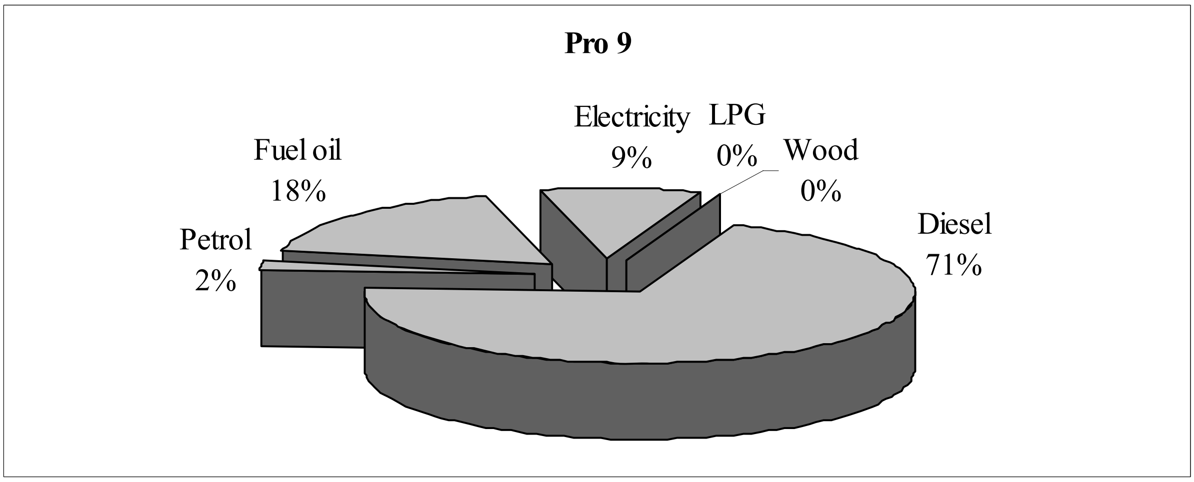


Figure 48: Pie chart showing percent contribution of each fuel to total energy turnover at Pro 9

At Pro 9, diesel was again the most important fuel, contributing 71% to the total energy turnover, as fuel oil trailed as the second most important energy source, contributing 18%. Electricity contributed 9%, while LPG contributed a humble 2% to the total energy turnover. Wood was not in use at this milk processing plant.

Table 11: Table showing the total and specific delivered energy turnover for processing plants

Factory code	*m*	$W_{DE(case)}$	$W_{SDET\ (case)}$
	[kg/a]	[kWh/a]	[kWh/kg]
Pro 1	7 200 000	3 598 783	0.4998
Pro 2	6 480 000	2 336 769	0.3606
Pro 3	9 900 000	3 583 975	0.3620
Pro 4	1 788 500	7 149 640	3.9976
Pro 5	360 000	1 676 127	4.6559
Pro 6	19 971 024	8 914 533	0.4464
Pro 8	47 615 936	15 625 345	0.3282
Pro 9	88 745 508	36 694 827	0.4135

Pro 9 consumed the most energy and also processed the largest mass milk per year, making it the largest plant included in this survey: it had a specific delivered energy turnover of **0.4135** kWh/kg milk. Pro 5 processed the least milk per year and also consumed the least energy: it had a SDET of **4.6559** kWh/kg milk, more than 10-fold higher energy requirement to process 1 kg of milk than at Pro 9.

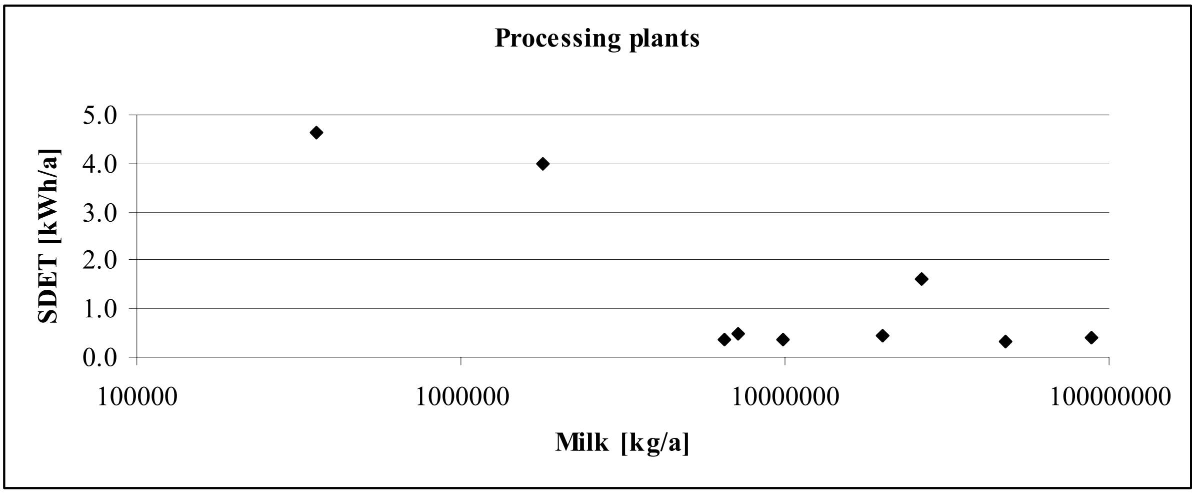


Figure 49: Scatter plot of SDET against milk processed at processing plants on a logarithmic scale

On the scatter plot, most processing plants are seen to lie close to each other within the $W_{SDET\ (case)}$ range of 0.5 kWh/ kg: the sizes of the most processing plants lie between 10 million and 100,000 tonnes per year. Only two plants fall within the range of processing around 1,000 tonnes of milk per year.

4.1.4 Distribution

After being processed and packaged, the milk at the processing plant could take any of three routes. It could either be sent directly to the retailer or directly to wholesalers who would then distribute the milk countrywide. The milk could also be transported to company depots all over the country. As shown in the illustration on figure 13 on page 51, the distribution routes taken from processing to the point-of-sale are quite complicated and require a more specific and detailed survey beyond the scope of this study. The word “distribution” is used here to incorporate all the possible routes the milk would take from the various surveyed factories to the point-of-retailing as one stage. The total energy turnover and amount of milk distributed are shown in table 12.

Table 12: Table showing the total and specific delivered energy turnovers of distribution centres

Distribution centre	***m***	***$W_{DE(case)}$***	***$W_{SDET(case)}$***
	[kg/a]	[kWh/a]	[kWh/kg]
D1	7 200 000	1 415 307	0.19657
D2	6 480 000	2 177 396	0.33602
D3	9 900 000	1 633 047	0.16495
D4	1 788 500	508 059	0.28407
D5	360 000	279 433	0.77620
D6	19 971 024	762 089	0.03816
D8	47 615 936	8 509 989	0.17872
D9	88 745 508	2 620 615	0.02953

In the stage of packaged milk distribution, only diesel was utilised as a fuel to run the light and heavy trucks carrying the milk to different parts of the country. (The milk distribution centre) D5 was the smallest distribution centre, distributing less than 500 000 kgs of milk per year; it also utilised the least energy for this activity but had the largest ***$W_{SDET\ (case)}$*** of **0.7762** kWh/kg milk. Although D9 distributed the most milk, it utilised four times less energy for this task than D8. As a result, D9 was the most energy-efficient distribution centre with a ***$W_{SDET\ (case)}$*** of **0.0295** kWh/kg milk. This means that **26 fold** more energy was needed to distribute 1 kg of milk at D5 than at D9. D5 stood out as a very energy-inefficient centre, meaning it had high energy requirements.

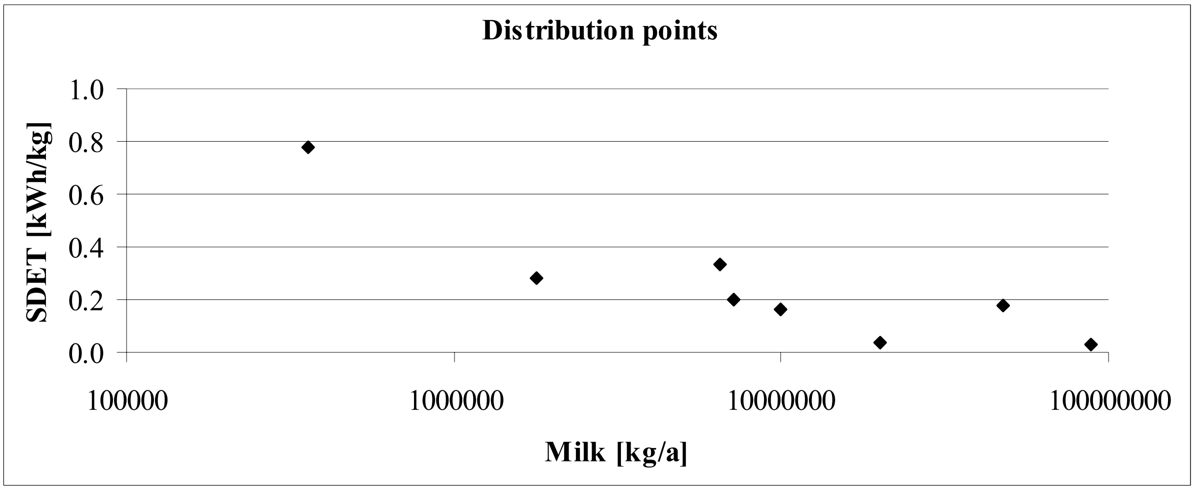


Figure 50: A scatter plot $W_{SDET\ (case)}$ against milk distributed on a logarithmic scale

Figure 51, provides a picture of how the ***$W_{DE\ (case)}$*** [kWh/a] relates with the total mass ***m*** [kg/a] of milk distributed at each of the surveyed collection points. Interestingly, larger differences are observed between the milk distributed and the total energy turnover for larger distribution centres as for smaller ones. Smaller distribution points utilised a lot more energy to distribute smaller volumes of milk as compared to their larger counterparts.

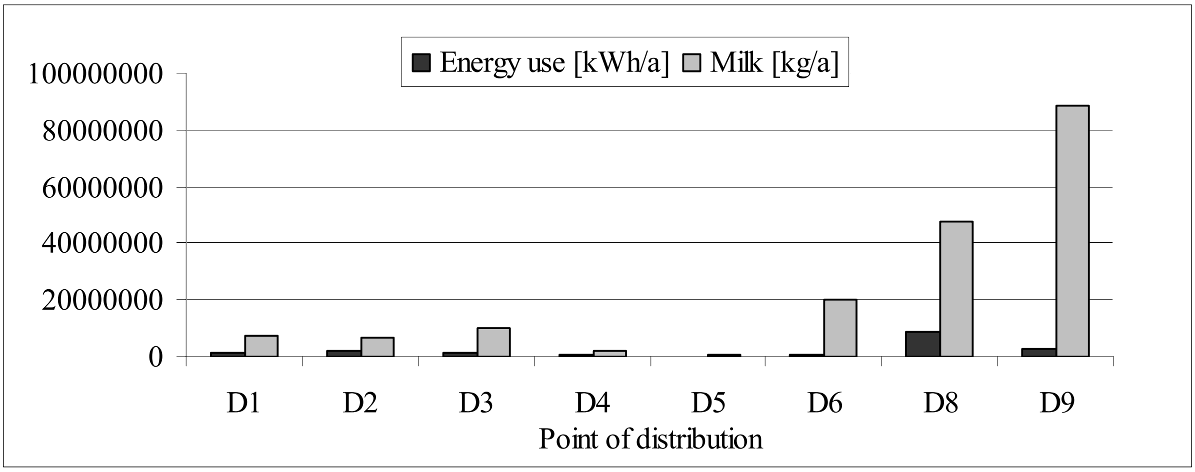


Figure 51: Figure illustrating the total energy turnover and mass of milk distributed in surveyed distribution points

4.2 Primary Energy Turnover ($W_{(PE)}$) and Specific Primary Energy Turnover ($W_{(SPET)}$)

Similar to the delivered energy results, the results obtained as primary energy turnover and specific primary energy turnover are hereby presented as $W_{PE\ (case)}$ and $W_{SPET\ (case)}$ respectively for all the studied cases. Some comparisons are also drawn between $W_{(PE)}$ and $W_{(SPET)}$ and presented.

4.2.1 Dairy farms

For all the surveyed farms, the calculated primary energy turnover was higher than the delivered energy turnover. This is a result of incorporating the energy used in the production of some secondary energy forms, such as electricity into the total energy use. The energy turnover from wood remained the same because wood is a primary energy source as well as a form of delivered energy.

Table 13: Table showing the $W_{PE\ (case)}$ at surveyed farms

Farms	$W_{PE(case)}$ [kWh/a]					
	Diesel	**Electricity**	**Petrol**	**Wood**	**LPG**	**Total**
Farm 1	644128	126047	860203	127500	0	**1 757 878**
Farm 2	986931	145867	80353	2975000	23792	**4 211 943**
Farm 3	1793	17018	1506	8500	0	**28 817**
Farm 4	41135	3063	0	8500	0	**52 698**
Farm 5	9523	5632	0	4654	0	**19 809**
Farm 6	2134	6759	927	7756	0	**17 576**

In terms of proportion of use, diesel still commanded a substantial share of the primary energy turnover in most farms by contributing most of the primary energy turnover. Wood became a more significant form of primary fuel in relation to electricity, as it was used in all surveyed farms in notable amounts; although electricity was still an important energy source at this stage. LPG was only used at one of the six surveyed farms, making it the least popular choice of fuel. Figure 52 diagrammatically illustrates these findings.

Farm 1 still maintained a trend similar to that observed for delivered energy turnover as almost 50% of the primary energy requirements came from petrol; diesel and wood also maintained their 38% and 9% shares respectively. At Farm 2, the trend is also maintained as wood dominated the primary energy use with slightly above 70% and diesel with slightly above 20%. Farm 3 showed slight changes in the percent shares but also maintained the trend in delivered energy turnovers. The share of wood as primary energy decreased to 30% from almost 50% in delivered energy, and electricity's share doubled to about 60%. Diesel's share was halved to around 5%.

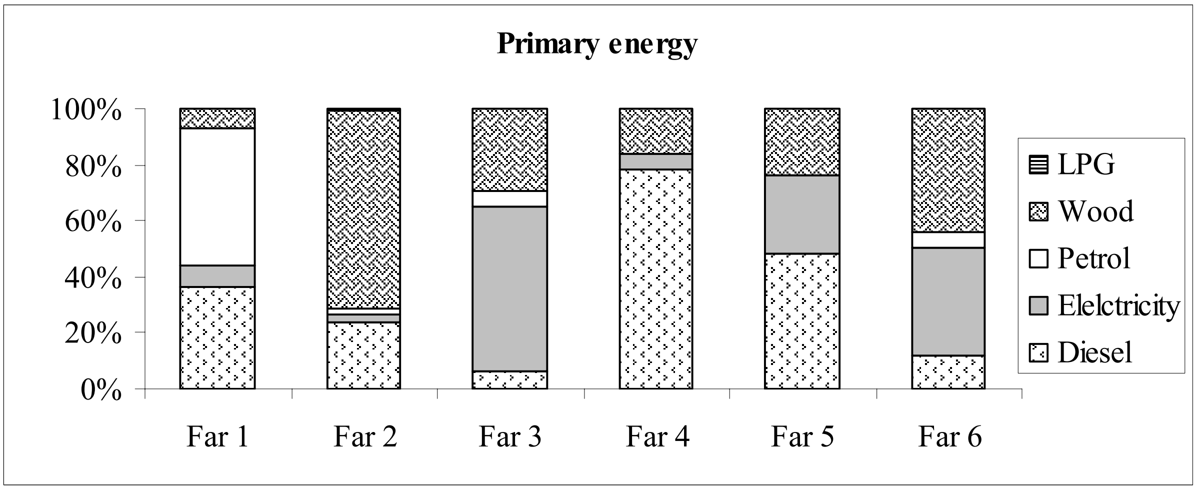


Figure 52: Chart showing the percent proportions of fuels contributing to primary energy turnover in surveyed farms

Farm 4 maintained the same trends as seen with delivered energy turnovers: diesel supplied about 80% of the $W_{PE\ (case)}$ and the rest supplied around 20%. The proportions changed slightly, but the trend is maintained at Farm 5 as diesel contributed slightly less than 50% and wood slightly above 20%, marking a decrease in the shares of both sources of energy. At Farm 6, both the proportions and trends changed as wood lost a bit of its share to contribute around 55%; electricity increased its share to contribute almost 40%, and diesel lost its place to contribute slightly above 10%.

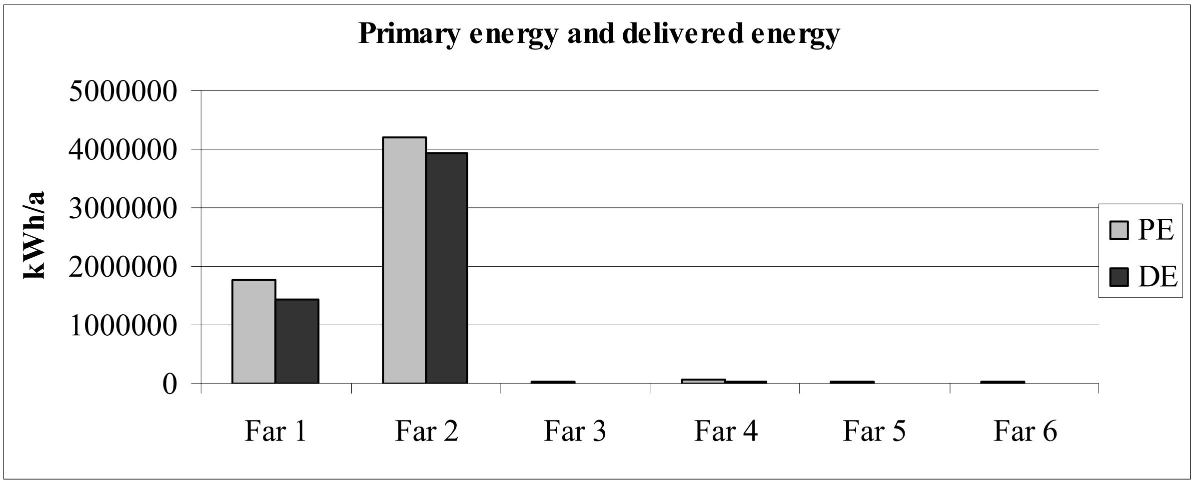


Figure 53: Chart comparing primary and delivered energy turnovers at surveyed farms

Upon comparing the primary and delivered energy turnovers, Farm 2 showed the smallest increase of 6% and Farm 3 the largest increase of 85% from delivered to primary energy turnovers.

4.2.2 Collection centres

Primary energy use in the collection stage is such that LPG contributed 0% as no centre used it. Diesel and electricity seemed to be the most important primary energy sources; however wood, although in use, commanded an insignificant share.

Table 14: Table showing the $W_{PE\ (case)}$ at surveyed milk collection centres

Collection centres	$W_{PE(case)}$ *[kWh/a]*						
	Diesel	**Electricity**	**Petrol**	**Wood**	**Fuel**	**LPG**	**Total**
Col 1	640 936	486 224	0	0	59238	0	**1 186 398**
Col 2	1 290 326	945 486	0	255 000	0	0	**2 490 812**
Col 3	2 999 234	8 752 026	0	612 000	0	0	**12 363 260**
Col 4	6 158 304	1 701 783	0	0	0	0	**7 860 087**
Col 5	170 735	217 300	0	0	0	0	**388 035**
Col 6	182 931	39 424	412 162	170 000	0	0	**804 517**

The percent shares of each fuel contribution to the $\boldsymbol{W_{PE(case)}}$ for the studied cases are demonstrated in Figure 54; to a large extent the trends resemble those observed in the delivered energy turnover. At Col 1, the trend is maintained with diesel having slightly above 50% share, followed by electricity with around 40% and fuel oil with 10%. The trend changed in Col 2 where diesel contributed the largest share (slightly above 50%) of the total primary energy use; electricity was second, supplying slightly below 40% and not unlike wood in the case of delivered energy turnover. In this instance, wood commanded only a 10% share. Col 3 also presented a change in the trends as electricity led the pack with around a 70% share, followed by diesel with around a 25% share in the total primary energy turnover, and wood contributed a mere 5%.

