IMPROVING THE PERFORMANCE OF THE FORMAL MILK SUPPLY CHAIN USING A LIFE CYCLE APPROACH

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M.Eng. Research Project

MEng/PG Diploma in Manufacturing Systems Engineering
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April 2019

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Thesis / Dissertation submitted in partial fulfillment of the requirements for the degree
Master of Engineering

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DECLARATION

This report contains no material which has been accepted for the award of any other degree or diploma in any university or equivalent institution in Sri Lanka or abroad, and that to the best of my knowledge and belief, contains no material previously published or written by any other person, except where due reference is made in the text of this report.

I carried out the work described in this report under the supervision of Dr. Himan K.G. Punchihewa.

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Signature : Date : 08 Apr 2019

Name of Supervisor : Dr. Himan K.G. Punchihewa

Abstract

In Sri Lanka, approximately 54.2 percent of the entire milk available for 2015 came from the formal milk supply chain and the rest was directed informally and consumed at home. The performance of supply chains in sustainability, is always on focus of continued trade growth. Therefore, new strategies and methods are required for risk-oriented and opportunity-oriented supply chain management. The methodology for the Life Cycle Assessment (LCA) can be described as a scientific technique to systematically evaluate the resource use of the product or service during the life cycle. Because of the high degree of intensity of energy affecting the overall performance of the dairy industry, the life cycle impacts linked with energy consumption in the formal milk supply chain is a particular concern.

The aim of this study was thus to increase the performance of the formal milk supply chain by employing a life - cycle approach to examine the effects of energy use in the dairy sector in Sri Lanka and to suggest a framework for evaluating the resulting impact of energy use on the environment. Accordingly, the definite objectives are to examine the use of energy in Sri Lanka's formal milk supply chain, to measure the environmental impacts during the recognized stages of the supply chain, to identify the most critical processes and to explore the resulting impacts of various alternative energy supply situations on the performance of the formal milk supply chain.

The study on the key stages of Sri Lanka's formal milk supply chain directed to the development of a methodology for assessing the impact of energy consumption on the environment during the life cycle. A case study was then carried out at a large-scale dairy manufacturer in Sri Lanka in which a life cycle assessment which was based on the supply chain and energy consumption was carried out. Finally, an impact assessment was done on potential performance variations in various energy supply scenarios. The impact evaluation of the life cycle was carried out by means of the Midpoint (H) method of ReCiPe (Ver 1.11, Dec 2014) in openLCA (version 1.7.0) with the ELCD database (version 3.2, Oct 2015). The results of the research were taken into account to determine the intensity of effects on the environment at the main stages of the supply chain process and to determine the possibility to mitigate negative impacts on the environment.

Finally, it was found that the dairy factory operation phase generally has the highest impact on the environment (64.0 %). Raw milk transportation phase also plays an important role being the second highest (26.3%). By comparing the different alternative energy supply scenarios, solar photovoltaic electricity generation can provide the highest environmental benefits. It was verified with the case study that the dairy sector can reduce the overall impacts approximately by 30% by replacing furnace oil with biomass for thermal energy supply. The use of solar power in milk-producing facilities and milk chilling centers to replace conventional power sources can, however, further reduce the total impact by up to 60 percent. In the long run, substituting conventional energy sources based on fossil fuel with local renewable (green) energy sources will also bring financial advantages to the country, whilst ensuring energy security and independence.

Key words: Life cycle assessment, Formal milk supply chain, Alternative energy, Environmental impact reduction

Acknowledgements

Writing this thesis was one of the most important academic challenges I've ever had to face. This study would not have been completed without the support, patience, and guidance of the following professionals. I owe them my heartfelt gratitude.

First of all, I would be extremely grateful to **Dr. Himan K.G. Punchihewa,** Senior Lecturer of the Department of Mechanical Engineering, University of Moratuwa, Who, despite his many other academic and professional engagements, committed to the role as my research supervisor, was a strength for me. I was inspired and motivated by his wisdom, knowledge, and commitment to the uppermost standards.

Also, I wish to express my appreciation to **Prof. Ruwan Gopura**, Head of the Department of Mechanical Engineering, University of Moratuwa who coordinated all these types of studies of our batch encouraging students and helping students to choose right supervisors for their studies, and facilitating.

I must be grateful to **Mr. Parackrama Weerasekara**, Operations Manager of Shaw Wallace Ceylon Ltd. for directing me to contact resource personal and providing guidance during this study.

I would like to express my gratitude to the Milk Procurement Manager of Richlife Dairies Ltd., **Mr. Mangala Kothalawala** for sharing his decades of experience in Milk Procurement & Milk Supply Chain Management in Sri Lanka with most of the top-class players in Sri Lankan dairy industry.

Also, I must be very grateful to **all the staff members of the Engineering Department, Milk Chilling Centers and Transport Department** of Richlife Dairies Ltd. for helping me in data collection and preparing the summary reports.

Finally, I would like to thank my wife **Dr. Bimalka Perera** for her unstinted support, motivation, love and patience.