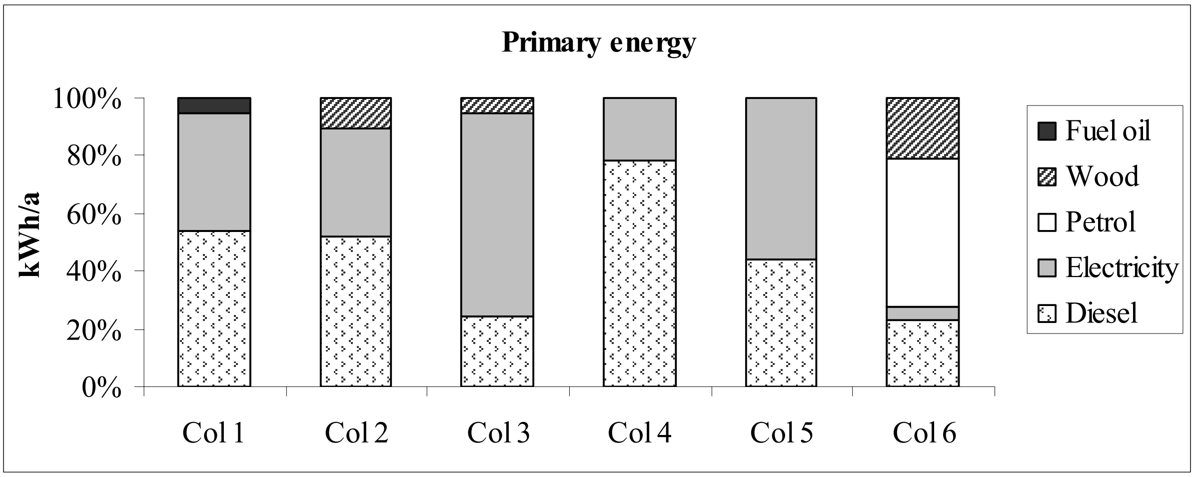


Figure 54: Chart showing the percent proportions of fuels contributing to primary energy turnover in surveyed collection centres

The trend at Col 4 remained unchanged, resembling that of the delivered energy turnover. A reversed order emerged at Col 5 as diesel came second to electricity with a 45% share in the total primary energy; electricity commanded a 55% share. Petrol still led the other fuels as it contributed around 50% to the total primary energy; wood and diesel contributed almost similar amounts of primary energy: each supplied slightly above 20%.

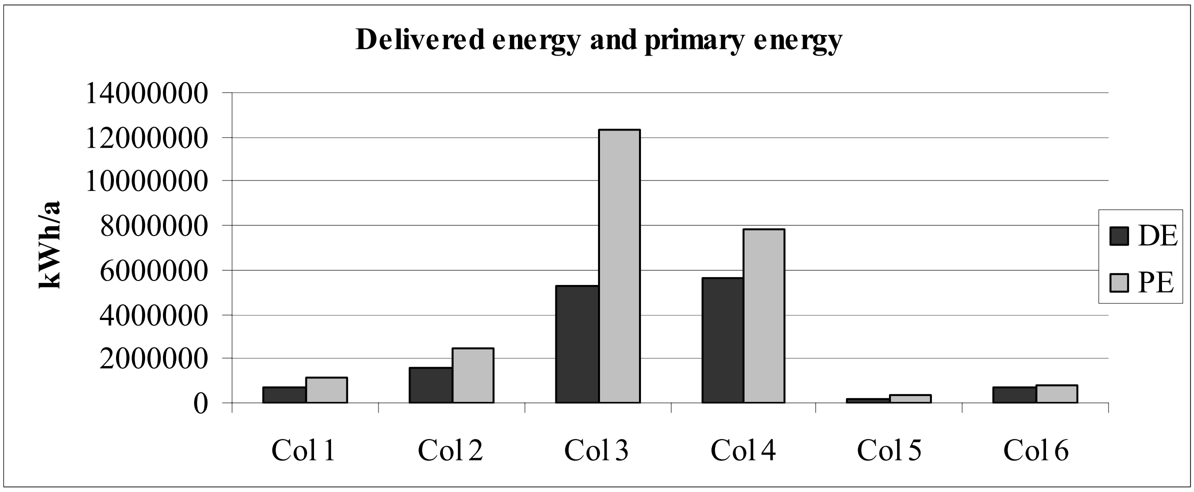


Figure 55: Chart comparing primary and delivered energy turnovers at surveyed collection centres

In all the cases $W_{PE\ (case)}$ was higher than $W_{DE(case)}$. The largest difference noted between the two energy turnovers was at Col 3, where a 132% difference was observed. Col 6 presented the most modest difference of 17%.

4.2.3 Processing plants

The results of total primary energy turnover $W_{PE(case)}$ for all fuels at surveyed processing plants are displayed on **Table 15**. **Figure 56** illustrates the proportions contributed by each of the fuels as a percentage of the total processors $W_{PE(case)}$.

Table 15: Table showing the primary energy turnovers of different fuels at processing plants

Processor	$W_{PE(case)}$ *[kWh/a]*						
	Diesel	**Electricity**	**Petrol**	**Fuel oil**	**LPG**	**Wood**	**Total**
Pro 1	3 163 522	429 037	0	0	6 224	0	**3 598 783**
Pro 2	830 414	29 190	124 876	1 352 290	0	0	**2 336 770**
Pro 3	1 856 772	594 000	0	1 133 204	0	0	**3 583 976**
Pro 4	526 099	100 800	2 304	94 437	6 426 000	0	**7 149 640**
Pro 5	504 927	11 712 000	0	0	0	0	**1 676 127**
Pro 6	1 362 097	635 363	0	6917074	0	0	**8 914 534**
Pro 8	12 971 292	2 654 034	9	10	0	0	**15 625 345**
Pro 9	25 914 947	3 436 920	696838	6629083	17 038	0	**36 694 826**

Figure 56 shows the percent shares commanded by the different energy sources in the total primary energy turnover. In Pro 1 the trend was similar to that of delivered energy turnover where electricity came second to diesel, contributing around 12%. The case was similar in Pro 2 as fuel oil led with a 58% share and petrol trailed with a mere 5% share in the $W_{PE(case)}$.

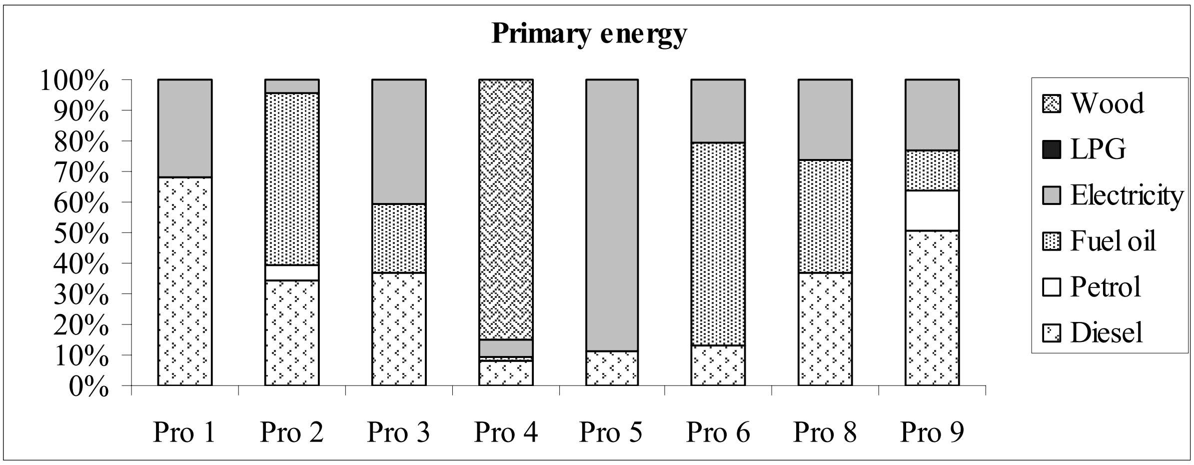


Figure 56: Chart showing the percent proportions of fuels contributing to $W_{PE\ (case)}$ in surveyed milk processors

At Pro 3, electricity was seen to be slightly ahead of diesel, as electricity contributed around 40% while diesel followed closely, contributing slightly below 40% to the total primary energy turnover. Fuel oil trailed behind with slightly above a 20% contribution. This differed from the order observed for delivered energy where diesel was first, fuel oil was next, and electricity came last.

As was the trend in Pro 4 for delivered energy, wood contributed around 85% and diesel slightly above 5%. The proportions of the different forms of delivered energy in primary energy turnover for electricity and diesel changed, but the order was maintained in the case of delivered energy at Pro 5. Electricity share increased to around 90% from 70%, and diesel's share decreased to only 10%. For Pro 6, fuel oil led the pack with slightly above 65%, as was the case for delivered energy. Diesel contributed slightly below 15% as it was overtaken by electricity, which here contributed about 20%--marking a 13% increase from 7% in the case of delivered energy turnover.

In Pro 8, diesel and fuel oil seemed to share the lead by commanding around 40% each, and then followed by electricity with a slightly increased share at around 25%. The observed trend in Pro 9 differed from that of delivered energy; the proportions also changed. Diesel's share decreased to 50%, followed by electricity whose share also increased to be slightly above 20%. Petrol and fuel oil both contributed around 10% each; this marked a decrease in the share of primary energy supplied by fuel oil from 18%; the contribution by electricity was also around 25%.

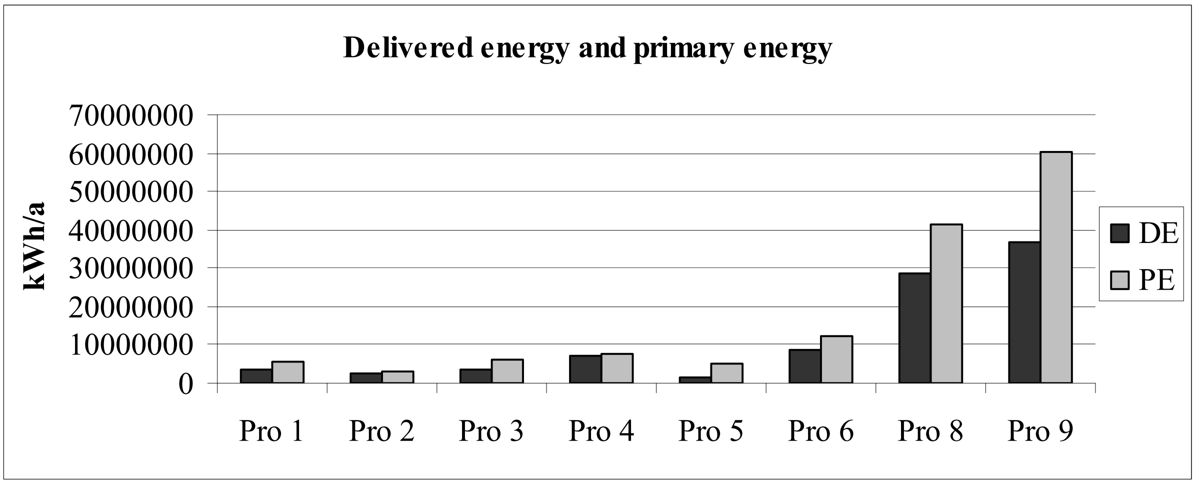


Figure 57: Chart comparing primary and delivered energy turnovers at surveyed processing plants

At this stage all cases had higher $W_{PE\ (case)}$ than $W_{DE\ (case)}$; however Pro 5 showed the largest increase by 69% while Pro 4 had the smallest increase of only 6%.

4.2.4 Distribution centres

At all the surveyed distribution centres, diesel was the major source of fuel used to run large trucks. Figure 57 shows the side-by-side comparison of $W_{(DE)}$ and $W_{(PE)}$. In all cases primary energy values surpassed those of delivered energy.

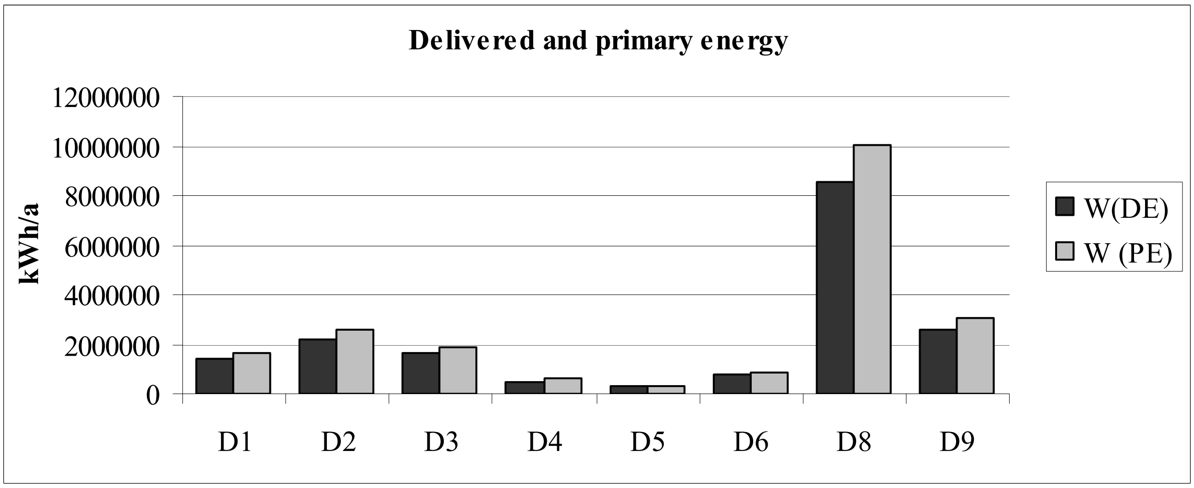


Figure 58: Chart displaying the comparison between primary and delivered energy turnovers at distribution centres

4.3 Global Warming Potential (GWP $_{(100)}$)

Preliminary calculations revealed that the GWP $_{(100)}$ resulting from fuel combustion for energy provision was almost equal to CO_2 emissions. This was because the specific emission values obtained for methane and nitrous oxide as CO_2-equivalents were negligible. This made no difference to the GWP$_{(100)}$ caused by energy use in this milk chain when added to the values obtained for CO_2 emissions. The results presented here are therefore only as CO_2 emissions.

4.3.1 Farms

Figure 59 shows the contribution of each fuel source used at the surveyed farms to the total farm CO_2 emission and also compares the total CO_2 emission among surveyed farms. The large-scale farms obviously had higher CO_2 emissions than the small farms. Farm 1 emitted the most $CO_{2,}$ followed by farm 2 and then farm 4. Farms 3, 5 and 6 contributed only small amounts of CO_2 into the atmosphere as a result of energy use. On farm 1, the use of petrol produced slightly above 55% of all CO_2 emissions on this farm while diesel contributed 40%. At farm 2, diesel contributed over 80% of all carbon emissions resulting from energy use: electricity, petrol and LPG shared the remaining 20%. Even though diesel only contributed about 21% of the energy at this farm. The substantial reduction in the total CO_2 emission at this farm was because 75% of the energy requirements at this farm came from wood--wood fuel has zero CO_2 emission resulting from to carbon fixing by growing plants. This was. At farm 4, diesel was the most dominant CO_2 emitter, contributing nearly 100% of all carbon emissions.

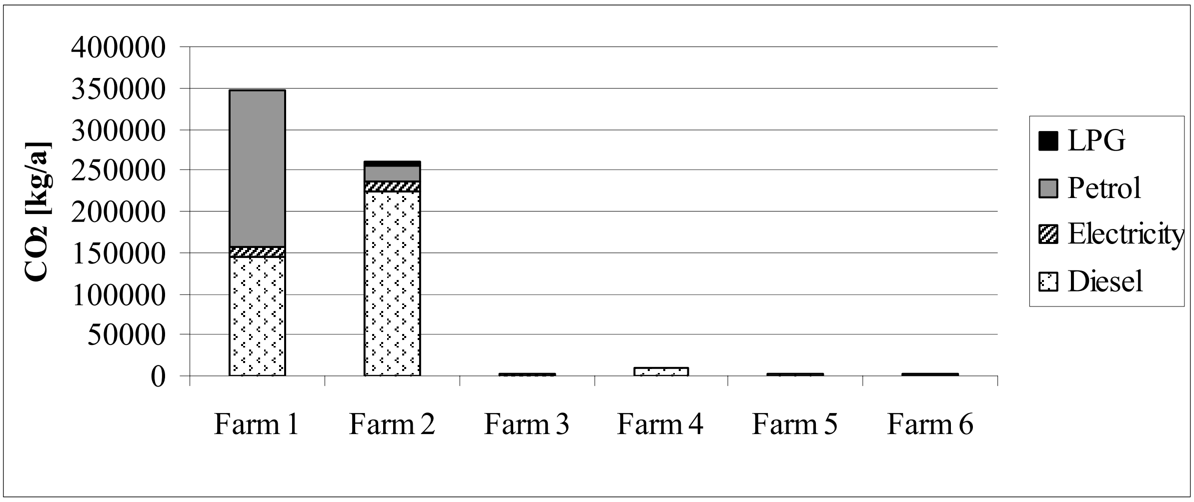


Figure 59: Chart showing fuel contribution to total carbon dioxide emission at surveyed farms

Table 16: Table showing the specific carbon dioxide emissions for the surveyed farms and collection centres

Farms	$m_{SCE(case)}$ [kg/kg]	*Collection centres*	$m_{SCE(case)}$ [kg/kg]
Farm 1	0.2470	**Col 1**	0.0935
Farm 2	0.1620	**Col 2**	0.0186
Farm 3	0.4261	**Col 3**	0.1041
Farm 4	0.9514	**Col 4**	0.0925
Farm 5	0.3104	**Col 5**	0.2185
Farm 6	0.0917	**Col 6**	0.2096
Average	**0.3648**	**Average**	**0.1228**

Specific CO_2 emission results are presented in table 16 and on a scatter plot in figure 60: larger farms have smaller $m_{SCE\ (case)}$ values than smaller farms. A good example is farm 4, which had an almost negligible total carbon emission but appreciably the highest $m_{SCE\ (case)}$ value, as clearly stands out.

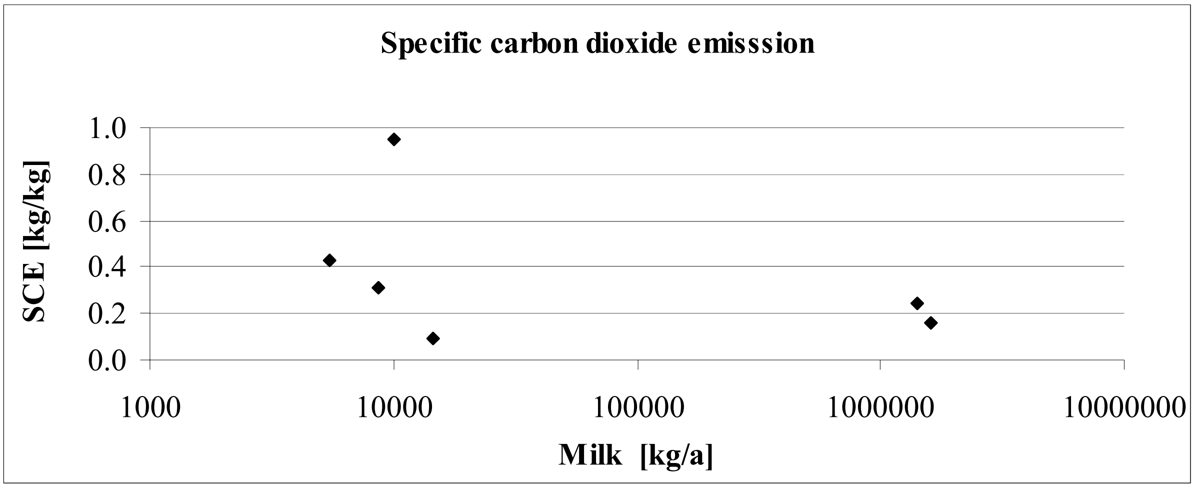


Figure 60: A scatter plot of the SCE against milk produced at surveyed dairy farms on a logarithmic scale

4.3.2 Collection centres

Clearly, for the farming stage, the two most important energy sources were diesel and electricity, as they made the most significant contributions to the total emission of CO_2 in the surveyed collection centres. Col 4 contributed the most CO_2 to the atmosphere, resulting in fuel combustion and diesel contribution of over 85%, leaving the remainder to electricity. The second highest carbon emitting collection centre was Col 3 where diesel contributed slightly more than 45%; electricity emitted slightly more than 50% of the total $m_{SCE\ (case)}$. Col 2 is the third highest carbon emitting bulking centre, where diesel contributed well over half of the total centres' carbon emissions while electricity contributed the rest.

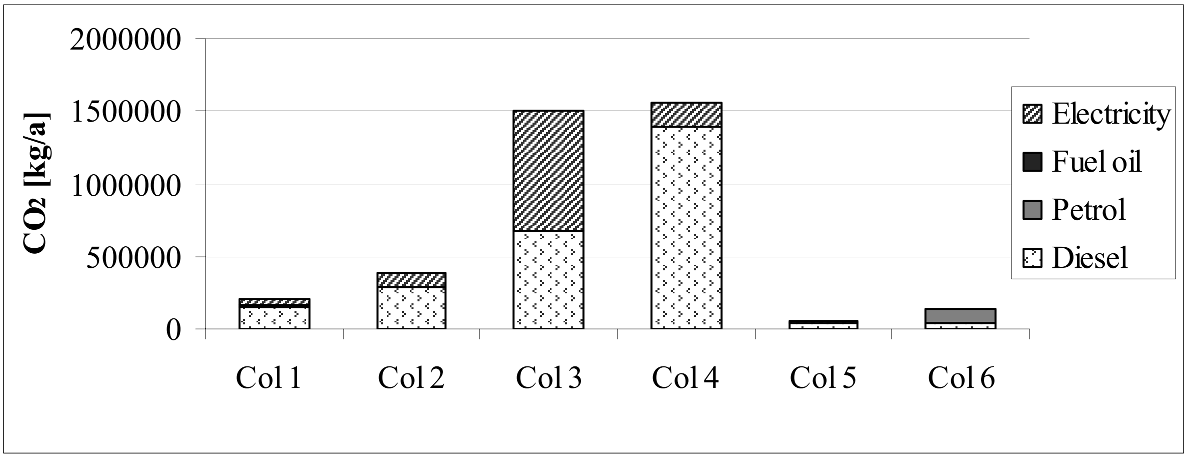


Figure 61: Chart showing fuel contribution to total carbon dioxide emission at collection centres

Col 1 was the fourth highest carbon emitter, where diesel also contributed well above 70% of the total $m_{SCE(case)}$ followed by electricity. Col 6 came after Col 1 in CO_2 emission: here petrol contributed more than half of the total carbon emission, followed by a significant contribution from petrol, and then electricity which trailed with a much smaller contribution. Col 5 had the least total carbon emissions, coming only from diesel and electricity.

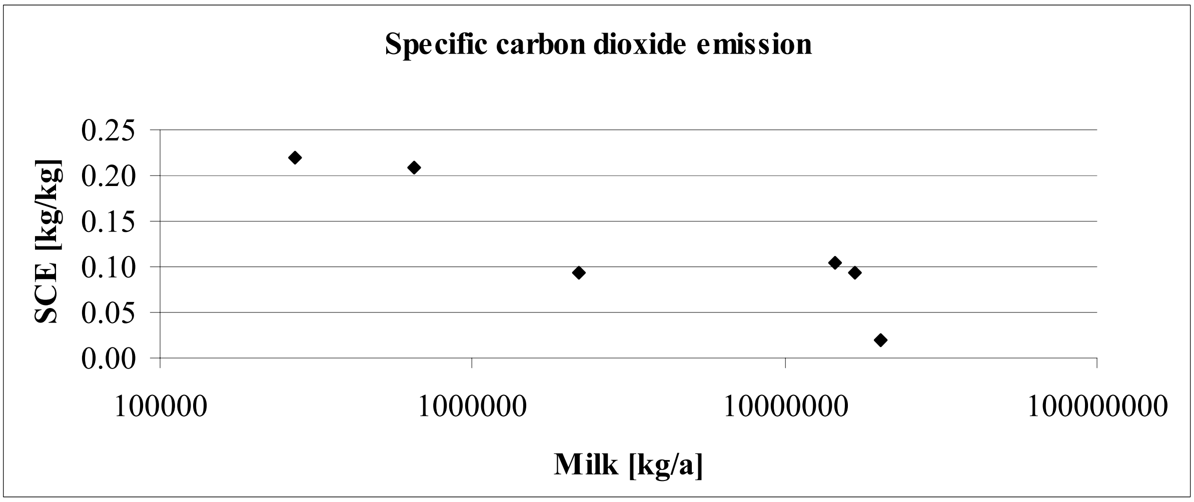


Figure 62: A scatter plot of the specific carbon dioxide emission at surveyed collection centres on a logarithmic scale

The scatter plot in figure 62 shows the specific carbon emissions $m_{SCE(case)}$ of the surveyed collection centres. It appears that smaller cooling centres--in terms of the mass of milk handled--seemed to have higher $m_{SCE(case)}$ values, despite having lower total emission values ($m_{CE(case)}$) as compared to their larger-scale counterparts.

4.3.3 Milk processors

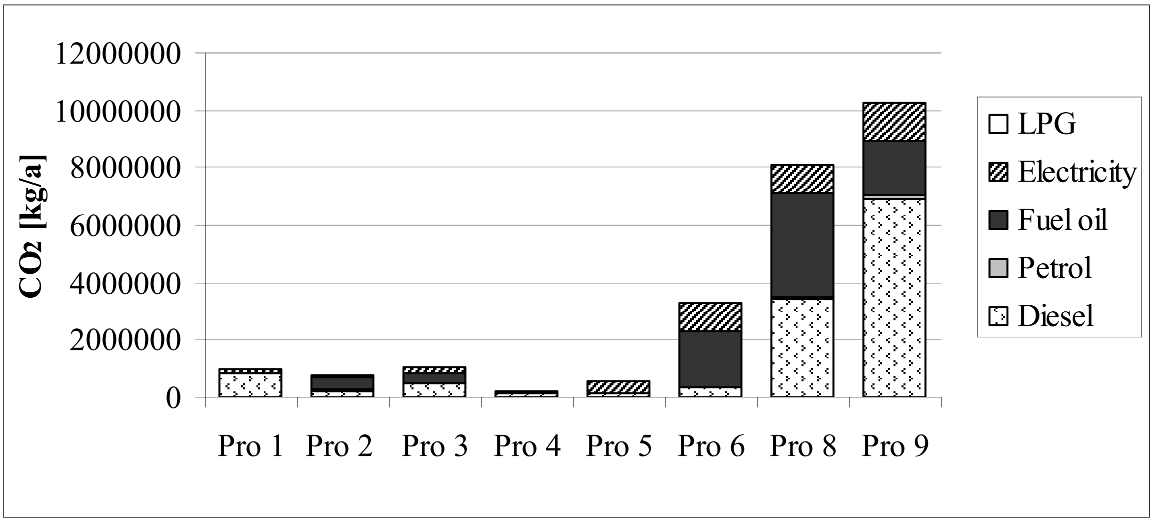


Figure 63: Chart showing fuel contribution to total carbon dioxide emission at processing plants

At the milk processing stage, Pro 4 contributed the least carbon into the atmosphere, and Pro 9 contributed the largest amounts of carbon to the atmosphere at slightly over 10 000 tonnes CO_2 per annum--most of which came from diesel combustion. Diesel contributed around 60% of all the emitted carbon, while fuel oil and electricity share the remaining 40%. Petrol took only a small share. Pro 8 was the second highest carbon emitting processor, releasing around 8000 tonnes of CO_2 per annum. In this case, fuel oil and diesel each contributed around 40%, while electricity produced around 20% of the reported total CO_2 emissions. Pro 6 was the third highest emitting processor of CO_2, releasing around 3 000 tonnes of CO_2 per year; fuel oil contributed the most to this $m_{CE(case)}$ and was followed by electricity, and then diesel. Pro 3 and Pro 1 both emitted approximately 1000 tonnes, making them the fourth highest carbon-emitting milk processing factories. Pro 2, 4 and 5 contributed less than 1000 tonnes CO_2 per annum into the atmosphere.

The specific CO_2 emissions $m_{SCE(case)}$ of all surveyed processing plants are presented in table 17. All the surveyed processors except Pro 5 seemed to contribute more or less similar amounts of CO_2 per kilogram of processed and packaged milk: less than **0.2** kgCO_2/kg milk.

Pro 5 had a specific carbon emission value of **1.6** kgCO_2/kg milk, which is eight (8) times higher than all the other processing plants.

Table 17: Table showing the specific carbon dioxide emissions for the processing plants and distribution centres

Processing plants	$m_{SCE(case)}$	***Distribution centres***	$m_{SCE(case)}$
	[kg/kg]		[kg/kg]
pro 1	0.7228	**D1**	0.0523
pro 2	0.6989	**D2**	0.0894
pro 3	0.6879	**D3**	0.0439
pro 4	0.6979	**D4**	0.0756
pro 5	2.1924	**D5**	0.2065
pro 6	0.7475	**D6**	0.0102
pro 8	0.7536	**D8**	0.0475
pro 9	0.6985	**D9**	0.0079
Average	**0.8999**	**Average**	**0.0666**

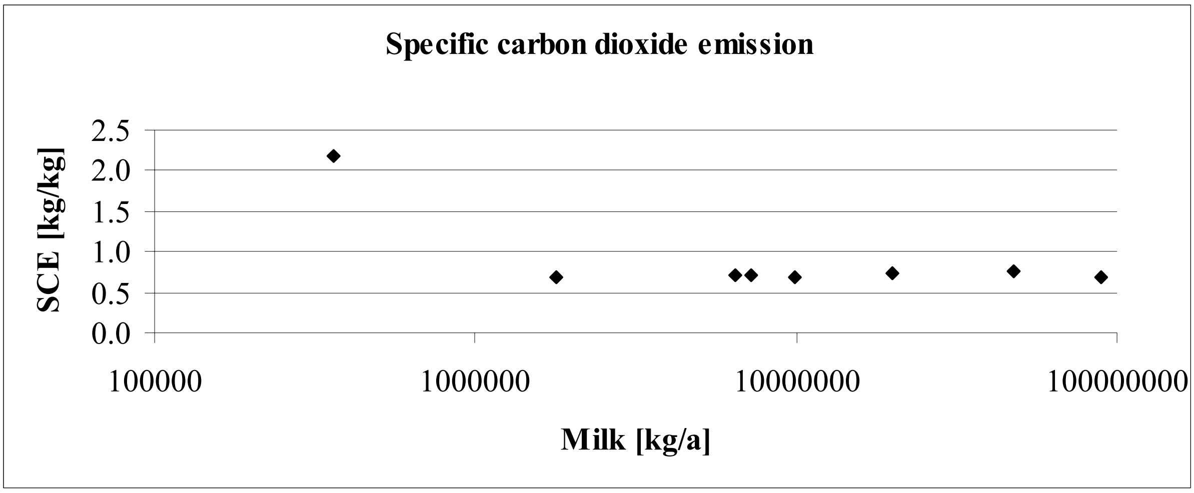


Figure 64: A scatter plot of the specific carbon dioxide emission at surveyed processing plants on a logarithmic scale

4.3.4 Distribution

Most distribution centres had carbon emission values ranging from slightly above zero to **0.1** kgCO_2/kg milk, with an exception of D5 that had an $m_{SCE(case)}$ value of slightly more than **0.2** kgCO_2/kg milk. D5 was managed by the same team that managed Pro 5. It was therefore interesting to observe from the results that management practices probably influenced efficiency of energy use and eventually the environmental burdens of a processing facility as well.

5 Discussion

5.1 Energy turnovers

5.1.1 Farms

The total energy turnovers $\boldsymbol{W_{DE\ (case)}}$ for the surveyed farms differed greatly, depending on the farm practices. Larger farms evidently had larger energy turnovers, since they required more energy to carry out daily farm activities, including milking. Small farms, on the other hand, carried out most of their farm work manually, meaning that most of the energy used did not get reflected as delivered (metered) energy, sometimes also called consumer energy. Obviously, small-scale farms also produced less milk compared to the large-scale counterparts. However, when the specific total energy turnovers were compared, the smaller farms seemed to have higher values than the larger farms: the smallest farm required 2.6 fold more energy to produce 1 kg of milk than the largest farm. This favoured the theory that larger businesses require less energy inputs to produce each unit of product.

The highest $\boldsymbol{W_{SDET\ (case)}}$ values--reported on Farm 4--may have been due to the high level of diesel consumption, which contributed 79% of the farm's energy requirements. This represented the highest proportion of any fuel use of all surveyed farms. Farm 6 produced the smallest $\boldsymbol{W_{SDET\ (case)}}$ values; this may have been a result of utilising a lot of wood fuel, contributing to 64% of the farm's energy needs. This was the second highest percent contribution of wood among all the surveyed farms. The most important energy sources at this stage were diesel and wood. Diesel was used for transportation of milk and some farm inputs in large scale farms, while wood was an affordable source of heat energy in small-scale farms; although the large-scale farms used it too.

The trends in primary energy turnover were mostly similar to those observed in delivered energy turnover. The only difference was that $\boldsymbol{W_{PE\ (case)}}$ was higher than the $\boldsymbol{W_{DE\ (case)}}$; this was a result of the inclusion of primary energy sources used to produce the delivered forms of energy into the calculations. Here, electricity presented a great difference in the primary and delivered energy turnover because 30% of Kenyan electricity was produced from fossil fuels and these were then included into the calculations. Wood presented the same values since it is both a form of delivered energy as it is a primary energy source; therefore, no change was noted in the primary and delivered energy turnovers for wood fuel.

5.1.2 Collection centres

At this stage of this product chain, the most important energy sources of energy were found to be diesel and electricity. Wood also proved to be fairly popular depending on availability and seasonality. Petrol and fuel oil were the least popular fuels at this stage. Col 4 was seen to use the most energy among all the surveyed bulking centres, and it was also the largest of all surveyed collection centres. This station was reported to use only diesel and electricity to power its activities: a practice also observed in Col 5, which utilised the least energy recorded at this stage. Col 6 was the only one of the surveyed centres that used petrol; while Col 1 was the only centre reported to utilise fuel oil to power its operations.

Diesel was used mainly to transport milk from the farms to the bulking centres and from the bulking centres to the processing plants. That is why so much of it was used at this stage. Modern milk tankers of capacities between 20 to 40 tonnes were observed to be the most common means of transporting milk to the processing plants. Although they had no refrigeration systems, the special insulation in them helped to hold the milk at temperatures between 3-6 ^{o}C from the bulking centres to the processing plants. For the very small bulking centres, large tankers usually went through several bulking centres to collect enough milk until they were completely filled up before proceeding on to the processing plant. This meant that a lot of energy was spent on collecting milk and transporting it, even before the actual processing and packaging began. It also was observed at this stage of the milk chain that the specific delivered energy turnover $W_{SDET\ (case)}$ of the collection centres revealed that larger businesses had smaller $W_{SDET\ (case)}$ values. An almost 10-fold difference between the smallest and the largest collection centres was observed.

When considering the use of wood fuel, it was seen to be popular only in the collection centres located in well-forested areas and served as a good substitute for electricity during the dry season. The dry season was also the period when electricity supply was reported to be very unstable, owing to the decreased water levels that were experienced in most hydroelectricity generation dams.

5.1.3 Processing plants

The processing stage of this product chain was dominated by the use of diesel, as most plants utilised diesel for transporting milk and for other utilities needed to run the milk processing plants. Most plants also had stand-by electricity generators that ran on diesel: power blackouts were very common in the dry spells. It was during this season that water levels in hydroelectricity generation dams reduce causing an inconsistent power supply. A few plants also operated boilers that ran on diesel; however, fuel oil was the fuel of choice used by most milk processing plants to run boilers for steam production. All these factories received electricity from the main national grid and used it mainly for cooling processes, the running of pumps and lighter functions, such as lighting the production halls and offices. LPG was only used by only a few plants--especially the larger ones to operate running fork lifts. Wood fuel was used by some plants to supplement steam production by combustion of fuel oil or diesel--especially in the dry season when a lot of wood was available and dry.

The use of fuel oil seemed to be due to the large energy requirements of this stage of this process chain. Given the high calorific value of this fuel, it was mainly applied to power steam-generation-using boilers. However, fuel oil was also very expensive to purchase and transport; therefore, most of the plants that did not use it were small companies that tried to limit their spending. Also at this stage the specific delivered energy turnover $W_{SDET\,(case)}$ of the collection centres revealed that larger businesses had smaller $W_{SDET\,(case)}$ values. The smallest processing plant required at least 22 times more energy to process 1 kg of milk.

5.1.4 Distribution centres

It was recorded during this survey that this stage of the milk process chain was entirely dependent on diesel. Diesel was the only form of delivered energy used for milk distribution in this chain. This was mainly because the distribution of finished products involved transportation of milk in large amounts from one point to another: sometimes transport further than 500 kilometres took place in heavy-duty trucks with large carrying capacities ranging from one tonne to 40 tonnes. Diesel was the most affordable fuel to transport such heavy loads in comparison to petrol. Refrigerated trucks also were reported to carry the milk for distances of up to 650 kilometres. The cooling systems on board these refrigerated trucks were diesel powered and were usually switched off during the backhaul. These trips were usually made twice to thrice a week. The smallest distribution centre--in terms of milk distributed per year--was shown to consume almost 26 times more energy to distribute 1 kg of milk than the largest distribution centre.

5.2 Carbon dioxide emissions (CO_2)

The specific carbon dioxide (CO_2) emissions for most farms ranged from 0.1 to almost 0.5 kg/kg milk; however, one farm emitted almost 1.0 kg CO_2/kg milk. Smaller farms were observed to employ "greener" farm practices, meaning that they practised farming that was shown to generally emit less CO_2 as compared to larger farms. The trends observed for energy turnovers were similar to those seen for the associated CO_2 emissions: larger-scale businesses releasing more total carbon emissions but resulting in smaller releases of CO_2 per functional unit. These tends confirm that indeed more CO_2 is released into the atmosphere when larger volumes of fossil fuels are burnt.

However, it must be noted that the specific carbon emissions for larger businesses that consumed more energy was in the long run reported to be less because they also produced larger volumes of product. The largest farm released 2.6 times less CO_2 for every kilogram of milk produced, as compared to the smallest farm. The smallest collection plant emitted almost 12 times more CO_2 per kilogram of milk collected than the largest collection centre. For processing, 14 times more CO_2 was released as a result of processing 1 kg of milk by the smallest processor than by the largest. During the distribution of processed milk, the smallest distribution centre released 26 times more CO_2 into the atmosphere as a result of using more energy to distribute 1 kg of milk than the largest distribution centre. From the provided empirical data, it looks quite intriguing to consider the ecological advantage of running larger businesses as compared to smaller ones in the context of this process chain. This phenomenon could be further explored to control carbon emissions produced by the food process chains.

5.3 The complete process chain results

Considering that each of the surveyed enterprises stood independent of all the others, each case was surveyed as a complete case study. Therefore the process of compiling a single specific energy turnover value ($W_{Total\ SDET\ (chain)}$) for the complete chain energy turnover was not obtainable by simply adding the values obtained from each stage. This is because of the difficulty in determining which case would best represent the chain's stage. Several procedures were explored to come up with results that would represent the complete chain and present the possibilities of intervention and improvement of this milk chain.

Of the surveyed farms, only two farms sent their milk to definite collection centres included in the survey and owned by the same company; the rest of the farms included in the survey were independent small-scale farms that sent their milk to any collection centre, depending on the price offered. A similar scenario existed for the surveyed collection centres: four of the surveyed collection centres sent their milk to processing plants owned by the same company while the others sent their milk to any processor they preferred. This scenario created a possibility of many combinations of the surveyed enterprises at different stages. With this in mind, several possibilities were explored with the aim of providing a practical picture for the complete dairy chain in Kenya.