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Nomenclature

Acronyms

BEV	Battery electric vehicle
CED	Cumulative energy demand
CNG	Compressed natural gas
DCC	Dairy collection center
ELCD	European reference life cycle database
EU	European Union
FG	Finished good
FU	Functional unit
GHG	Greenhouse gas
GIS	Geographical information system
GPS	Global positioning system
GWP	Global warming potential
HAP	Household air pollution
HC	Hydrocarbons
ICEV	Internal combustion engine vehicle
IDF	International Dairy Federation
IEA	International Energy Agency
IPCC	Intergovernmental panel on climate change
ISO	International organization for standardization
JRC	Joint research center
LCA	Life cycle assessment / analysis
LCIA	Life cycle impact assessment
LCI	Life cycle inventory
LPG	Liquefied Petroleum Gas
MCC	Milk chilling center
µPP	Micro power producers
NRE	New renewable energy
PV	Photovoltaic
RM	Raw milk
SL	Sri Lanka

SNF	Solid non fat
TTW	Tank-to-wheel
UK	United Kingdom
UN	United Nations
UOM	Unit of measure
USA	United States of America
WMP	Whole milk powder
WTT	Well-to-tank

Units

toe	tonnes of oil equivalent
MT	Metric tonnes
LKR	Sri Lankan rupees
kWh	kilowatt hours
GWh	Gigawatt hours
t-CO_2/MWh	tonnes of CO_2 per Megawatt hour
PJ	Peta Joule
kt	kilo tonnes
TJ	Tera Joule
MJ/kg	Mega joule per kilogram produced
mPt/MJ	million points per mega joule
Ltr	Liter
kg 1,4 DB eq	kilogrammes of 1,4 Dichlorobenzene equivalent
kg CFC-11eq	kilogrammes of Trichlorofluoromethane equivalent
kg CO_2eq	kilogrammes of Carbon Dioxide equivalent
kg N eq	kilogrammes of Nitrogen equivalent
kg NMVOC	kilogrammes of Non-Methane Volatile Organic Compounds
kg P eq	kilogrammes of Phosphorus equivalent
kg SO_2 eq	kilogrammes of Sulphur Dioxide equivalent

1 INTRODUCTION

1.1 Sustainability performance of supply chains

As trade continues to grow, the economic, environmental and social performance of supply chains is always on focus, with academics reviewing and highlighting practice. The challenge for focal companies is to manage media coverage risks, which often focus on environmental and social issues within supply chains. The most secure way of managing these risks is to avoid unwanted sustainability issues. In spite of that, the management of performance in sustainability has surpassed the period of mere risk management for pivotal companies and modern brand leaders. The desire for making a contribution to sustainable development is rising with increased awareness among business leaders. Also, increasing awareness of the design of 'Sustainable Products' emerges in many consumer markets. As a result, new strategies and methodologies are required for both opportunity-oriented and risk - oriented supply chain management [1].

1.2 Life cycle assessment (LCA) framework

Life Cycle Assessment (LCA) is characterized as a scientific method for the systematic assessment of use of resources and possible environmental effects related with a service or product during the full life cycle, from extraction through production and consumption to end - of - life by collecting an inventory (list) of material, related energy, environmental releases, land inputs and water [2].

LCA's system evaluation is recognized as a cradle - to - grave assessment, ranging from raw material extraction from the ground to the manufacture, the application of product and recycling and disposal at the end. The perspective is such that each stage depends on the one before it, addresses all phases of the life cycle. In order to provide the most reliable estimates of tradeoffs in technology selection, all environmental factors are taken into account. The basic framework of a life cycle assessment can be found in Figure 1.2.1. Defining the study’s obejectives and scope is the first step. The next (second) step is the compilation of a list (inventory) of the necessary environmental data, that is, material and energy. The next (third) phase is known as life cycle impact assessment in accordance with ISO 14040 standard. The results are also interpreted to help the process of decision-making. Comprising an extensive LCA, the entire system that generate technology or fuel is taken into consideration to avoid shifting environmental problems from place to place [2].

LCA can therefore be utilized for quantifying the environmental impacts of a product or a process in the supply chain over all life cycle stages. Therefore, country specific data and evaluations are important to quantify the impact of the life cycle in a certain background of a specific industrial application. LCA is therefore a data-intensive process. Also, deficiency of data will result in unreliability in the evaluation which will result in a limited application of the method. It poses challenges, in particular where strict monitoring actions are not being done in developing countries and therefore limited accessibility of the essential data [3].

Integrating LCA in the design of processes can help in identifying early - stage hotspots and avoid risks associated with environmental certifications and, ultimately, in several areas of their lifecycles, improve product environmental aspects. These improvements promote cost savings through reduced waste generation and rationalization of resource utilization as well as brand and reputation benefits [2].

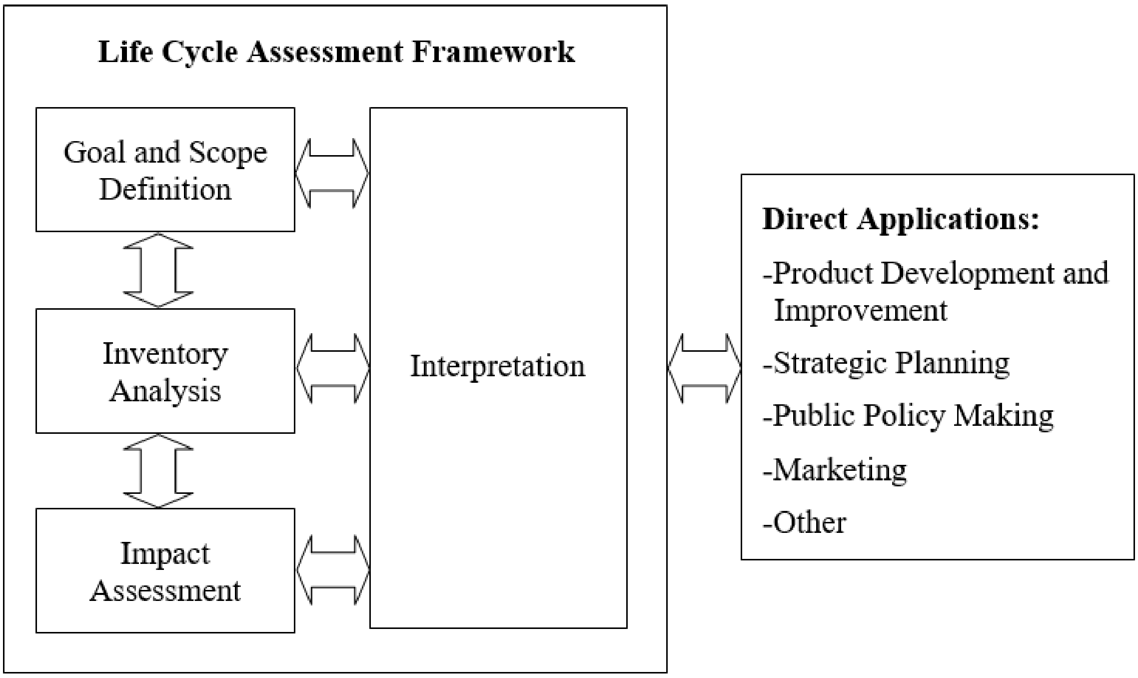


Figure 1.2.1: Framework for life cycle assessment based on ISO 14040:2006 [4]

Because of the high degree of demand for energy that contributes to the sustainability performance of supply chains, the life-cycle effects linked with energy consumption in the sector of manufacturing, are a particular focus. The entire life cycle of a process or a product needs to be assessed in order to have a complete idea of energy consumption and related environmental performance. Most of the industrial energy performance evaluations now focus on the direct energy usage and emissions which result in the process of manufacturing, thereby ignoring the effects and embodiment of energy in other life cycle stages such as material manufacture, transportation and waste disposal. Furthermore, the life cycle effects of the generation of energy (from the growth of infrastructures to end - of - life) are normally ignored, as direct carbon emission is taken into account in the assessment of environmental impacts of various energy sources. These limitations not only underestimate the true effects of the production process but also prevent potential areas for improvement from being identified. A way to think about life-cycles will help to identify the most critical issues and potential energy improvement strategies in the dairy industry and to take the most informed decisions for a sustainable industry [3].

1.3 Energy use and environmental impacts

Energy is an issue that has rapidly grown in importance in recent years. Not only has energy costs generally increased, but worldwide awareness of both our current energy uses' unsustainability and the impact of our fossil fuel emissions on CO_2 emissions [5]. Energy utilization and related environmental effects in the contemporary world are therefore a major source of concern. The International Energy Agency (IEA) reports that the energy sector accounts for two-thirds and 80% of the entire GHG (Global Greenhouse Gas) releases. GHGs and other energy-related toxic emissions have been related to anthropogenic climate change, resulting in bad impacts on the environment, e.g.: global warming. Awareness of the depletion of fossil fuel has increased in the various industries, especially with the industrial development and corresponding increases in the consumption of energy worldwide. Climate action targets were launched in the light of the concerns mentioned above about energy consumption and its environmental impacts. 195 countries agreed on a restriction and reduction of environmental releases for combating the climate change threat in 2015 under the Paris Climate Agreement (COP21) [3].

In its various forms, the global manufacturing industry contributes to a significant use of energy and emissions. Around 54 per cent of the global total energy supply is consumed by the industries. In 2012, 66 % of energy consumed was used by the manufacturing industry, which accounts for 35.6 % of worldwide energy consumption. In addition, the global consumption of industrial energy will increase by a yearly rate of 1.2 %. Focus on energy consumption and related emissions in various industries is therefore essential in proposing measures to mitigate harmful environmental and health effects [3].

Food production also impacts the environment in many ways, and energy consumption and contamination occur in many phases in the life cycle of a food produce. Increased agricultural and industrial practices are therefore a recommended way to increase output and meet the growing demand for food worldwide, but without occupying the rest of the natural ecosystems. With increasing outputs, as well as inputs to promote those outputs, agriculture and the food industry are increasingly dependent on energy sources such as fossil energy, directly from plowing processes and industries, or by using energies such as synthetic fertilizers and packaging materials. As a result, the production process is increasing. Thus, the responsibility of the food industry needs to be extended from the manufacturing site to the whole product chain in a more holistic and integrated product - orientated way, and to succeed [6].

A number of studies looked at energy demands in the dairy market, but mainly focused on European dairy systems and there was, however, a lack of research regarding milky food systems energy performance in developing or regions with varying climatic conditions [6].