5.3.1 Average specific delivered energy turnover ($W_{Total\ SDET\ (chain)}$) for complete chain

The use of averages was among the possibilities explored, to create a complete picture of energy turnover throughout the Kenyan milk chain. It involved the results obtained after allocating the delivered energy turnover $W_{DE\ (case)}$ to the functional unit, resulting in presented $W_{SDET\ (case)}$ in kWh/kg milk. Arithmetic means for each stage included in this survey: the surveyed farms, collection centres, processing plants and distribution centres, were calculated and presented as $W_{SDET\ (stage)}$. Although this is not statistically sound because the survey was designed as an embedded case study, meaning that each studied case was a complete case study and could stand by itself. Table 18 gives the complete picture of the chain-specific delivered-energy turnover.

Table 18: Table showing the averages of $W_{(SDET)}$, $W_{(SPET)}$ and m_{SCE} for all stages of the Kenyan milk process chain

Stage	$m_{(stage)}$ *[kg/a]*	$W_{SDET(stage)}$ *[kWh/kg]*	$W_{SPET(stage)}$ *[kWh/kg]*	$m_{SCE(stage)}$ *[kg/kg]*
Farms	507 254	2.20± 1.3	2.9813	0.3648
Collection	9 118 848	0.48 ± 0.3	0.7782	0.1228
Processing	22 757 621	1.38 ± 1.7	2.8774	0.3169
Distribution	22 757 621	0.25 ± 0.2	0.2947	0.0666
Chain total		**4.3137**	**6.1534**	**0.8711**

The $W_{Total\ SDET\ (chain)}$ for the complete chain was found to be **4.31 kWh/kg** of milk. This means that each kilogram of milk ready for sale requires 4.31 kWh of energy to produce--from the farms all the way through to processing and packaging--with all transport efforts included. In comparison, **6.1534 kWh** of primary energy was required to produce, transport, process and distribute 1 kg of milk: in turn **0.8711 kg** of CO_2 would be released in the process. Figure 65 gives the findings for the complete Kenyan fresh milk process chain as reported in Table 18. Clearly, the agricultural and the processing stages are shown to consume the most energy; although the surveyed dairy farms' energy consumption appears to be slightly higher than energy required for milk processing. The distribution stage is the least energy consuming of all the stages. The doughnut diagram on figure 66 clearly shows the percent share of each stage in the $\boldsymbol{W}_{\text{Total SDET (chain)}}$ of 1kg of milk ready for retailing at a large depot.

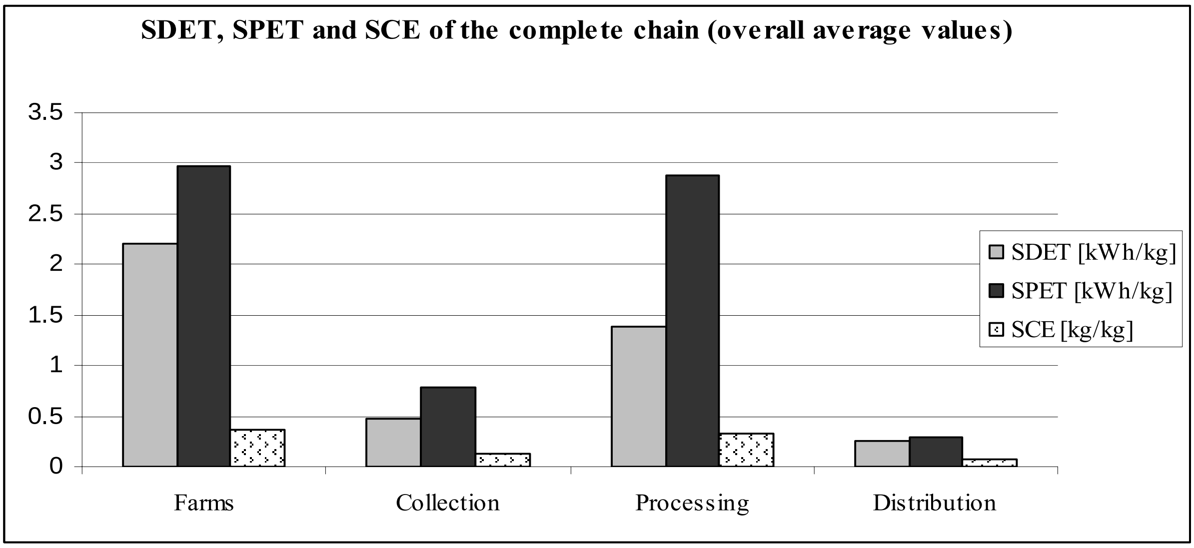


Figure 65: Figure comparing the SDET, SPET and SCE of the complete chain based on overall average values

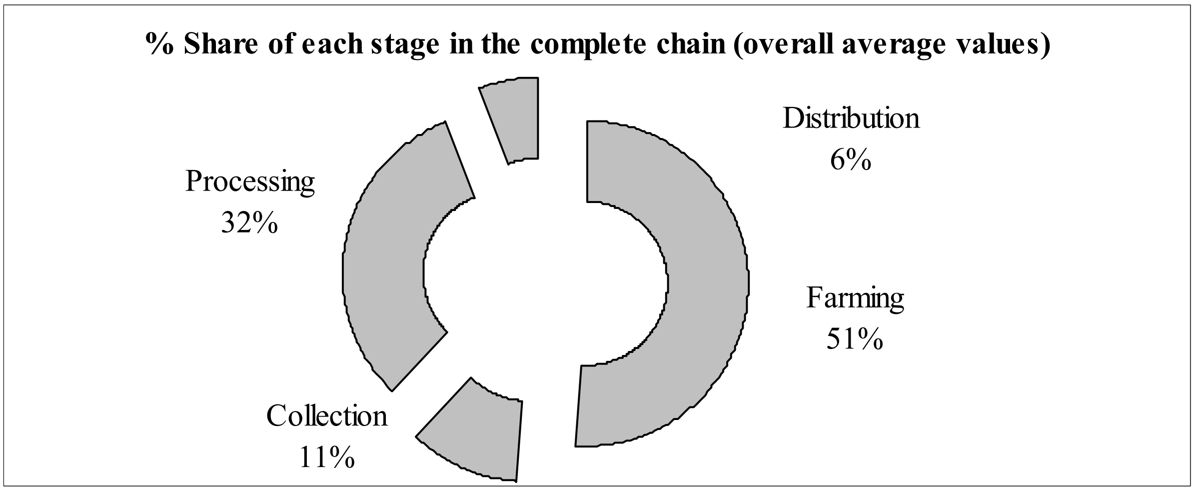


Figure 66: Doughnut diagram showing percent share of each stage in $W_{\text{Total SDET (chain)}}$ of 1 kg milk

Figure 66 shows that the dairy farms consumed the most energy (51%) to produce 1kg of milk; the processing stage followed with 32%. The distribution stage had the least share at

6%. This points out that the farms and processing stages are the most energy-consuming stage in this chain. This also shows that the farm level may turn out to be an important environmental “hot spot” for this dairy chain. Similar observations have also been reported by other researchers. Eide (2002) carried out an LCA of a dairy chain with the specific objectives to find any “hot spots” in the life cycle of milk and to determine the influence of transport. She found the agricultural phase to be the main hot spot in the life cycle of milk for almost all the environmental themes studied. Hanssen *et al*; (2007) reported the raw material production to be the most important part of the life cycle of most drinking products, including milk. They set up an LCA to study the environmental effectiveness of the Norwegian beverage sector by establishing total energy consumption and global warming potential of eight beverages.

5.3.2 Complete chain-specific delivered energy turnover based on business sizes

In order to present the effect of business sizes on energy use at all important chain stages, the surveyed cases at all stages were divided into three categories based on their size. Within these three clusters, averages of $W_{SDET\ (case)}$ were calculated and taken to represent a stage as $W_{SDET\ (stage)}$ in each category. These calculated $W_{SDET\ (stage)}$ were then added up to give a complete chain picture in each of the three categories. The basis upon which the three categories of business sizes were built is provided in table 19. Upon applying this basis, several comparisons were made between the results obtained for the three possibilities of $W_{Total\ (chain)}$ values obtained.

Table 19: Table showing the basis of business scale classification used for complete chain summations

Chain stage	Business scale in kg milk per year		
	Small	Medium	Large
Dairy farms	< 10,000	>10,000 < 1,000,000	>1,000,000
Collection centres	<1,000,000	>1,000,000 < 5,000,000	> 5,000,000
Processing plants	< 5,000,000	> 5,000,000 < 10,000,000	> 10,000,000
Distribution	< 5,000,000	> 5,000,000 < 10,000,000	> 10,000,000

The respective average $W_{SDET\ (stage)}$ values for the chain based on the sizes of the businesses are given in table 20. Three categories were explored as small-, medium- and large-scale businesses at all surveyed chain stages.

Table 20: Table showing the average SDET of all stages in the three categories

Chain stage	***Average $W_{SDET(stage)}$ [kWh/kg]***		
	Small scale	*Medium scale*	*Large scale*
Dairy farms	2.23	2.61	1.74
Collection centres	0.90	0.33	0.26
Processing plants	4.33	0.41	0.70
Distribution	0.53	0.23	0.30
Complete Chain	**7.99**	**3.58**	**3.00**

Under this classification, the small-scale businesses had the largest, specific-delivered energy turnover, meaning they consumed the most energy: **7.99 kWh** to produce 1 kg of milk as compared to their counterparts with larger businesses. The large-scale businesses once again demonstrated their ability to produce a similar amount: 1 kg using less energy **3.00 kWh**. Differences also were observed in the percent contribution of each stage to the complete chain for the different business sizes. These findings of lower energy turnover at large-scale farms explain the trend in farm structures in North America reported by Wolf (2003). He noted that milk production had increased, with dramatic increases in milk produced per cow, but with a steep decline in the number of milk cows and fewer farms with larger herds. He further explained that the incentive to increase farm size is derived from the economies of size that may be achieved by spreading the capital, labour and managerial costs across more units of milk production. Empiric evidence from previous studies indicates a declining cost of production over a large range of herd sizes (Wolf, 2003).

Figures 67 to 69 show the percent contribution of each stage to the $W_{Total\ SPET\ (chain)}$ of the complete chain in the different categories of business sizes. It is clear that in the small-scale category, the processing stage contributed the largest share and distribution contributed the smallest. This chain represents the typical case for the Kenyan chain as small businesses continue coming up at all stages of the chain, clearly seen in figure 67.

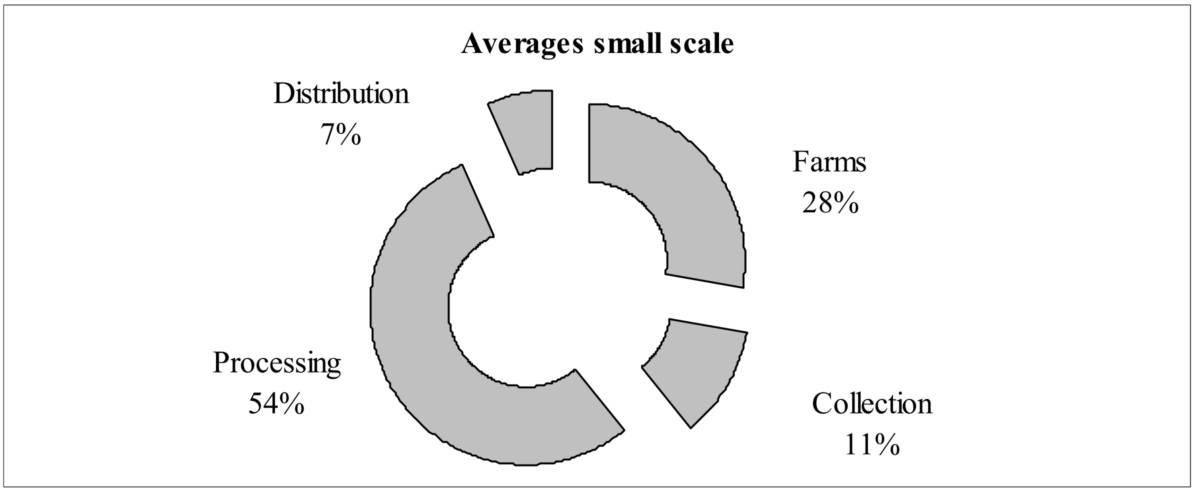


Figure 67: Chart showing the percent contribution of each stage to the total small-scale chain

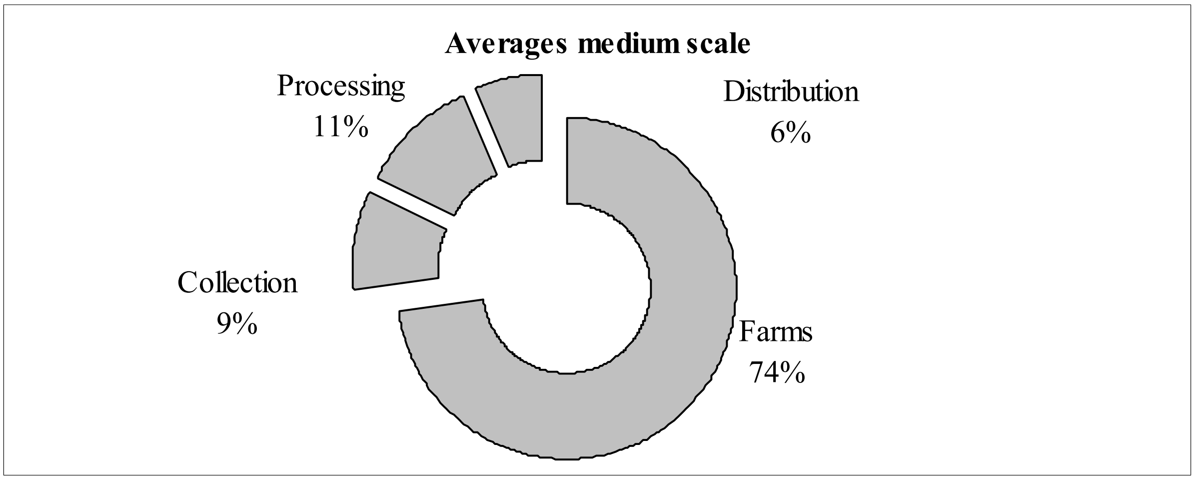


Figure 68: Chart showing the percent contribution of each stage to the total medium-scale chain

For the medium-scale category, the farms are still seen to contribute the largest share to the chain, followed by the processing stage. This means that most of the energy demand was experienced during milk production. This also translated into larger amounts of CO_2 into the environment and therefore, substantially contributing to global warming. Noteworthy, too, is that all the stages in this category contributed larger percentages to the total specific energy turnover: at least 10% for each stage compared to their counterparts in the small-scale category.

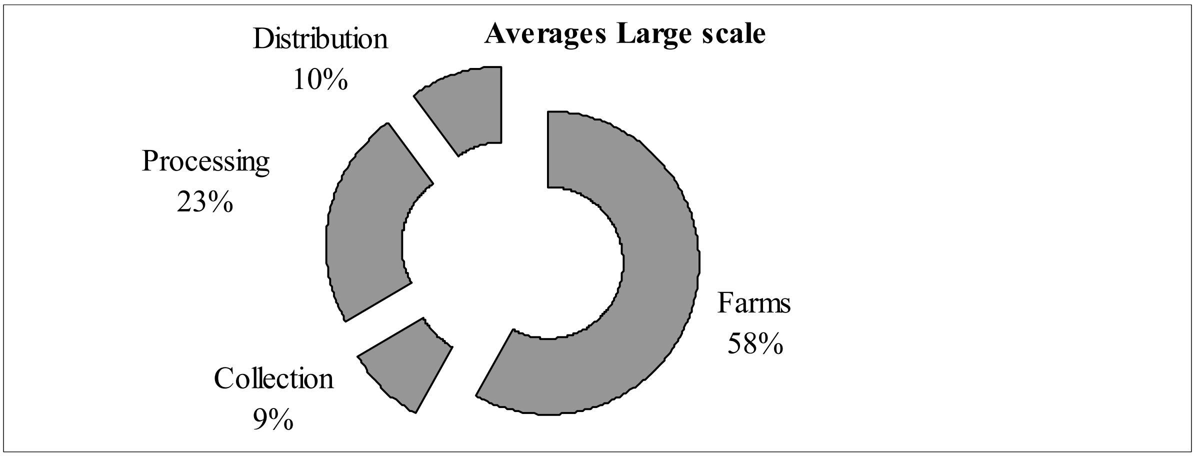


Figure 69: Chart showing the percent contribution of each stage to the total large-scale chain

In the large-scale category, the farms were seen to be the greatest let down as they claimed 71% of all the energy required to produce 1 kg of milk in this chain. This may be because large farms, although they had lower, specific-delivered energy turnover compared to smaller farms, utilised more fossil fuel to carry out around-the-farm day-to-day activities as compared to small-scale farms that used manual labour leading to generally larger $W_{SDET(case)}$ values, as compared to the other stages. This showed that the farming stage was very crucial in the whole process chain and could not be ignored. This was confirmed by the findings of other researchers who applied the LCA methodology to milk chains, noting that agriculture was among the important hot spots in this diary chain (Hispido *et al.*, 2003, HØgaas, 2002 and Cederberg & Mattson, 2000).

5.3.3 Complete, specific delivered energy turnover of the "best-case scenario"

The "best-case scenario" for the three business size categories was also explored. This option included only the best cases in each business size category. "Best cases" in this study were defined as those cases with the smallest $W_{SDET\,(case)}$ values in each category. These cases were selected, presented and summed up to give the $W_{Total\ SDET\ (chain)}$ best-case scenario: the most energy-efficient chain that requires the least energy to produce, process and package 1 kg of milk. The results obtained are given in table 21.

Table 21: Table reporting only the best cases in each of the three categories

Chain stage	***SDET in kWh/kg milk***		
	Small scale	*Medium scale*	*Large scale*
Dairy farms	1.637	0.835	1.024
Collection centres	0.736	0.327	0.078
Processing plants	4.000	0.360	0.328
Distribution	0.284	0.165	0.030
Total	**6.657**	**1.687**	**1.460**

Clearly, the small-scale chain required the most energy to produce 1 kg of milk: **6.657 kWh/kg** milk. The large-scale chain was the most energy efficient, requiring nearly 4.6 times less energy to produce 1 kg of milk: **1.460 kWh/kg** milk. The energy requirement of medium-scale and large-scale businesses differed very slightly, although the large-scale businesses had slightly higher values. This observation is supported by the fact that once the advantages of producing more have been achieved--here described as "ecology of scale"--the energy required to produce any extra unit differs only slightly from that of producing the previous unit. It also indicates that relatively large businesses may have begun to experience diseconomies of scale and, thus, resulting in no more lowering of their energy needs. However, the medium-scale businesses still had much lower $W_{SDET\ (case)}$ values of **1.687** compared to the **6.657 kWh/kg milk** observed in small-scale businesses. Figure 70 compares the percent contribution of all the stages in each scale category. All in all, the dairy farming stage still emerges as a "hot spot" in this chain because it utilises a lot more energy to produce 1 kg of milk than all the other stages. The processing stage is the second most important stage. The collection stage comes third in all the cases except for large-scale best cases.