1.4 Dairy industry in Sri Lanka

Dairy farming was practiced between rural people in Sri Lanka from prehistoric times. Traditionally milk animals perform several functions as organic fertilizer and fuel to produce dairy for household consumption, males as a means of transport and dung. They can serve as a reserve for capital and provide jobs for farmers over slow periods and improve stability of revenue. That is currently one of the main rural poor jobs. Dairy cows generate a continual income and cushion revenue shocks caused by the lack of crops for poor people with resources. Milk is a small farmers' cash crop, which transforms low value agriculture into a value - added commodity by products, agricultural residues and inexpensive family labor. They can move from subsistence to market - based revenue through regular dairy sales. Small scale milk production in the country is predominant. Its efficiency as an integrated agriculture system offers thousands of rural residents in Sri Lanka financial health and social security [7].

In 2015 the country's dairy industry showed significant development in the past two years while 61 percent of milk and related produces demand (71,026.84 MT of milk and milk products worth LKR 44.3 billion) remain dependent on imports. Of the available overall milk (around 403.2 million liters), in 2015 there was about 218.3 million liters (54.2 per cent) of milk in the formal dairy supply chain, and the rest was transported on informal roads as well as consumed domestically. This situation has strengthened the capacities of local livestock to deal with milk and milk products 'self-reliance' [7].

The increase in per person use of milk, from 45.16 liters per annum in 2014 to 48.56 liters per annum in 2015, has also been observed for imports of milk and milk products. Milk imports (milk-and dairy equivalents of liquid milk) grew by almost 22% in 2015, compared to 2014[7]. But the global per capita milk usage was 111.5 kg in 2015 [8].

The industry's energy requirement is met via a mixture of electricity grid, diesel, oven, kerosene, LPG and biomass sources. There is a increasing evidence of environmentally-sustainable and energy-efficient production practices among the dairy producers involved in Sri Lanka's formal milk supply chain. However, becaue of the deficiency in surveillance and regulatory procedures, a limited data on the effects to the environment, is currently available in Sri Lanka. The development of an environmentally sound industrial sector must address this issue. Global interest in sustainable, environmentally friendly products is growing. There is a global interest for such products. With consumers increasing their awareness of the environmental burden of the goods used by them, request for greater environmental liability in the manufacturing sector has increased. Sri Lanka's dairy industry can therefore take advantage of integrating the environmental sustainability concept in every process in its supply chain with life cycle thinking. In addition, this method can lead to financial advantages for the dairy industry via direct and indirect energy and resource costs savings. Consumers were also found to be ready to spend fair prices for "green" produces. This can further deliver a competitive gain to dairy companies in the marketplace with environmentally aware production and green labelling [3].

1.5 Aims and objectives of the study

In order to assess and evaluate the environmental impacts of the Sri Lankan dairy sector, the objective of this research is to enhance the sustainability results in the formal milk supply chain using the life cyclic approach.

The specific objectives are therefore to

1. Quantify environmental effects from energy use within the formal milk supply chain of Sri Lanka during the identified phases
2. Determine the most critical environmental impact processes
3. Study the effect on the sustainability performance of the formal milk supply chain of alternative energy supply scenarios

This research emphasizes Sri Lankan's dairy industry's limitations and challenges in integrating sustainable manufacturing concepts built on lifecycle thinking, and consider the necessity to fill out information gaps. This study is expected to address the shortcomings in the analysis of energy consumption of life cycle and the figures of environmental performance, particularly in Sri Lanka's dairy sector and in the countries being developed, in general, and to support policymakers further design for a sustainable industry.

1.6 Thesis outline

There are 7 chapters in this thesis. Chapter 1 deals with the idea of evaluating the life cycle, as well as the goals and objectives of the study. Chapter 2 is an evaluation of the literature of prevailing researches in this field. The literature was evaluated and examined critically to detect the gaps in existing studies needed to define the research aims. The methodology used for this study is discussed in Chapter 3. In Chapter 4, it was discussed (i) how the relevant data was obtained for the study via selected methods, such as literature survey, accessing databases, and models; (ii) how the life cycle assessment, by measns of the ‘openLCA’ model in the research, was performed; (iii) how different (alternative) energy supply scenarios were taken into account; and (iv) The assessment of potential advantages to the Sri Lankan dairy industry in different alternative energy scenarios. The analysis findings are discussed in Chapter 5. In Chapter 6, the results of the study were presented as summaries and conclusions. Recommendations for future research are included in this section. The references used in this study were finally listed in Chapter 7.

2. LITERATURE REVIEW

2.1 Energy balance of Sri Lanka-2015

There is certainly an incredible transformation of the energy systems around the world. There is no exception to the energy industry in Sri Lanka. Transactions in the energy field have entered a new stage, with the traditional power suppliers dominated by large - scale suppliers and numerous users changing form into value chains operated by many small suppliers dealing with many users. These changes mainly occurred in on - site energy generation using a solar photovoltaic ceiling and in large quantities of industrial thermal energy use, which moved from central fossil fuels to large - scale fuelwood supplies. These emerging complexities will still affect timely reporting of transactions in the energy sector [9].

Sri Lanka's energy sector suffered a number of unforeseen events during 2015, starting from relatively low oil prices following a lengthy escalation and also a low likelihood of high electricity - related events. In the course of 2015, the positive developments in renewables continue to indicate a mature form of the market, aside from these events. Management of the energy demand side attracted the attention of policy makers and led the government to set up a Presidential Energy Demand Side Management Task Force to prepare a five - year plan to deal with growing demand in the most economical way. Coal electricity has become a strong generator for base load and has largely relieved the country of the burden of costly power generation from liquid fossil fuels. In 2015, coal generation accounted for 34% of the total country's electricity production [9].

Biomass remains the largest source of energy supply, fulfilling a large part of domestic cooking energy demands. Hydro - power for generating power has been extensively developed, but studies have shown that wind and solar power generation has great potential. In view of the severe limitations imposed by the country's demand profile, the full exploitation of those resources is delaying. Results of offshore oil resources are currently being investigated. Until now, the primary energy supply has dominated biomass. But biomass and petroleum currently dominate equally, at 39% of the total supply of primary energy. Coal accounts for 10%, and 9% of hydro power, while New Renewable Energy (NRE) accounts for 3%. The main secondary source of energy remains electricity. In 2015, the total energy generation amounted to 13,206.8 GWh of which 51% was produced by thermal power plants. In 2015, NER generation reached 11% and succeeded in meeting the policy objective of generating 10% of NER electricity by 2015. By 2015, approximately 38.8 GWh of solar net metering had been implemented, further strengthening NRE's policy goal to generate 10 per cent electricity by 2015 [9].

Like previous years, household, commercial and other industries were the largest energy consuming sector in 2015 and accounted for 40.6 percent of the total country's energy demand. The share in the transport sector, mainly met by liquid petrol, represented a 28.8% share of energy consumption, while the industry surpassed transportation demand by 30.6% [9].

The grid emission factors calculated for 2015 indicate 6 896E-01 t - Co2/MVh for the simple operating margin, 1.007 t - CO2 / MVh for the build - margin and 8.481E-01 t - CO2 / MWh for the combined margin [9].

Table 2.1.1: Key energy statistics [9]

Primary Energy (PJ)	**2014**	**2015**
Biomass	205.6	202.2
Petroleum	190.8	202.6
Coal	38.5	51.9
Major hydro	36.7	49.3
New Renewable Energy	12.6	15.3
Total	**484.2**	**521.4**

Imports (kt)	**2014**	**2015**
Crude Oil	**1,828.8**	**1,676.8**
Coal	**1,606.6**	**1,881.5**
Finished Products	**2,847.5**	**2,995.3**
LPG	198.0	277.0
Gasoline	584.8	899.0
Avtur	234.9	270.8
Auto Diesel	1,394.4	1,288.8
Fuel Oil	348.4	203.3
Avgas	0.2	0.1
Bitumen	56.0	32.2
Mineral Gas Oil	30.9	24.1

Refined Products (kt)	**2014**	**2015**
Crude Input	1,824.0	1,692.1
Naphtha	117.0	136.6
Petrol	152.3	154.2
Avtur	168.5	154.6
Kerosene	65.2	75.2
Diesel	496.2	516.7
Furnace Oil	641.2	552.5
Solvents	2.5	1.5
Total Output	**3,466.9**	**3,283.3**

Grid Capacity (MW)	**2014**	**2015**
Major Hydro	1,377.0	1,377.0
Thermal Power	2,213.0	2,028.0
New Renewable Energy	439.7	455.0
Micro Power Producers (μPP)	13.3	27.7
Total	**4,042.9**	**3,887.6**

Gross Generation (GWh)	**2014**	**2015**
Major Hydro	3,649.7	4,904.4
Thermal (Oil)	4,419.3	2,339.2
Thermal (Coal)	3,525.0	4,457.2
New Renewable Energy	1,217.5	1,467.1
Micro Power Producers (μPP)	18.6	38.8
Total	**12,830.1**	**13,206.8**

Average electricity price (LKR/kWh)	18.5	16.4
Net oil imports as % of non-petroleum exports	41.3	24.6

Total Demand (PJ)	**2014**	**2015**
Biomass	204.5	200.7
Petroleum	135.9	171.4
Coal	2.6	2.3
Electricity	39.5	42.3
Total	**382.5**	**416.6**

Demand by Sector (PJ)	**2014**	**2015**
Industry	98.9	127.5
Transport	112.5	119.8
Household & Commercial	171.0	169.3
Total	**382.4**	**416.6**

Industry Demand (PJ)	**2014**	**2015**
Biomass	73.1	75.5
Petroleum	9.8	35.8
Coal	2.6	2.3
Electricity	13.5	14.0
Total	**98.9**	**127.5**

Transport Demand (PJ)	**2014**	**2015**
Petroleum	112.5	119.8
Total	**112.5**	**119.8**

HH, Comm, Other (PJ)	**2014**	**2015**
Biomass	131.4	125.2
Petroleum	13.6	15.8
Electricity	26.0	28.3
Total	**171.0**	**169.3**

Electricity Demand (GWh)	**2014**	**2015**
Domestic	4,051.1	4,444.7
Religious	72.1	76.4
Industrial	3,758.2	3,880.1
Commercial	2,985.2	3,178.9
Street lighting	135.3	160.7
Total	**11,001.9**	**11,740.9**

Grid Emission Factors (t-CO2 /MWh)	**2014**	**2015**
Operating Margin	0.6938	0.6896
Build Margin	0.7490	1.0067
Combined Margin	0.7214	0.8481

GDP at 1982 factor cost prices (million LKR)	452,246	473,954
Commercial Energy Intensity (TJ/LKR million)	0.39	0.46
Electricity Sold (kWh/person)	532.1	560.0
Petroleum Sold (kg/person)	194.9	207.7

2.2 Environmental effects of energy use

Energy utilization industries are increasingly conscious of the consequences of greenhouse emissions from their processes – both direct energy consumption and electricity generated from the processing plant remotely [5].