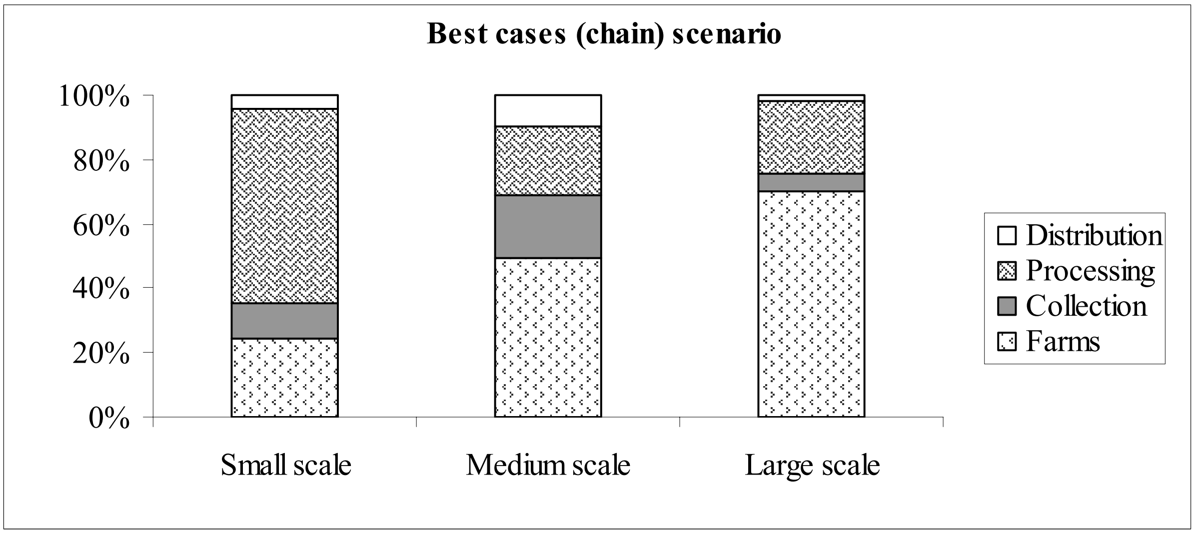


Figure 70: Chart showing the percent contribution of each stage to the total large-scale chain (best cases only)

The overall best-case scenario was also generated by summing up the cases with the overall lowest, specific delivered energy turnover values across all three categories. This overall best-case chain yielded a $W_{Total\ SDET\ (chain)}$ of **1.271 kWh/kg** milk. This means that in a supply chain where the most energy-efficient dairy farm, collection centre, processing plant and distribution point come together to form one chain, it would require only **1.271 kWh** to produce, process and package 1 kg of milk ready for sale at a large depot or retailer. This is a very impressive energy-efficient process chain in contrast to the worst-case scenario that was summed up from values reported in table 20 that yielded **8.37 kWh/ kg** milk: a difference of 7.099 **kWh/ kg** of milk between the overall best case and the overall worst case.

Upon comparing the $W_{Total\ SDET\ (chain)}$ for the average-case scenario and the $W_{Total\ SDET\ (chain)}$ of best-case scenario, differences are seen in the percent contribution of each stage ($W_{SDET\ (stage)}$) to the $W_{Total\ SDET\ (chain)}$ as seen in figure 71; although the order of appearance of the stages in terms of delivered energy turnover remained the same. The distribution stage was seen to contribute the smallest share to the fluid milk chain totals; while dairy farms contributed the most in both of the compared process fluid milk chain scenarios. Interestingly, the percent share of dairy farms was higher by **15%** than the best overall cases. The share of processing decreased by only **6%** and that of milk collection by a mere **5%**: this may have resulted from the substitution of less energy-efficient cases by more efficient cases as best-overall cases.

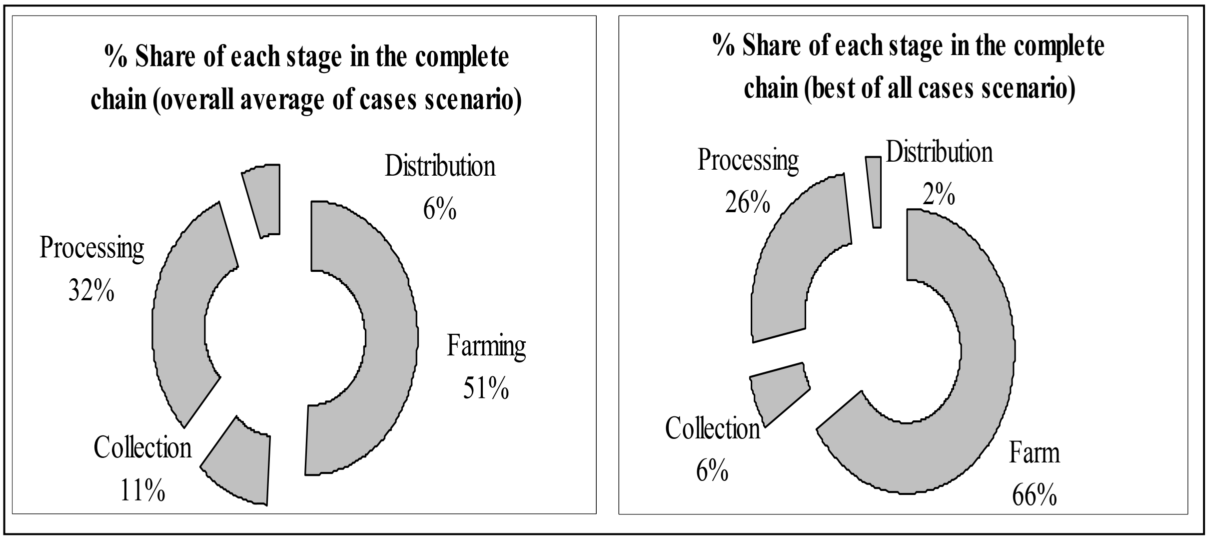


Figure 71: Doughnut diagrams comparing the percent contribution of each stage in the overall average chain and the best overall chain

5.3.4 Company chains

Among the five companies surveyed, none had all the stages to include for a complete chain. Each of companies had corresponding cases in at least two stages of the whole chain. Complete chains for the surveyed companies were constructed using the industry averages calculated from all the surveyed companies for each stage and were used to fill up the gaps of missing stages. Figure 72 gives the findings for all the five company chains as reported in table 22.

Table 22: Table showing the specific primary and delivered energy turnovers of company chains

Company code	*Total Milk*	*Sum SDET*	*Sum SPET*	*Sum SCE*
	[kg/a]	**[kWh/kg]**	**[kWh/kg]**	**[kg/kg]**
Ad	15 177 254	3.629	5.409	0.775
Pl	14 296 348	7.227	7.975	0.475
Kb	39 139 734	4.668	8.452	1.120
Bk	196 097 140	1.728	2.446	0.442
Lm	29 426 102	3.207	4.552	0.636

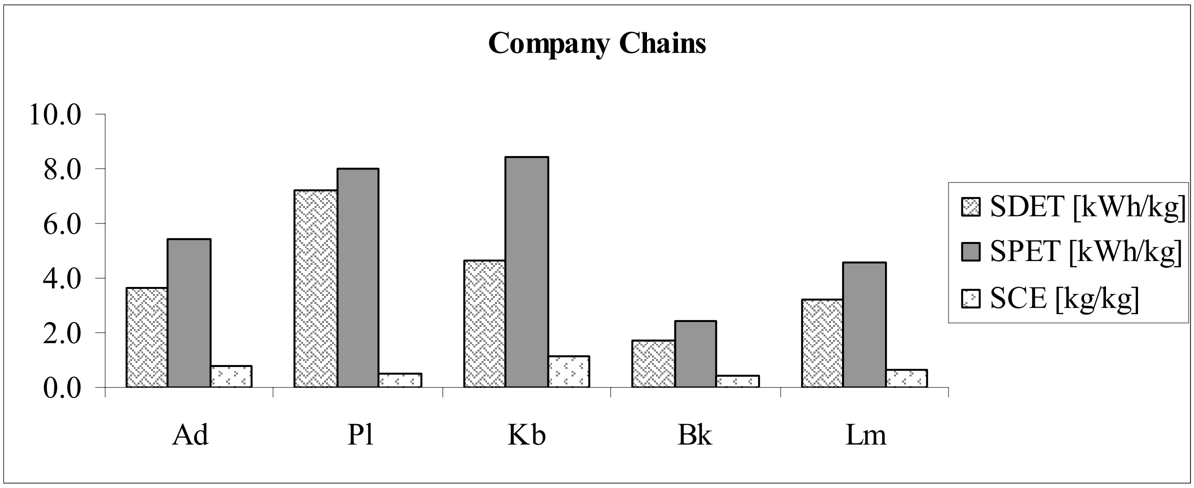


Figure 72: Figure comparing the SDET, SPET and SCE of company chains

Company code Bk emerged as the most energy-efficient chain because it presented the lowest specific energy requirements $W_{Total\ SDET\ (chain)}$. This may have been because this company benefited from operation efficiencies presented by its size. It was the largest among the surveyed companies, handling the largest volume of milk per annum. Company code Pl was the smallest of all surveyed company chains because it handled the smallest milk volumes per year and required the most energy per kilogram of milk. These findings are again supported by the idea of "ecology of scale."

Although Pl had the highest $\boldsymbol{W\ Total}_{SDET\ (chain)}$ values, it had slightly lower $\boldsymbol{W}_{SPET\ (case)}$ values than company code Kb. This result may have arisen from the use of less electricity and more wood as energy sources in most of the Kb enterprises: electricity tends to convert to higher primary energy requirements due to the burning of fossil fuels during electricity generation. In the Kenyan electricity mix, fossil fuel accounted for 30% of energy requirement for electricity generation. It is also noteworthy that Pl is located in an area where milk production does not perform very well. This then translated into high energy requirements in transportation of animal feed for the cows, thereby raising the $\boldsymbol{W}_{Total\ SDET\ (chain)}$ per kilogram of milk.

Although company code Kb was the second largest of all surveyed chains, it did not seem to require lower energy per kilogram of milk handled. This might have been caused mainly by low efficiency levels in the company's operations. This company chain had many branches in different parts of the country that obtained all supplies from a central point that was sometimes too far for some of the branches. Due to its size, managerial inefficiency and a lot of beaurocracy in the procurement of supplies may have contributed to too much energy used in transport, hence resulting in higher energy requirements.

Although company chains Ad and Pl were within the same business scale in terms of volumes of milk handled per annum, company chain Ad seemed to benefit from its size by providing more efficient management and shorter chains in decision making than Kb. This, therefore, translated into less energy requirements per kilogram of milk for Kb than Pl. The percent contributions of each stage to the company chains were also compared and the findings presented in figure 72. Additionally, company Pl mostly distributed its milk regionally, as opposed to company chain Bk that was countrywide and distributed its milk to most parts of the country. Despite all the transport effort involved, Pl had higher energy requirements per kilogram of milk: 7.2 kWh as opposed to Bk that had 1.7 kWk. This shows that transport distances in a food chain are not as important as efficiency of operations (Schlich & Fleissner, 2004). Company chains Ad and Lm were also regional although they had $\boldsymbol{W}_{Total\ SDET\ (chain)}$ values of 3.6 and **3.2** kWh/kg milk respectively.

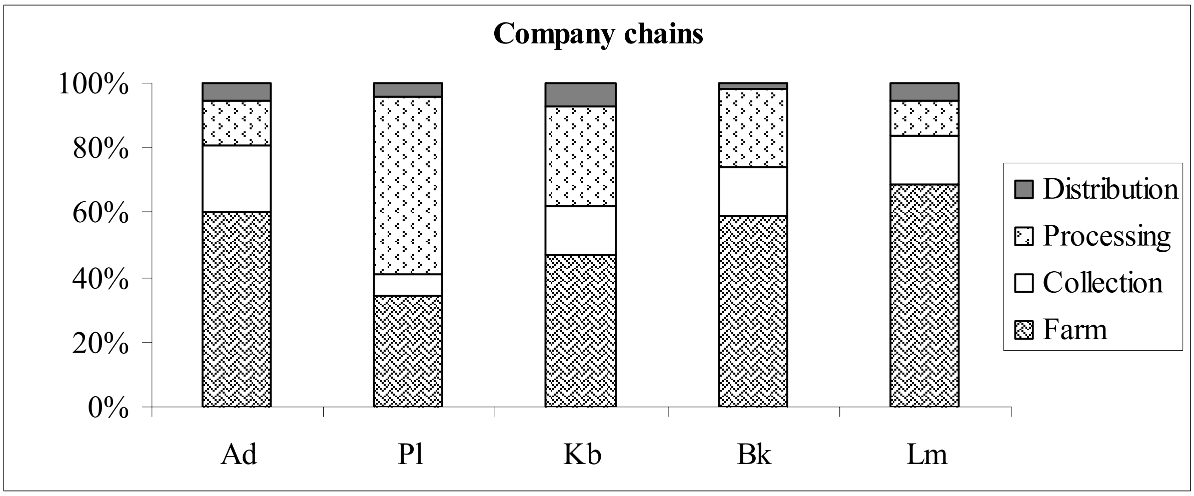


Figure 73: Figure comparing the percent contribution of each stage in the company chains

As an emphasis in the company's chains as well, the farming stage still emerged as an environmental hot spot in these chains because it represented the stage where most energy was utilised per kilogram of milk in all the company chains, except for Pl company where processing was the most energy-consuming stage. This may have resulted because company chain Pl owned the largest of all surveyed farms and needed very low input from small-scale dairy farmers at the processing stage. The large-scale farm translated the benefits of "ecology of scale" throughout the chain by utilising energy efficiently, hence lowering the $W_{Total\ SDET\ (chain)}$ for this company chain.

The actual share of the farming stage in each company chain differed depending on each company's operational efficiencies. However, since most companies did not own dairy farms of their own, and they relied on milk from a large number of small-scale farmers to supply them with milk, the farming stage was the most difficult to control for most company chains. Therefore in the long run, these companies inherited the inefficiencies of small-scale dairy farming into their chain. Clearly, it is advantageous for dairy processing companies to have their own farms (preferably large-scale ones) to produce most of the milk needed for processing. The distribution stage was the least environmental damaging as it consumed the least energy among all company chains.

A scatter plot of the company chains against the size of the companies based on the volumes of milk handled per annum is presented as figure 74. This shows four out of the five companies clustering between 10 million and 100 million ranges: only one lay outside this range. Three of the five companies have $W_{Total\ SDET\ (chain)}$ values between 3.0 and 5.0 kWh/kg of milk; only two companies lie outside this range: one has above 7.0 kWh/kg of milk and the other below 2.0 kWh/kg of milk handled.

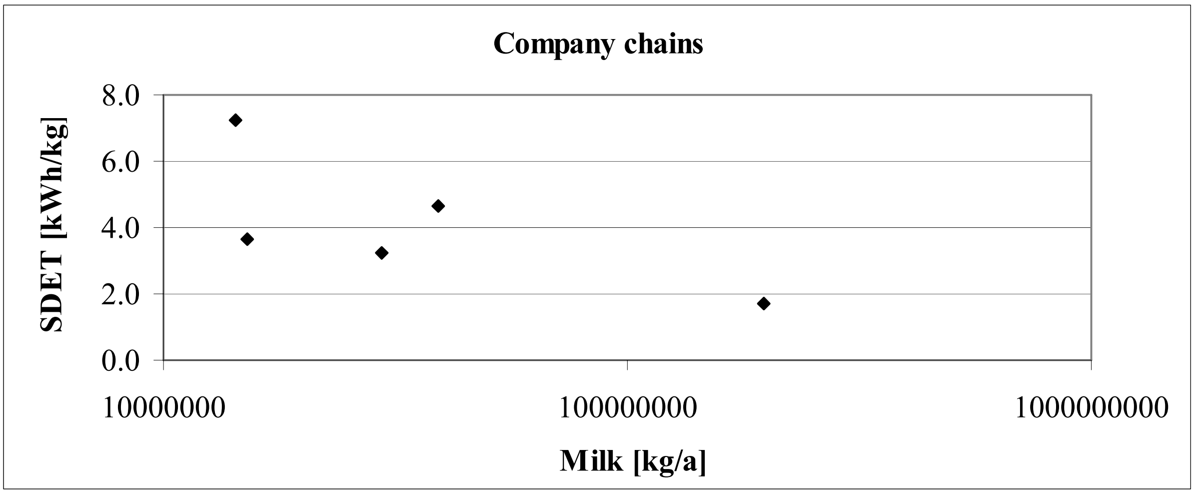


Figure 74: A scatter plot of $W_{Total\ SDET\ (chain)}$ against milk handled by company chains on a logarithmic scale

5.4 Discussion on ecology of scale

It is well known that the scale of output can have a significant bearing on the specific energy turnover. Here, the scale is indicated by the total throughput of raw milk at the surveyed dairy enterprises. In the scatter diagrams provided, each dairy enterprise was is plotted in terms of scale (throughput of raw milk or milk produced at dairy farms) in kilograms [kg] and specific delivered energy turnover (SDET) in [kWh/kg] milk handled. Also, trend lines and R^2 values, based on the data obtained, are shown superimposed on the scatter diagrams. $\mathbf{R^2}$ is the measure of the extent to which scale "explains" the variations in specific energy turnovers between the dairy enterprises surveyed. R^2 may take any value between 0 and 1.0: a value of 0 would mean that 0% of the variation is "explained" by scale; a value of 1.0 would mean that 100% of the variation is "explained" by scale. For example, an R^2 of 0.57 would mean that 57% of the variation among dairy enterprises is "explained" by differences in scale of operation.

Throughout this study, efforts were made to explore the hypothesis of ecology of scale as a central scientific hypothesis existing in this dairy chain: first at each stage among the surveyed cases, and later in different complete-chain scenarios. Scatter plots of the specific delivered energy were prepared and trend lines were fitted to establish the applicability of this hypothesis. This theory, as mentioned earlier, supports the view that transport distances of food products from production to consumption is not as important as the energy efficiency of the businesses in that process chain. By and large, larger businesses are sizes that are supported by this school of thought as they consume less energy per unit product and, therefore in the case of energy, this resulted in a "greener" process chain that releases less GHGs to the atmosphere.

5.4.1 Farms

At the milk production stage in the dairy farms, the $\boldsymbol{W}_{SDET\ (case)}$ for all the surveyed farms were plotted against the farm sizes in kilograms of milk produced per annum ($\boldsymbol{m}$). To the scatter plot a trend line was added. The resulting graph is shown in figure 75. The trend line seemed to approach the x-axis asymptotically showing that an "ecology of scale" relationship does exist between the business size and the specific energy turnover.

The equation of the relationship is such that $\mathbf{y} = 14.15\ \mathbf{x}^{-0.1843}$. This relationship fits with $\mathbf{R}^2$ value of 0.57. Although the relationship suggests that smaller farms are more burdensome to the environment than existing larger farms, it is not a very strong hypothesis as shown by the degree of certainty of only 57%. This may be due to the small number of cases surveyed in this case. However, further studies could be mounted with the aim of further exploring this particular objective, specifically for this process chain. The break-even point for this stage can be said to be producing at least **1000 tonnes** of milk per year.