The environmental problems of the effects of energy generation and consumption are linked to the natural environment and availability of resources, human health and the built environment, [5].

2.2.1 Human health and the built environment

Energy consumption for food preparation, hot furniture, travel and production of goods among many other purposes is central to human activity. But every energy source poses some risks to health. Today's energy systems have the greatest impact on health through extraction and combustion of solid fuels: biomass and coal. The domestic air pollution caused by the poor combustion of solid-state fuels consumed for home cooking and heating is exposed to two - fifths of humanity. In addition, almost everybody in the earth is exposed to a certain amount of open-air contamination caused by combustion of fuel. They are the largest environmental emissions for biomass and coal, further originated from other petroleum fuels, in particular oil. With the proximity of combustion to people (ie, as the intake portion increases) and the portion of partial combustion, per unit of valuable energy, the health benefits of emissions - recession interventions rise. Therefore, in view of the broad use of solid fuels in households, major health and climate co - benefit opportunities lie in moving away from solid-state fuels and intensely increases of household combustion efficiency [10].

Human - made climate change is already imposing health effects, especially on poor populations, which is caused mainly but not entirely by energy use. In the coming decades it is likely that health impacts of climate change will grow steadily. Major efforts to mitigate and adapt can decrease the extent of future impacts. CO2 emissions must be reduced dramatically by energy efficiency measures and by a move away from fossil fuels for the long run, while fuel switching and better combustion are equally important in reducing the rate of warming of other climatically modified pollutants such as methane, black carbon and ozone precursor. These non-CO2 pollutants also directly damages the health of the environment, thereby reducing their emissions results in significant co-benefits in the near future. Moving urban design to fuel efficient modes of transport also benefits health by increasing physical activities and reducing motor vehicle crashes and the exposure to noise [11].

Although the quantitative comparison with the major energy risks is hard due to the potential of low - probibility disasters with a high consequences, other energy sources, such as nuclear, also present some risk. The health effects of most new and renewable sources of energy are likely to be much lower, but attention is necessary to ensure that those energy sources are carefully managed. Energy efficiency measures are usually desirable, although care must be taken to prevent possible health effects resulting from reduced building air exchange [10].

To completely know health and climate costs and advantages throughout storage, production, transport and end - use processes, the method to evaluating energy sources is essential. This approach allows for the identification and evaluation of trade - offs, as well as full costs and full benefit accountability. This is a crucial process because there are numerous trade - offs, many of which are directly humane. Multidisciplinary approaches and methods like assessments of health impacts may be helpful [10].

While energy is crucial to people's wellbeing, energy systems play a major role in the global disease burden. Solid fuels HPA was responsible, in 2010 for ~3.5 million premature deaths and general outdoor air pollution, which has a great energy factor, for ~3.1 million premature deaths in the same year as per to the Global Burden of Disease 2010 study. A significant proportion of the external air pollution in Asia in particular comes from poor household combustion of fuel, which shows that around half a million premature deaths caused by the outdoor air pollution worldwide stem from household pollution. The addition of the indirect role of energy in the management of pollution and the occupational risks would likely add 10 - 20 percent more to these figures and would almost double these values by including road traffic accidents and the role of power in physical inactivity. Due to uncertainties, the direct effects of energy systems are greater than those of many other risks other than malnutrition that rival the global effects of tabaco, alcohol and high blood pressure, and that they are global in health alone. The immense share of the direct impact is due to the poor fuel combustion management. Consequently, energy is clearly a global health problem [10].

Emissions from power stations to the atmosphere will also have a number of consequences for the human / built environment. The emission particulates in buildings that decrease their attractiveness will be deposited. Particulates will also be deposited in the areas where people live and their normal daily activities could be affected. Sulfur Dioxide emitted into the atmosphere is combined to produce sulphuric acid in combination with water vapor. Likewise, the dioxide of nitrogen becomes a nitric acid. These acids can powder building materials like concrete or steel and degrade protective surfaces, for example paint. Furthermore, air pollution will affect crop, forest resources, fish and wildlife directly. Gasses and smoke are released from energy production and thus degrade the human and natural environment.

Table 2.2.1: Greenhouse gas emission and impacts on well-being [12]

	Impacts on Human Health and Well-being					
GHG Emissions	**Environment/ ecosystem impacts**	**Human health**	**Food security**	**Physical security and safety**	**Socio-economic**	**Other impacts**
	↑ in temperature	↑ in deaths due to heat stress	↑ of hunger	↑ human vulnerability	↑ energy requirements for cooling	↑ threatened livelihood of communities
	↑ extreme weather events, floods, droughts	↑ diseases e.g. diarrhea and vector-borne diseases	↕ crop production		↑ loss of economic properties	↑ vulnerabilities of poor countries and amongst most vulnerable: women; children; aged; indigenous groups
	↑ sea surface temperature ↕ precipitation ↑ land and sea ice melting ↑ ocean acidification	↑ water scarcity ↓ sanitation			↓ overall capital e.g. natural, social	↑ impacts on human rights and justice

2.2.2 Eco systems and the natural environment

A service provided by species and ecosystems results in many forms of energy. The way energy is exploited and used makes energy a crucial environmental issue, with frequent impacts on ecosystems, in particular on the sourcing, production, transmission and usage of conventional fossil fuels and even on renewable options. Ecosystems are also crucial to meeting the increasing demand for energy. In order for future energy supply to increase sustainably, ecosystem quality and integrity must be well managed and improved [12].

The effect on communities ' resiliency will be challenged by climate change such as changes in water levels, temperature, rainfall and wind conditions. The consequences will be greatest for those who directly rely on ecosystems for their supply of energy, such as biomass. Therefore, ensuring energy protection must be a top priority while preserving the integrity of the ecosystem in the face of anticipated climate change. Despite its importance, the interconnections and implications of these connections between these three issues are relatively little known [12].

Biomass has always been the most frequently used source of energy. The traditional use of biomass for cooking and heating still depends upon 2.5 billion people, but more modern bioenergy uses are also promoted, for example, by copra for combined heat and energy production and biogas production. Ecosystems deliver both commodities (feedstocks, biomass, and enzyme digestors) and services (pollination, soil formation, water and climate regulation) in biofuels and biomass - based energy [12].

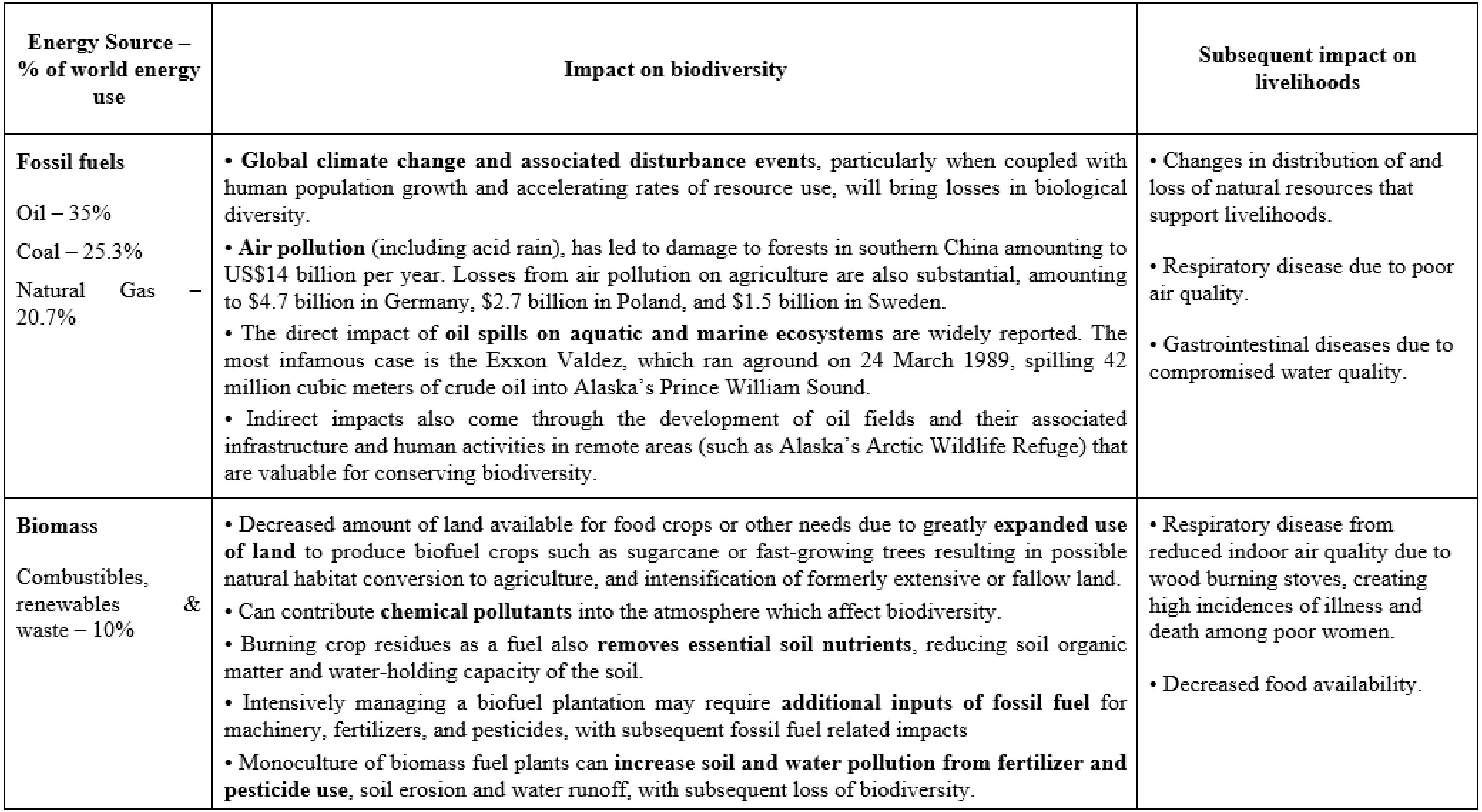
A key ecosystem service is the water supply, which supports many energy generation options. Water is used for gas and oil manufacturing, as well as to support biomass production and use in hydroelectric plants. Ecosystem services for energy generation are more modern applications including the utilization of ocean currents for electricity generation [12].