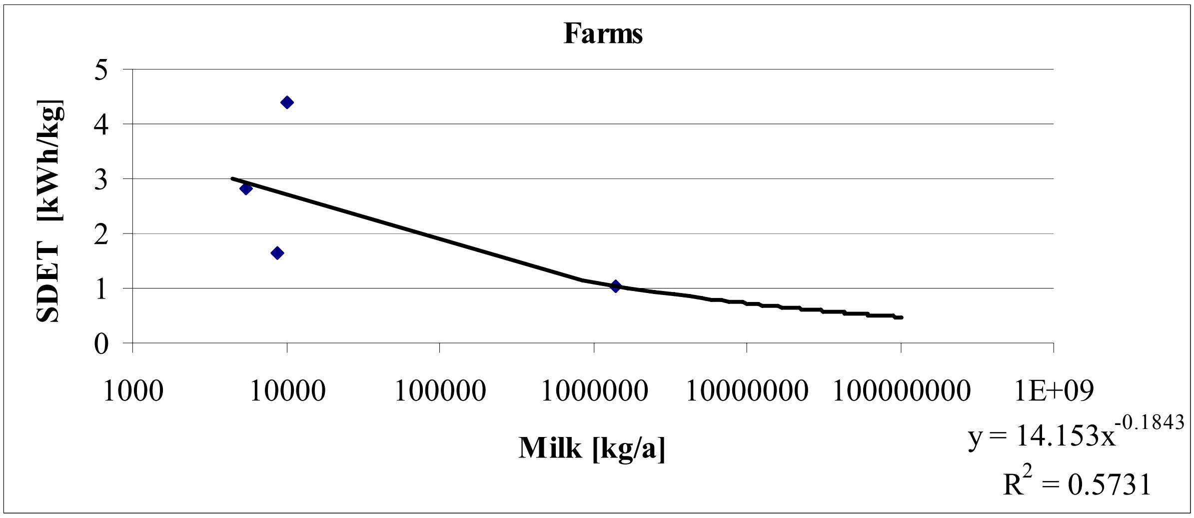


Figure 75: A scatter plot with a trend line showing the relationship between farm size and WSDET

5.4.2 Collection centres

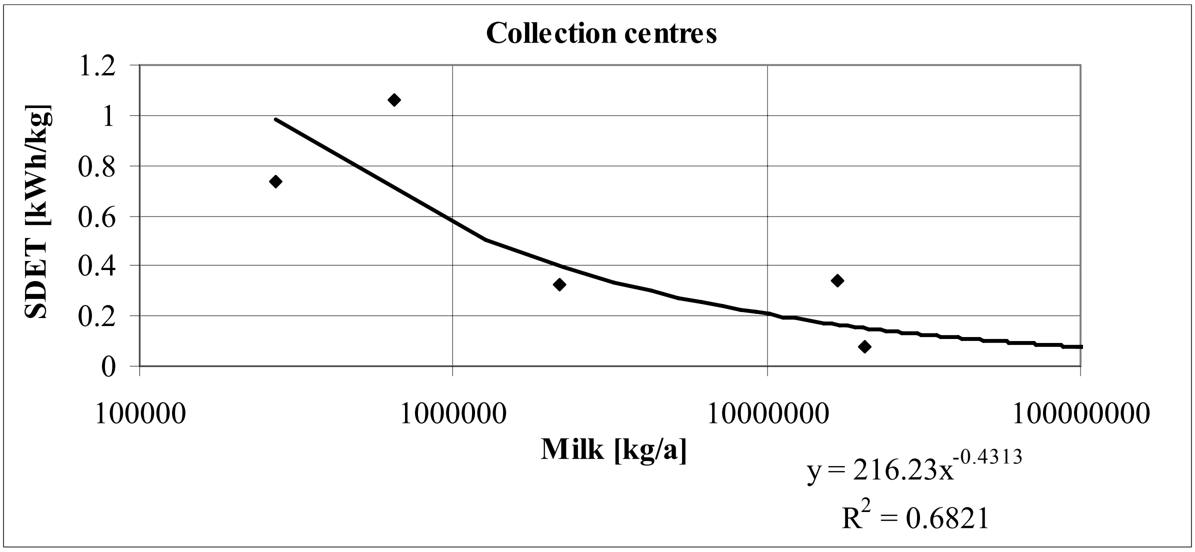


Figure 76: A scatter plot with trend line showing the relationship between size of collection centre and WSDET

At the milk collection stage, the trend line was fit with a degree of certainty $\mathbf{R^2}$ = 0.68 producing the equation $\mathbf{y} = 216.23\ \mathbf{x}^{-0.4313}$. This means it can be stated with 68% certainty that the idea of ecology of scale exists in this stage of this milk chain. Although this degree of certainty is not conclusive, it is acceptable. For this stage, the minimum business size for efficient energy use appears to be collecting at least **10 thousand tonnes** of milk per year.

5.4.3 Processing plants

At this stage of the surveyed process chain, there seems to exist a relationship supporting the energy efficiency of larger processing plants as opposed to smaller processing plants that require more energy to process 1 kg of milk. With a 70% degree of certainty, there is proof for the idea of ecology of scale.

The equation of this relationship is: $\mathbf{y} = 3293.2\ \mathbf{x}^{-0.5284}$ and $\mathbf{R^2} = 0.70$

The “break-even point” lay at around **10 thousand tonnes** of milk per year for efficient energy use during milk processing.

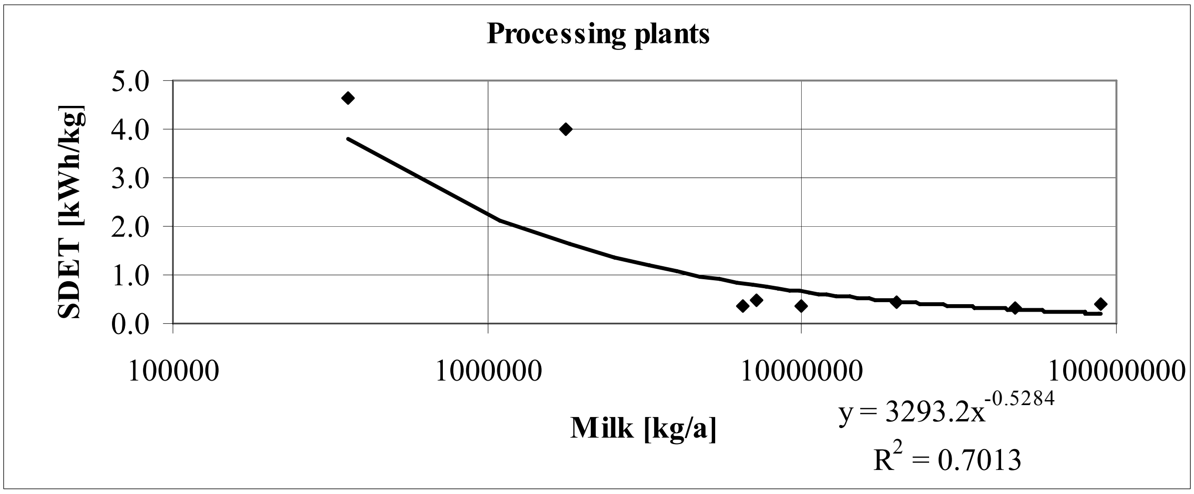


Figure 77: A scatter plot with a trend line showing the relationship between size of processing plant and WSDET

5.4.4 Distribution centres

The distribution centres also displayed a relationship of ecology of scale, although one can only say that with 68% confidence. The minimum business size in this case is processing at least **100 thousand tonnes** of milk per year. The equation of the graph for this relationship was found to be: $\mathbf{y} = 561.52\ \mathbf{x}^{-0.511}$ and $\mathbf{R}^2 = 0.68$

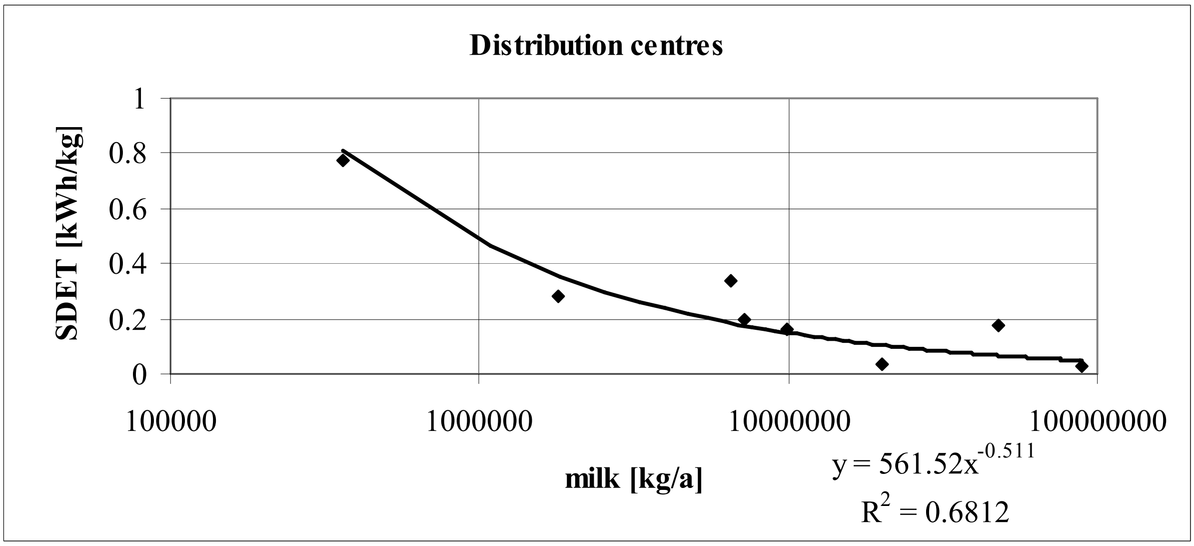


Figure 78: A scatter plot with a trend line showing the relationship between size of distribution centres and WSDET

5.4.5 Complete chain

The complete chain results were also explored for the complete chain based on the different scenario used to create a complete chain picture, as explained earlier in this chapter. With 88% confidence, one can claim that the idea of ecology of scale is supported by this milk chain based on the average energy turnover of the three categories introduced earlier in this chapter. The break-even point would be said to be at least **100 thousand tonnes** of milk per year; the equation was found to be: $\mathbf{y} = 321.69\ \mathbf{x}^{-0.2569}$ and $\mathbf{R}^2 = 0.88$

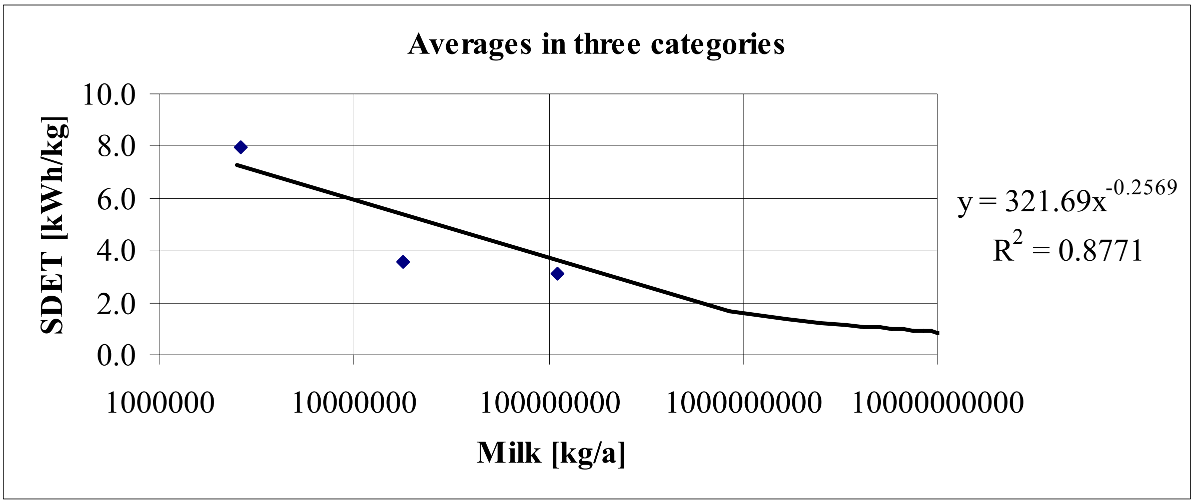


Figure 79: A scatter plot with a trend line showing the relationship between size of business and W_{SDET} of the complete chain based the averages of three categories

Upon plotting a scatter diagram of the best-case scenario and adding a trend line, an equation that supports the ecology of scale was obtained with a degree of certainty: $\mathbf{R}^2 = 0.75$ and the equation was $\mathbf{y} = 1829.2\ \mathbf{x}^{-0.8337}$. The minimum business size required for efficient energy use in this process chain is at least **100 thousand tonnes** of milk per year. Figure 80 gives the diagram of these findings.

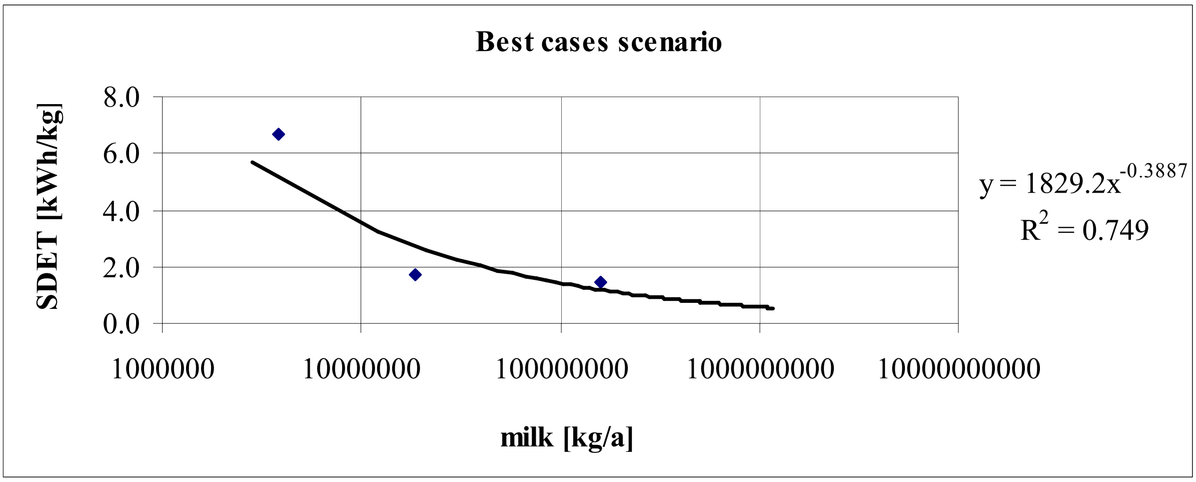


Figure 80: A scatter plot with a trend line showing the relationship between size of business and W_{SDET} of the complete chain based the best-case scenario

The company chains were plotted on the basis of milk processed per year and yielded the graph on figure 81, showing with 79% confidence that ecology of scale does exist in this process chain. The equation generated by these findings was: $\mathbf{y} = 762.3\ \mathbf{x}^{-0.3278}$ and the break-even point seemed to lie at handling at least **100 000 tonnes** of milk per year.

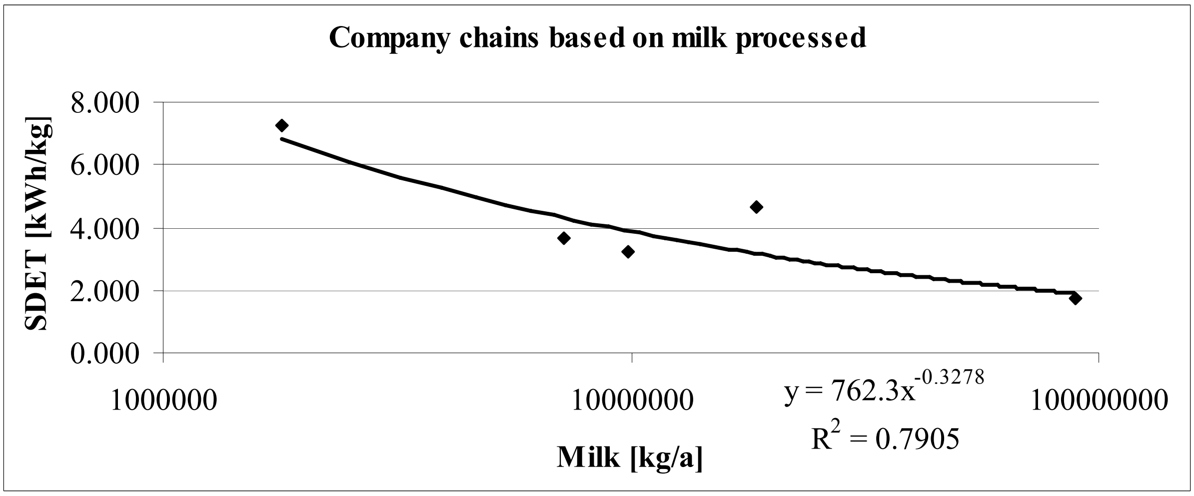


Figure 81: A scatter plot with a trend line showing the relationship between size of business and SDET of the complete chain based the company chains

In order to estimate the company's performance in meeting the predicted SDET values, the equation generated in figure 81 ($y = 762.3x^{-0.3278}$) was used to calculate the "predicted" SDET values of the plants according to the model, if scale were the only factor determining the SDET values of companies. This is the theoretical value each company would achieve if only scale was influencing their SDET values. To estimate which company "realised" this theoretical potential, the calculated SDET values were compared to the actual SDET values.

The ratio of actual-to-predicted SDET then was used as an indication of how good the achieved SDET value is compared to what the model predicts that it should be if the effects of scale were removed. A figure of 100% meant the company's SDET value is exactly what the model says it should be. A figure greater than 100% suggests that the actual value is higher than predicted and, hence, worse performance than predicted by model; while a figure lower than 100% suggests that the value is lower than predicted and, hence, better performance than the model predicts.

Table 23: Table of the performance of different company chains as predicted by model

Company code	*Actual SDET [kWh/kg] milk*	*Predicted SDET [kWh/kg] milk*	*% Performance*
Ad	3.63	4.31	84
Pl	7.23	6.80	106
Kb	4.67	3.16	148
Bk	1.73	1.89	91
Lm	3.21	3.88	83

A graph of the whole chain's results--based on the processing stage as the baseline of the other stages--was plotted for specific energy turnover against business size produced the graph on figure 82. The equation of the relationship existing between business size and energy turnover was presented with a $\mathbf{R^2} = 0.84$ degree of certainty to be $\mathbf{y} = 72.008\ \mathbf{x}^{-0.1742}$.

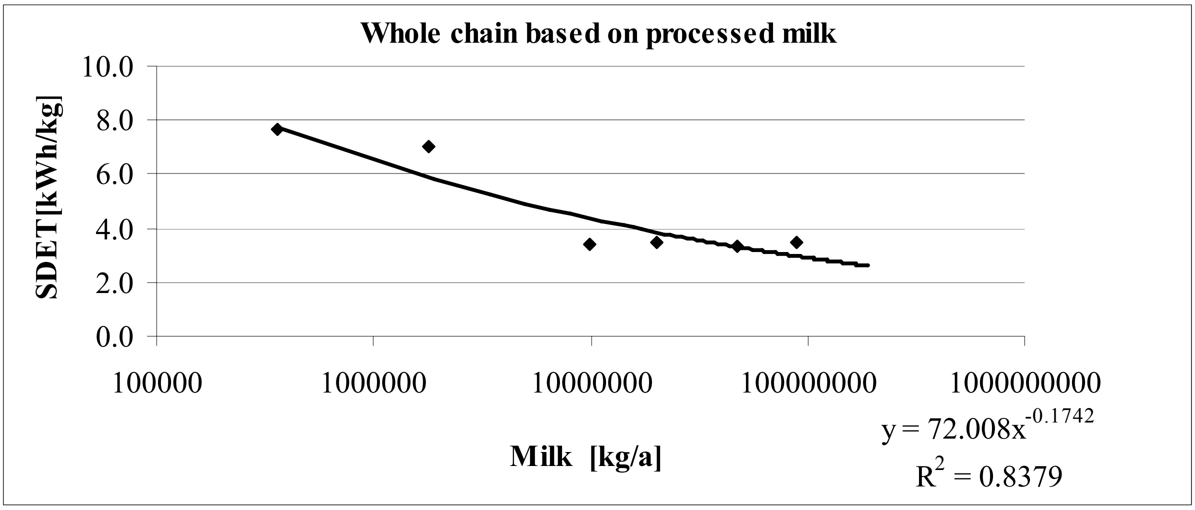


Figure 82: A scatter plot with a trend line showing the relationship between size of business and WSDET of the complete chain based on the processing stage

Conclusions

Energy balances as a component of Life Cycle Assessment (LCA), as a standardised method, was used to establish a specific database of energy consumption. The environmental emissions related to the main processes of diary farming, milk collection and transport, processing and distribution of processed packaged milk were also established. Diesel emerged as the most important energy source, while electricity was very important in all surveyed enterprises. These, therefore, present the best potential for greening this product chain. Fuel oil was extremely important during the processing stage for steam production purposes: at the farm level, wood fuel played a special role too as it was relied on by most small-scale farmers for heat provision in their dairying activities.

The energy data obtained in the survey was allocated to an appropriate functional unit, here defined as 1 kg of milk at large depots awaiting retailing, to establish the specific energy turnover of milk production, collection and cooling, processing and distribution stages of the milk processing chain in Kenya. It was found that on average, 1 kg of milk required around **4.31 kWh** of delivered energy until it is ready for retailing. At its best, only **1.27 kWh** of delivered energy was required to produce 1 kg of milk and process it until it was ready for retailing: **8.37 kWh** per kg milk is required at the worst case.

The established database was successfully used to calculate primary energy, and it was established that on average **6.15 kWh** of primary energy was needed to produce 1 kg of milk and process it until it was ready for retailing. The environmental impacts using CO_2 emissions of the fluid milk chain were also calculated and determined that **0.87 kg** of CO_2 were released into the atmosphere whenever a kilogram of milk was produced, processed and transported until it was ready for retailing in the surveyed milk chain.

The minimum business size advisable for energy-efficient milk production, processing and distribution that enjoys the advantages of “ecology of scale” in the Kenyan milk industry was established by comparing different business sizes in terms of energy and found to lie at handling at least **100 000** tonnes of milk per year.

The environmental “hot spots” (life-cycle steps that are more burdensome to the environment) of the Kenyan milk chain--with respect to energy consumption and emissions that can contribute to global warming--were identified as the farming stage. This stage was seen to consume the most energy per kilogram of milk produced and as a result released the largest amounts of CO_2 per kilogram of milk produced. Although the emissions of methane and nitrous oxide--resulting from ruminant digestion and manure handling on the farm--were excluded from this survey, had they been included, the environmental emissions of the farm level would have increased tremendously. This confirms the fact that this stage is a serious environmental “hot spot” of this fluid milk chain.

A clear digressive logarithmic digression was observed in most plots of specific energy turnover against business size in kilograms of milk handled per year, suggesting that there is a certain degree of “ecology of scale” being experienced in this fluid milk chain at all stages. However, since at some levels of the chain sample sizes were small, this is not a very strong conclusion. Due to certain constraints, only a handful of dairy farms were surveyed, since they were meant to only give a picture of the energy situation at the agricultural level; further research is recommended for the agricultural level of this milk supply chain in order to obtain more information for a particular process chain. More work, specifically for this chain, may also be carried out in order to improve on some aspects of this study, such as the retailing phase that was left out of this study due to limited funds. This proves that applying the LCA methodology is useful for studying food process chains in developing economies. It is, however, worth to note that the most important setbacks were data availability and limitations in terms of monetary and time resources.

Summary

The energy turnovers of food supply chains have been studied before by other scientists. However, these studies have been carried out on different and unique food supply chains and as a result, conclusions and recommendations have been made with specific reference to the studied systems (Schlich, 2008; Herdtert, 2008; Krause, 2008; Schroeder, 2007, Schlich and Fleissner, 2004). Additionally, some researchers have warned against using data collected and conclusions made on specific food supply chains and attempting to apply them to other food supply chains, claiming that this would most likely not lead to real environmental improvements in the intended food supply chains (Owens, 1997). In light of this, it should be noted that no such study has been reported in literature on cases from developing economies, especially in Africa. This has made it difficult to recommend any tangible improvements on the environmental performance of such economies due to the lack of applicable baseline empirical data. The present study was designed as a case study of the Kenyan fluid milk chain to try and contribute to filling this gap.

The Kenyan case was chosen for this study due to the unique features of the Kenyan dairy sector as influenced by historical, social, geographical and cultural factors. For any substantial changes to be made toward a more sustainable and efficient energy utilisation, the required modifications to this food supply chain would be more effective if they were drawn from the Kenyan perspective and are based on Kenyan empirical data. Such data has been lacking even though it has been required by the dairy industry to make adjustments that would help it cope with increasing energy costs and environmental awareness, which is increasing among Kenyan consumers. This survey has made tangible efforts to establish empirical data on energy turnover of the Kenyan dairy enterprises and to use that data to try and establish the influence of business scale--here described as milk throughput on the specific energy turnovers of the studied enterprises, in terms of efficiency of energy use.

Energy is a major input in all parts of the food industry, as most processes involved in food production and processing consume energy. Recent increases in energy costs and concerns about global warming have encouraged food processors to try and optimise their energy use. In addition to that, energy use--especially the burning of fossil fuel--contributes significantly to the production of green house gases (GHGs) and ultimately climate change. It is also understandable that the increasing energy prices and depleting natural petroleum reserves have pushed the issue of energy to take a centre stage in many round table discussions among

food producers and processors. This is not only for ecological reasons but also for economic reasons as well, since it is increasingly difficult to maintain reasonable profit margins without considering the high cost of the energy input. In the recent past, energy has become a hot topic among consumers in the developing world, as global warning has been closely associated with the utilisation of fossil fuels, among other activities. Global warming is finally taking its toll by bringing climatic changes among the poorest of the poor in these regions that mostly depend on rain-fed agriculture to stay alive. The situation in Kenya is no different. Small and upcoming diary enterprises are trying to improve their profit margins by making attempts at using the available energy sources more efficiently; this study could not come at a better time.

Briefly, the history of the Kenyan dairy industry is that before 1954 commercial dairy production was the sole preserve of the white farmers living in the “white highlands” of the Rift Valley and around the Nairobi area. The period after independence in 1964 was marked by a large drop in cattle population and in large-scale farms, with a significant increase of small-holder contribution in dairying activities. This was because of a large transformation in land acquisition, division and redistribution, shifting from the large-scale “white settler” farms to much smaller portions. Co-operatives and other agencies emerged to assist small-scale farmers in marketing their produce both in the rural (informal) and urban (formal) markets. Between 1969 and 1992 the Kenyan dairy industry was controlled by the government, which gave the policy guidelines, set prices and determined the players in the industry, as well as setting the market rules. This resulted in a protected monopolistic market by one major government-owned milk processor to whom all dairy farmers countrywide had to supply their milk. Due to several issues, this milk processing company failed after some years, forcing the government of Kenya to put specific policy actions that liberalised the dairy market and encouraged commercialisation and privatisation of dairy support services in 1992. Since then, many small dairy enterprises have been cropping up in the farming areas of the country, often found around the mountainous escarpments of the Great Rift Valley and the Mount Kenya region. As a result, it is needful to establish a minimum business size that would be associated with efficient energy use and lowered costs of production.

As a result of this rapid growth, the establishment of empirical data on the energy use situation in the Kenyan dairy sector, and the use of this data to establish minimum business sizes that would result in more efficient energy use, have been anticipated by the dairy enterprises and could not have come at a better time. As the world tries to combat climate change by seeking alternative energy sources, each economy needs to do their part by putting efforts at utilising the existing fuels responsibly and sustainably. However, this can only come as a second step after establishing empirical data on energy use in our food supply chains, and this survey is helping Kenya to do just that. However, there is still a need for more Kenyan scientists to apply modern techniques, such as LCA, to establish energy requirements and resulting environmental impacts for other rapidly growing sectors. Therein lays the possibility of identifying inefficiencies and burdensome stages that can help to lower production costs in terms of energy use, as well as the environmental burden of Kenyan food supply chains.

There are several tools that have been developed by scientists to assist in identifying the environmental impacts of food supply chains. This study chose to apply Life Cycle Assessment (LCA) and, specifically, the energy balances as a component of LCA as the standardised method to establish a specific database of energy consumption and environmental emissions related to the main processes involved in the fluid milk life-cycle, starting from the agricultural to the milk distribution stage in Kenya. This was mainly driven by the fact that it is a standardised method and is quite versatile in its application. Besides identifying the environmental impact of the product or activity, LCA also identifies which activities in the product life-cycle contribute most to these impacts (Berlin, 2002) and, therefore, allow for appropriate and site-specific interventions that can bring real improvements in the environmental performance of the studied food process chain. This study limited itself to energy consumption, since energy consumption may lead to reduction in the direct cost of products, in addition to being directly linked to environmental performance of a product (Tokyo, 2000). The turnovers of energy in all steps of the process were first evaluated and then allocated to the functional units. From this database, the primary energy and environmental impacts were then calculated (Schlich and Fleissner, 2003). The study then went further to identify the environmental hot spots (life-cycle steps that are more burdensome to the environment) of the Kenyan milk chain, with respect to energy consumption and emissions that can contribute to global warming. By comparing the specific energy turnovers of different business sizes (here defined in terms of milk handled per year), the minimum business sizes advisable for a more energy-efficient milk supply chain that enjoys the advantages of ecology of scale in Kenya were also established.

The theory of **ecology of scale** supports the setting up of larger business sizes to favour lower emissions to the environment and borrows from the long-time economic concept of "economy of scale" (also "economies of scale"), which economists have used to describe the declining dependency of average production costs per unit on increasing number of units produced. This scientific theory supports that the energetic turnover and ecological impacts of a food supply chain at the point-of-sale depend on business size in inverse ratio, regardless of the distance between primary production and point-of-sale (Schlich, 2004). The cases of beef, pork, lamb, apples and wine analysed by (Herdtert, 2008; Krause, 2008; Schroeder, 2007, Schlich, 2004 and Fleissner, 2001) have articulately approved this hypothesis: that businesses of sufficient size can--from an energetic point of view--operate more efficiently than small businesses, regardless of whether they are operating regionally or globally, as opposed to frequent assumptions that less transport distances are obviously more ecologically friendly by emitting less GHGs because they consume less energy.

The product in this case was defined as fresh milk pasteurised, homogenised and packaged in a paperboard package ready for sale. The functional unit (FU) was defined as 1kg of fresh processed milk in a distribution depot ready for wholesaling or retailing. The retailing stage was left out due to the complexity and difficulty in obtaining accurate data for this complicated stage within a limited budget and limited time. In the Life Cycle Inventory analysis (LCI), only the delivered (metered) energy requirements were considered from the dairy farms: through the transportation of milk to bulking and cooling stations, cooling at bulking stations, transportation to the processing plants, actual processing and packaging, to the distribution stage. The study was therefore a typical second-order LCA. In order to simplify the study, the most important processes during the life cycle of milk in Kenya were included: activities involved one step before the actual inputs were also included, but the capital costs were left out.

The entire investigation was designed as an embedded multiple-case study, since it involved surveying more than one unit of analysis. The whole study was organised in such a way that it included several studies put together in order to complete the whole life cycle of the Kenyan dairy industry; each study (analysis) focussed on a particular life-cycle stage or unit process in the milk production and process chain. The four (4) main stages that were included are namely: production of milk at the farm, bulking and cooling of milk at cooling stations, milk processing, packaging and distribution of processed, packaged milk from the dairy to large company depots, or large-scale retailers, ready for further retailing. For each of these stages or unit processes, a multiple-case study was mounted to help collect information about the use of energy. In each of these multiple-case studies, replication logic was followed, which differs from the kind of sampling logic where a selection is made out of a population for inclusion in the study. In this type of sample selection, each individual case study consists of a "whole" study, in which facts are gathered from various sources and conclusions drawn based on those facts. As Yin (1994) pointed out, generalisation of results, from either single- or multiple-case study designs, is made to theory and not to populations. The study was a descriptive case study, also known as an “attributional” LCA study, which sought to establish the *status quo* of energy utilisation in the Kenyan milk supply chain. Therefore, the selection of cases was done to offer the opportunity to maximise what could be learned from each case, knowing that time and funds were limited. The selected cases were mostly willing subjects easily attainable within limited resources.

The results obtained from this study show that all the surveyed dairy enterprises had unique fuel mixes. Most dairy farms used diesel, electricity and wood fuel to power their day-to-day activities, although diesel contributed the largest share to the farms’ total energy turnovers. Among the surveyed collection centres, diesel and electricity were still the most important energy sources; while petrol and fuel oil were the least popular. At the milk processing stage, fuel oil emerged as an important fuel, in addition to diesel and electricity. Diesel was the sole energy source used to power small and large vehicles used to transport milk to the large milk distribution depots. In general, the surveyed small-scale dairy enterprises, as described in terms of milk throughput, were observed to require more energy to produce a kilogram of milk than their large-scale counterparts. For instance, among the included milk processing plants, the smallest dairy was found to require an approximated 22-fold more energy to process a kilogram of milk than the largest of the surveyed dairies.

These observations translated into larger-scale enterprises being seen as more environmentally friendly from an energetic perspective. This was because they required lower amounts of energy per kilogram of milk handled, which translated to less CO_2 per kilogram of milk being emitted into the atmosphere as a result, and thus better environmental performance. In the long run, the specific carbon emissions of larger businesses were reported to be low in spite of consuming more energy to produce larger volumes of product. The largest farm released about 2.6 times less CO_2 for every kilogram of milk produced when compared to the smallest farm. The smallest collection plant emitted almost 12 times more CO_2 per kilogram of milk collected than the largest collection centre. During milk processing, 14 times more CO_2 associated with processing 1 kg of milk was released by the smallest processor than by the largest. During the distribution of processed milk, the smallest distribution centre released 26 times more CO_2 into the atmosphere as a result of using energy to distribute 1 kg of milk than the largest distribution centre. From the provided empirical data, it looks quite intriguing to consider the ecological advantage of running larger businesses as compared to smaller ones within the context of this milk supply chain. This phenomenon could be further explored to control carbon emissions produced by the food process chains.

The present study also attempted to present a picture of specific energy turnover of the complete fresh milk supply chain in Kenya. The complete milk supply chain was found to have a specific delivered-energy turnover of **4.31 kWh/kg** of milk. This meant that each kilogram of milk ready for sale required 4.31 kWh of energy to produce it from the farms, process and package it--with all transport efforts included. This translated into **6.1534 kWh** of primary energy being required to produce, transport, process and distribute 1 kg of milk: in turn **0.7483 kg** of CO_2 would be released in the process. An applicable classification for the business sizes into small-, medium- and large-scale was also developed by the study, and using that classification, the surveyed cases were divided into three categories based on business size at all stages. Under this classification, the small-scale businesses had the largest specific delivered-energy turnover, meaning that they consumed the most energy: **7.99kWh** to produce 1 kg of milk as compared to their counterparts with larger businesses that required substantially less energy; **3.00 kWh** to produce a similar amount.

These findings offer great support to the thesis of ecology of scale and add weight to its potential as being an important key to more environmental-friendly food processing. The relationships between business scale and specific energy turnover were further explored and found to be more important than transport distances involved in this milk supply chain. In all surveyed cases, clear logarithmic digressions were observed on specific delivered-energy turnovers in relation to firm size. However, some cases presented stronger digressive logarithmic relationships than others. Upon comparing the specific energy turnovers of all the surveyed stages of this milk supply chain, the agricultural stage emerged as the one requiring the most energy to produce a kilogram of milk, and as a result, released the most CO_2 into the atmosphere. Consequently, it was identified as an important hot spot among all the explored scenarios of this milk supply chain. The optimum business size for efficient energy use, also termed as the break-even point for the investigated dairy farms, was found to be producing at least **1000 tonnes** of milk per year; for milk collection at least **10 thousand tonnes** of milk per year, and for processing and distribution of fresh milk a throughput of at least **100 thousand tonnes** of milk per year. For the complete fresh milk supply chain handling, at least **100 thousand tonnes** of milk per year was found to be energy efficient.

Presumably, diesel is an important fuel source and may therefore provide a useful target with the aim of making changes in this milk supply chain to improve its environmental performance. Electricity also emerged as an important energy source, although efforts need to be made to tap the existing potential and increase the production of hydroelectric and geothermal power in order to make the Kenyan electric mix “greener” than it now is and to ultimately reduce the associated CO_2 emissions. Due to certain constrains, only a handful of dairy farms were surveyed, as they were meant to only give a picture of the energy situation at the agricultural level; further research is recommended for the agricultural level of this milk supply chain in order to obtain more information for a particular process chain. Ultimately, this study recommends the application of energy balances as part of the LCA methodology as a useful method in studying the environmental performance of food supply chains in developing economies, and the establishment of “hot spots” and optimum business sizes for more energy-efficient food supply chains. This methodology may also be adopted for benchmarking purposes in food supply chains.

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FACHBEREICH 09
Agrarwissenschaften,
Ökotrophologie und
Umweltmanagement

Use of delivered energy in a food process chain: A case study of the Kenyan fluid milk chain

Appendices

Presented by:

Grace Chitsaka Mwangome., MSc.

from

Kilifi, Kenya

Energy Balance Survey of the Dairy Industry in Kenya

Farm Energy Inventory

Date: ______________________________

Questionnaire No: ______________________________

Introduction

This study seeks to establish the energy used in the whole dairy food chain with emphasis on packaged fresh milk. For that purpose, this questionnaire hopes to gather information on total materials used and energy consumed in the dairy farm, so that the total amount of fuel used can be allocated to the materials transported during milk production. Eventually, it is hoped that information on the efficiency of production will be generated to give advice on the overall logistics of the industry in Kenya.

Instructions:

1. Please read each question carefully before answering it.
2. Please indicate the source of data reported using letters **E**, **D** or **I** where **E** stands for **E**stimated data, **D** for **D**irect data (derived directly from administrative system) and **I** for **I**ndirect data (based on some sort of calculation).
3. Please refer to the year 2006 for all annual data requested.
4. Please be assured of the confidentiality of all data hereby given. This data shall strictly be used for academic purposes **ONLY** and has no commercial applications whatsoever.

SECTION A (Introduction of farm)

1. Name and title of respondent……………………..…..…………………………………
2. Name of farm..……………………………………………………….………………..
3. Office telephone/Address. …………………………………………………………………

   …………………………………………………………………………………………
4. Location of farm/ Area/Town…………………..……………………………………..
5. Since which year farm has been operational. ……………………………………..……….
6. Size of the farm:……………………..………ha
7. How much land is on pasture………………………………..ha
8. How many employees do you have……………………………………..
9. How far from here do most of them live………………………………
10. What means of transport do they use to get here………………………………………

SECTION B (Dairy farming section)

1. Dairy farming income (% of farm income): …………………………………
2. How many heads of cattle are in the farm ……………………………heads
3. How many are milked ……………………..…
4. How many are beef cattle……………………………………………………………..
5. How much milk do you produce on average/cow/year:…………………….………kg
   1. What percentage of milk produced is sent for processing: …………%
   2. What percentage is not (specify the purpose(s)…...........................%
6. Where do you send your milk for processing…………………….…………………...….
7. How far is the factory from here: ……………………………km
8. Do you transport the milk yourself to the dairy? Yes/No
9. If Yes to 9; above, what means do you use:…………………………………………
   1. How many times is the milk delivered in a day…..…………………
   2. What type of vehicle is used………………………………………….
   3. What type of fuel is used……………………………………………..
   4. How much fuel is consumed per trip…………………………..litres
   5. Are the vehicles loaded on the return trip (Yes/No)
   6. If yes to v. above,
      - a) What do they carry…………………………………………kg
      - b) How much/trip ………………..………………………………kg

SECTION C (Animal feed section)

1. For your animal feed, what is the ratio of fodder to concentrates………………………
2. Name the (2) two major fodder sources for the animals:
   a. ………………………………………………………………………..
   b. ……………………………………………………………………….
3. What percentage of total fodder does each represent
   a. …………………..…………………………………………………%
   b. ………………………………………………………………………%
4. What is the average cow weight in this farm……………………….………………..kg
5. Do you prepare fodder in the farm? (Yes/No)
6. If yes to 3. above, how much per day……………………….………………kg/day
7. Name the major feed concentrates used
   a. ……………………..……………………………………………
   b. ………………………………………………………………..
   c. ………………………………………………………………..
8. What are the four (4) main feed concentrates raw materials as percentage of total
   i. ………………………………………………………………………%
   ii. ……………………………………………………………………..…%
   iii. ……………………………………………………………………..%
   iv. ………………………………………………………………………%
9. How far is your concentrates supplier from here……………………………………km
10. How do you obtain your concentrates supplies? Self-delivery/Supplied
    i. What type of vehicle(s) are often used………………………………………
    ii. What type of fuel is used ……………………………………………
    iii. How much fuel is consumed per kilometre………………………………..litres
    iv. How many trips are made per week…………..……………………………..
    v. Are the vehicles loaded as they go for concentrates (Yes/No)
    vi. If yes to v. Above,
        a) What do they carry………………………………………….
        b) How much is carried per trip…………………..………kg
11. How much farmyard manure is produced per cow per year……………..kg
12. What do you do with the farmyard manure? ……………………………………………

……………………………………………………………………………………………

SECTION D (Water usage & disease control)

a) What is/are your major water source(s)as a percentage of total water used
    a. ………………………………………..……………...………%
    b. ………………………………………………………………...……%
    c. ………………………………………………………………..%

b) How much water do you use per year……………………………….……………..m^3
    i. How much water is used for animal feed ………………………………m^3/year
    ii. How much is for other purposes……………………………….…………m^3 /year
    iii. How much rainfall was received in the year 2006…………………………..mm

c) Name the major disease control method used…………………………………………...

d) Name the major weed control method used……………………………………………

e) Which major medicines/chemicals do you purchase for:
    a) Disease control……………………………………………kg/month
    b) Weed control………………………………………………kg/month

f) Who supplies your farm with medicines/chemicals
    a. Name of supplier……………………………………………………….
    b. Distance from here………………………………………………km

g) How are the chemicals/medicines delivered here (self-delivery/ supplier)

h) If self-delivery,
    i. How many trips/month are made to bring medicines…………..……trips/month
    ii. What kind of vehicles are used……………………………………………….
    iii. What kind of fuel is used…………………………………….………………
    iv. How much fuel is needed per trip………………...………………..litres
    v. Are the vehicles loaded when going to pick medicines (Yes/No)
    vi. If yes to iv. Above,
        a) What do they carry …………………………………………………
        b) How much is carried per trip…………………………………….……kg

i) Name the main fertilizers used for supply of:
    1) Potassium………………………………………………………………
    2) Phosphorus……………………………………………………………..
    3) Urea …………………………………………………………………………

j) How much fertilizer is used per year:
    1) ……………………………………………………………………..kg
    2) ………………………………..………………………………….kg

3) ……………………….………………………………………kg

k) Name the supplier(s) and their distance of location from here:

1) …………………………………………………………………….km

2) ……………………………………………………………………..km

3) ……………………………………………………………………..km

l) Who delivers the fertilizers (Self-delivery/Supplied)?

m) If Self-delivery

i. What type of vehicle is used……………………………………………………….

ii. What type of fuel is used………………………………………………………….

iii. How much fuel is consumed per kilometre…………………………………….

iv. How many times are fertilizers delivered per week……………………………….

v. Do the vehicles carry anything as they deliver fertilizers (Yes/No)

vi. If Yes to v., above,

a) What do they carry…..…………………………………………………

b) How much is carried per trip…………………………………………..kg

SECTION G (Energy Inputs)

1. Total fuel consumption for internal transport (within the premises)

Fuel Type	Total amount of input transported (kg)	Total consumption of fuel (litres)
Diesel oil		
Gasoline		
Liquefied Petroleum Gas		

2. External transport

Name of product transported	Road transport			
	Distance	Truck capacity	Actual load	Empty return
	km	Tonnes	Tonnes	(Yes/ No)
Others (specify)				

3. Summary of fuel consumption

Energy inputs Please specify the total energy mix you use for the total production department. If you have data in other units than the ones proposed below, please mark them clearly.		**Why we want to know this?** With this energy allocation columns we want to further precisely allocate the energy inputs to the production.				**Data source for total**		
						Direct data (derived directly from administrative system)	**Indirect data** (based on some sort of calculation)	**Estimated data**
Total	**Total use in year ___**	**Unit**	**Other Unit**	**Used for climate control and lighting, etc.**	**Used for production machines**			
Electricity from public grid		**kWh**		%	%			
Natural gas		**MJ**		%	%			
Light oil		**MJ**		%	%			
Heavy oil		**MJ**		%	%			
Coal		**MJ**		%	%			
Biomass/Wood								
Heat from other suppliers (warm water or steam)		**MJ**		%	%			
Own electricity generation (wind, water, sun and biomass)		**kWh**		%	%			
Total energy consumption		**MJ**		%	%			

4. What is the approximate moisture content of the wood used…………….………%

Data sheet for unit process.

This data sheet seeks to quantify all major inputs used for milk production in an effort to establish the resources needed to produce a kilogram of milk.

Completed by (Title)		Date of completion:	
Institution:		Unit process identification	
Time period: Year		Starting month:	
Material Inputs	Units	Quantity	Origin
Water Consumption 1)	Units	Quantity	Origin
Energy Inputs 2)	Units	Quantity	Origin
Material Outputs (Including products)	Units	Quantity	Destination

1) For example, surface water, drinking water etc.

2) For example, heavy fuel, medium fuel, light fuel oil, kerosene, gasoline, natural gas, propane, coal, biomass, grid electricity

Thank you for your cooperation!

Energy Balance Survey of Dairy Industry in Kenya

Dairy Factory Energy Inventory

Date:__________________________

Questionnaire No:______________________________

Introduction

This study seeks to establish the energy used in the whole dairy food chain with emphasis on packaged fresh milk. For that purpose, this questionnaire hopes to gather information on total materials used and energy consumed in the dairy factory, so that the total amount of fuel used can be allocated to the materials transported during milk production. Eventually, it is hoped that information on the efficiency of production will be generated to give advice on the overall logistics of the industry in Kenya.

Instructions:

5. Please read each question carefully before answering it.
6. Please indicate the source of data reported using letters **E**, **D** or **I** where **E** stands for **E**stimated data, **D** for **D**irect data (derived directly from administrative system) and **I** for **I**ndirect data (based on some sort of calculation).
7. Please refer to the year 2006 for all annual data requested.
8. Where possible, please attach copies of electricity and water bills to support given data.
9. Please be assured of the confidentiality of all data hereby given. This data shall strictly be used for academic purposes **ONLY** and has no commercial applications whatsoever.

SECTION A (Introduction of dairy processor)

1. Name of dairy processor…………………..………………………………………
2. Office telephone number…………………………………………………..………
   Email
   address…………………………………………………..……………...
3. Location of dairy/ Area/Town…………………………………..…………..……..
4. Since which year has the Dairy has been operational? ………………………….….
5. Size of the land on which the plant stands:…………………………….………ha
6. How many employees work here…………………………………………………..
7. How far from here do most of them live……………………………………….km
8. By which means of transport most of them get here…………………………………
9. Average number of supplying farms……………………………………………..
10. Average distance from supplying farms………………………….……………...…..km
    i. Closest farm distance………………………………………………….km
    ii. Furthest farm distance…………………………………………………km

SECTION B (Milk reception section)

1. How much milk do you receive per year………..…………………..kg
2. Do you collect milk from farms yourself (Yes/No) …..……………………
3. If yes, how do you transport it
   i. What is the regular means of transport used ……………………………………
   ii. How often is the milk delivered (trips per day)…………………..………..
   iii. Are vehicles loaded when going to collect milk? (Yes/No)…………………
   iv. If Yes to (iii) above, what do they carry……………………kg………..……
   v. What is the fuel source used………………………………………..….
   vi. How much fuel is used per trip……………………………………………litres
4. What do you do with the milk soon after reception (mark the appropriate procedure)
   a) Chill it ……………………………^{0}C
   b) Store it at room temperature ………………….^{0}C
   c) Process it immediately…………………………..
5. If a) to 4 above,
   i. Which cooling method is used…………………………….……………..
   ii. Which coolant is used…………………………………………………….
6. How long is the milk held before processing starts………………………….minutes

SECTION C (Milk processing section)

1. How much milk is lost in milk losses during processing per day……………..…….kg
2. How much milk do you process per year ……………………………..…………….kg
3. What percentage of received milk is processed into fresh milk ……..…..…………..%
4. What other products do you process? Give amount as percentage of all processed milk
   - **i.** ………………………………………………%
   - **ii.** ………………………………………………%
   - **iii.** ………………………………………………%
   - **iv.** ………………………………………………%
5. Is all the fresh milk packaged? (Yes/No)…………………………….……..………..
6. If No to 4. Above, what happens to the unpackaged milk.…………………………..
7. If Yes to 4. Above, name the (4) four major packaging materials used as percentage of total packaging used for fresh milk
   - i. ……………….……………………………………………………..……%
   - ii. ………………………………………………………………………..…….%
   - iii. ……………………………………………………………………………..%
   - iv. ………………………………………………………………………………%
8. How much of each packaging material is used per month
   - i. ……………………………..……...…kg
   - ii. ………………………………….……kg
   - iii. ……………………………………….kg
   - iv. ……………………………….………kg
9. How much waste paper is generated per day…………………………...……kg
10. How is the packaging material delivered here? (Supplier/ Self-delivery)
11. How far is your source of each packaging material from here
    - i. ……………………………………………………...……km
    - ii. ……………………………………………………………..km
    - iii. ………………………………………………………………km
    - iv. ………………………………………………………………km

12. If self-delivery,
    - a. What is the regular transport means…………………………….……..
    - b. What type of fuel is used…………………………….………………..

c. How much is used per trip…………………………………………….litres
d. How many trips are made per month………………………………...trips
e. Are the vehicles loaded as they collect packaging (Yes/No)
f. If Yes to e., above,
    i. What do they carry………………….……………………
    ii. How much………………….………………………..… kg

SECTION D (Cleaning and sanitisation)

1. What detergents are used for milk lines' sanitisation?
    I. ……………………………………………………
    II. ……………………………………………………
    III. ……………………………………………………
    IV. ……………………………………………………
2. How much of each detergent is used per month
    I. ……………………………………………………
    II. ……………………………………………………
    III. ……………………………………………………
    IV. ……………………………………………………
3. How far is your detergent supplier from here?..km
4. How are they delivered here? (Supplier/ Self-delivery)………………………………
5. For self-delivery
    i. What transport means are used…………………………………..
    ii. What fuel type is used……………………………………………..
    iii. How much fuel is consumed per trip……………………….litres
    iv. How often are deliveries done in a month………………………..
    v. Are vehicles loaded when going to collect detergents? (Yes/No)
    vi. If Yes to **v**. above,
        a) What do they carry ……………………………………………
        b) How much…………………………………………………..kg

SECTION E (Water and other resources)

1. Name your 2 (two) main water sources
    I. ……………..…………………………………………
    II. ……………………………………………………..

2. How much water do you source per year……………………………………….m^3
3. How much water is used as product water……………..…………………….m^3
4. How much water is used in cleaning per year……………………………..m^3
5. How much water is discarded as waste water per year………………………m^3
6. Where do you dispose of wastewater…………………………………….
7. Do you pre-treat wastewater before disposing of it? (Yes/No)……………..……...
8. What is the BOD, COD or TSS of your wastewater at the point of disposal………..…
9. How much urban solid waste is generated per day:
    1) In peak season…………………………………………………….kg
    2) In low season……………………………………………………….kg
10. How many times did you service your machines (excluding motor vehicles) in 2006? ....times
11. Do you service your motor vehicles regularly (Yes/No)………………………..……..
12. How often are the company vehicles serviced per month………………………times

SECTION F (Product distribution)

1. What percentage of your fresh milk sales occur away from here……….%
2. What is the average distance from most of your sale outlets……………..km
    i. Nearest …………………………km
    ii. Furthest…………………………..km
3. What transport means do you use for product distribution…………………….
    a. How many vehicles are used per day…………………………..
    b. What is the capacity of each…………………………………..tonnes
    c. How much does each carry per trip…………………………..tonnes
    d. What fuel type is used……………………………………………….
    e. How many trips are made per vehicle per day…………………trips
    f. How much fuel is used per trip…………………………….litres
    g. Are the vehicles loaded on the return trip (Yes/No)
    h. If yes to g. above,
        i. What do they carry……………………………………..…
        ii. How much is carried per trip……………………..kg/trip
4. Do you use refrigerated trucks in product distribution……………………….
    a) If yes, how many are they and what are their capacities

…………………………………………………………………………………….kg
……………………………………………………………….……………………kg
…………………………………………………………………………………..……kg

b) What cooling mechanism is used, name the refrigerant………………………
c) What fuel source is used ……………………….
d) How much fuel is required per trip……………………………………….litres

SECTION G: Unit process data sheet (milk processing and packaging)

This data sheet seeks to quantify all major inputs used for fresh milk production in an effort to establish the resources needed to produce a half a litre of packaged fresh milk.

Completed by (Title)		Date of completion:	
Institution:		Unit process identification	
Time period: Year		Starting month:	
Material Inputs	Units	Quantity	Origin
Water Consumption [1]	Units	Quantity	Origin
Energy Inputs [2]	Units	Quantity	Origin
Material Outputs (Including products)	Units	Quantity	Destination

[1] For example, surface water, drinking water etc.

[2] For example, heavy fuel, medium fuel, light fuel oil, kerosene, gasoline, natural gas, propane, coal, biomass, grid electricity

SECTION G (Energy inputs)

1. Total fuel consumption for internal transport (within the premises)

Fuel Type	Total amount of input transported	Total consumption of fuel/ month (Litres)
Diesel oil		
Gasoline		
Liquefied Petroleum Gas		

2. External transport

Name of product transported	Road transport			
	Distance	Truck capacity	Actual load	Empty return
	km	Tonnes	Tonnes	(Yes/ No)
Others (specify)				

3. Fuel sources and use

Energy inputs Please specify the total energy mix you use for the total production department. If you have data in other units than the ones proposed below, please mark them clearly.		**Why we want to know this?** These energy allocation columns will allow for further precise allocation of the energy inputs in the production.				**Data source for total**		
Total	**Total use in year**	**Other Unit**	**Unit**	**Used for climate control, and lighting, etc.**	**Used for production machines**	**Direct data** (derived directly from administrative system)	**Indirect data** (based on some sort of calculation)	**Estimated data**
Electricity from public grid			**kWh**	**%**				
Natural gas			**MJ**	**%**	**%**			
Light oil			**MJ**	**%**	**%**			
Heavy oil			**MJ**	**%**	**%**			
Coal			**MJ**	**%**	**%**			
Biomass/Wood (give moisture content %)			**MJ**	**%**	**%**			
Heat from other suppliers (warm water or steam)			**MJ**	**%**	**%**			
Own electricity generation (wind, water, sun and biomass)			**kWh**	**%**	**%**			
Total energy consumption			**MJ**	**%**	**%**			

Thank you for your cooperation!

Energy Balance Survey of Dairy Industry in Kenya

Cooling plant Energy Inventory

Date:________________________

Questionnaire No:__________________________

Introduction

This study seeks to establish the energy used in the whole dairy food chain with emphasis on packaged fresh milk. For that purpose, this questionnaire hopes to gather information on total materials used and energy consumed in the cooling plant, so that the total amount of fuel used can be allocated to the materials transported during milk production. Eventually, it is hoped that information on the efficiency of production will be generated to give advice on the overall logistics of the industry in Kenya.

Instructions:

1) Please read each question carefully before answering it.
2) Please indicate the source of data reported using letters **E**, **D** or **I** where **E** stands for **E**stimated data, **D** for **D**irect data (derived directly from administrative system) and **I** for **I**ndirect data (based on some sort of calculation).
3) Please refer to the year 2006 for all annual data requested.
4) Where possible, please attach copies of electricity and water bills to support given data.
5) Please be assured of the confidentiality of all data hereby given. This data shall strictly be used for academic purposes **ONLY** and has no commercial applications whatsoever.

SECTION A (Introduction of cooling plant)

11. Name of cooling plant……………………..…………………………………………

12. Office telephone number……………………………………………………….………

Email ddress…………………………………………………………..……………...

13. Location of dairy/ Area/Town…………………………………….…..……………….……..

14. Since which year has the cooling plant has been operational? ……………………….….…

15. Size of the land on which the plant stands:………………………………..………ha

16. How many employees work here………………………………………………………..

17. How far from here do most of them live……………………………………………..km

18. By which means of transport most of them get here…………………………..

19. Average number of supplying farms……………………………………………..

20. Average distance from supplying farms……………………….……………...…..km

    i. Closest farm distance……………………………………………………km

    ii. Furthest farm distance……………………………………………km

SECTION B (Milk reception section)

7. How much milk do you receive per year………..…………………..kg

8. Do you collect milk from farms yourself (Yes/No) …..……………………

9. If yes, how do you transport it

    i. What is the regular means of transport used ………………………………

    ii. How often is the milk delivered (trips per day)……………………..………..

    iii. Are vehicles loaded when going to collect milk? (Yes/No)…………………

    iv. If Yes to (iii) above, what do they carry………………kg……..…….

    v. What is the fuel source used…………………………………………….….

    vi. How much fuel is used per trip…………………………………………litres

10. What do you do with the milk soon after reception (mark the appropriate procedure)

    a) Chill it ……………………………^{0}C

    b) Store it at room temperature …………………^{0}C

    c) Transport it immediately…………………………..

11. If a) to 4. above,

    iii. Which cooling method is used……………………….……………..

    iv. Which coolant is used……………………………………………….

12. How long is the milk held before transportation takes place……………….minutes

SECTION C (Cleaning and sanitisation)

6. What detergents are used for milk lines sanitisation?
   - I. ……………………………………………………
   - II. ……………………………………………………
   - III. ……………………………………………………
   - IV. ……………………………………………………
7. How much of each detergent is used per month
   - I. ……………………………………………………
   - II. ……………………………………………………
   - III. ……………………………………………………
   - IV. ……………………………………………………
8. How far is your detergent supplier from here?..km
9. How are they delivered here? (Supplier/ Self-delivery)………………………………
10. For self-delivery
    - i. What transport means are used…………………………………..
    - ii. What fuel type is used……………………………………………..
    - iii. How much fuel is consumed per trip……………………….litres
    - iv. How often are deliveries done in a month…………………….
    - v. Are vehicles loaded when going to collect detergents? (Yes/No)
    - vi. If Yes to **v**. above,
      - a) What do they carry ……………………………………………
      - b) How much…………………………………………………kg

SECTION D (Water and other resources)

13. Name your 2 (two) main water sources
    - I. …………….………………………………………
    - II. ……………………………………………………..
14. How much water do you source per year…………………………….m^3
15. How much water is used as product water……………..………………m^3
16. How much water is used in cleaning per year………………………………..m^3
17. How much water is discarded as waste water per year…………………………m^3
18. Where do you dispose of wastewater………………………………………….

19. Do you pre-treat wastewater before disposing of it? (Yes/No)……………………...

20. What is the BOD, COD or TSS of your wastewater at the point of disposal……….…

21. How much urban solid waste is generated per day:

    1) In peak season……………………………………………………kg
    2) In low season…………………………………………………….kg

22. How many times did you service your machines (excluding motor vehicles) in 2006? ....times

23. Do you service your motor vehicles regularly (Yes/No)……………………….……..

24. How often are the company vehicles serviced per month………………………times

SECTION E (Product distribution)

4. What is the average distance from most of your processing plants ……………..km
    iii. Nearest …………………………km
    iv. Furthest…………………………..km
5. What transport means do you use for milk transportation…………………….
    i. How many vehicles are used per day…………………………..
    j. What is the capacity of each…………………………………..tonnes
    k. How much does each carry per trip…………………………..tonnes
    l. What fuel type is used……………………………………………….
    m. How many trips are made per vehicle per day…………………trips
    n. How much fuel is used per trip……………………………litres
    o. Are the vehicles loaded on the return trip (Yes/No)
    p. If yes to g. above,
        iii. What do they carry…………………………….…
        iv. How much is carried per trip………………..kg/trip

SECTION F: Unit process data sheet (milk cooling)

This data sheet seeks to quantify all major inputs used for fresh milk production in an effort to establish the resources needed to produce a half a litre of packaged fresh milk.

Completed by (Title)		Date of completion:	
Institution:		Unit process identification	
Time period: Year	Starting month:		
Material Inputs	Units	Quantity	Origin
Water Consumption 1)	Units	Quantity	Origin
Energy Inputs 2)	Units	Quantity	Origin
Material Outputs (Including products)	Units	Quantity	Destination

SECTION G (Energy inputs)

4. Total fuel consumption for internal transport (within the premises)

Fuel Type	Total amount of input transported	Total consumption of fuel/ month (Litres)
Diesel oil		
Gasoline		
Liquefied Petroleum Gas		

5. External transport

Fuel sources and use

Energy inputs Please specify the total energy mix you use for the total production department. If you have data in other units than the ones proposed below, please mark them clearly.		**Why we want to know this?** These energy allocation columns will allow for further precise allocation of the energy inputs in the production.				**Data source for total**		
Total	**Total use in year**	**Other Unit**	**Unit**	**Used for climate control and lighting, etc.**	**Used for production machines**	**Direct data** (derived directly from administrative	**Indirect data** (based on some sort of calculation)	**Estimated data**
Electricity from public grid			**kWh**	**%**				
Natural gas			**MJ**	**%**	**%**			
Light oil			**MJ**	**%**	**%**			
Heavy oil			**MJ**	**%**	**%**			
Coal			**MJ**	**%**	**%**			
Biomass/Wood (give moisture content %)			**MJ**	**%**	**%**			
Heat from other suppliers (warm water or steam)			**MJ**	**%**	**%**			
Own electricity generation (wind, water, sun and biomass)			**kWh**	**%**	**%**			
Total energy consumption			**MJ**	**%**	**%**			

Thank you for your cooperation!