Increasing attention is being paid to oceans as part of the effort to reduce emissions of greenhouse gases and meet future energy demands. Thermal, tidal wave, and wind power technologies are under development which are currently the most advanced offshore wind and tidal power. Although Tidal Energy does not emit greenhouse gases or acid rain, its environmental consequences are not clear. Much impact is specific to the site. e.g. barrier effect on local tides, for example. Additional information on benthic communities, fish, mammals, and birds such as disturbances caused by noise, the shadow, electromagnetic fields, and changed water conditions and habitat structures has not been determined [12].

Contaminants, however, can pollute waterways directly when they are released into the environment in energy plant emissions. Because atmospheric movement ecosystems in even remote surroundings transported air emissions over wide distances. For example, remote lakes are acidified and forestry ecosystems in North America and Europe are affected by acid rain [12].

Deposition of acids will also affect soils and could further affect fragile ecosystems. Other activities of humans are affected by the degradation of the environment. Tourism will be affected and leisure areas will be put at risk for swimming and fishing activities.

Table 2.2.2: Energy sources and impacts [12]



Energy Source – % of world energy use	**Impact on biodiversity**	**Subsequent impact on livelihoods**
Fossil fuels Oil – 35% Coal – 25.3% Natural Gas – 20.7%	• **Global climate change and associated disturbance events**, particularly when coupled with human population growth and accelerating rates of resource use, will bring losses in biological diversity. • **Air pollution** (including acid rain), has led to damage to forests in southern China amounting to US$14 billion per year. Losses from air pollution on agriculture are also substantial, amounting to $4.7 billion in Germany, $2.7 billion in Poland, and $1.5 billion in Sweden. • The direct impact of **oil spills on aquatic and marine ecosystems** are widely reported. The most infamous case is the Exxon Valdez, which ran aground on 24 March 1989, spilling 42 million cubic meters of crude oil into Alaska's Prince William Sound. • Indirect impacts also come through the development of oil fields and their associated infrastructure and human activities in remote areas (such as Alaska's Arctic Wildlife Refuge) that are valuable for conserving biodiversity.	• Changes in distribution of and loss of natural resources that support livelihoods. • Respiratory disease due to poor air quality. • Gastrointestinal diseases due to compromised water quality.
Biomass Combustibles, renewables & waste – 10%	• Decreased amount of land available for food crops or other needs due to greatly **expanded use of land** to produce biofuel crops such as sugarcane or fast-growing trees resulting in possible natural habitat conversion to agriculture, and intensification of formerly extensive or fallow land. • Can contribute **chemical pollutants** into the atmosphere which affect biodiversity. • Burning crop residues as a fuel also **removes essential soil nutrients**, reducing soil organic matter and water-holding capacity of the soil. • Intensively managing a biofuel plantation may require **additional inputs of fossil fuel** for machinery, fertilizers, and pesticides, with subsequent fossil fuel related impacts • Monoculture of biomass fuel plants can **increase soil and water pollution from fertilizer and pesticide use**, soil erosion and water runoff, with subsequent loss of biodiversity.	• Respiratory disease from reduced indoor air quality due to wood burning stoves, creating high incidences of illness and death among poor women. • Decreased food availability.

Hydroelectricity ~2.2% of energy use	Building large dams leads **to loss of forests, wildlife habitat, and species populations**, disruption of natural river cycles and the degradation of upstream catchment areas due to inundation of the reservoir area. • Dam reservoirs also emit **greenhouse gases** due to the rotting of vegetation and carbon inflows from the basin. • On the positive side, some dam reservoirs provide **productive fringing wetland ecosystems** with fish and waterfowl habitat opportunities.	• Alterations in availability of freshwater resources (both improved and declining depending on situation) for human use. • Population displacement.
Nuclear energy ~ 6.3 %	• A nuclear accident would **have grave implications for biodiversity survival** generally and not just humans • Water used to cool reactors is released to environment at significantly above ambient temperatures and accentuates **ecological impact on riverine fauna** of climatic accidents such as heat waves. • Produces relatively **small amounts of greenhouse gasses** (during construction of the infrastructure required). • Because of the potential risks posed by nuclear energy, some nuclear plants are surrounded by **protected areas**. For example, the Hanford Site occupies 145,000 ha in south-eastern Washington State: it encompasses several protected areas and sites of long-term research and provides an important sanctuary for plant and animal populations.	• Radiation-related diseases if a nuclear accident occurs. • Decreased productivity of ecosystems impacted by high temperature water. • Possible population displacement.
Alternative energy sources Wind power Solar energy Tidal power Geothermal energy ~0.5%	• **Ecosystem disruption** in terms of desiccation, habitat loss at large wind farm sites; undersea noise pollution. • Tidal power plants may **disrupt migratory patterns** of fish, reduce feeding areas for waterfowl, disrupt flows of suspended sediments, and result in various other changes at the ecosystem level. • Large photovoltaic farms **compete for land** with agriculture, forestry, and protected areas. • Use of **toxic chemicals** in the manufacture of solar energy cells presents a problem both during use and disposal. • Disposal of water and wastewater from geothermal plants may cause significant **pollution** of surface waters and ground water supplies. • Rotors for wind power can cause some **mortality** for migratory species, terrestrial and marine.	• Decreased species populations to provide basic materials of life. • Unknown impacts from noise, shadows, electromagnetic fields affecting fish and mammal populations (food source). • Toxins released to the environment may cause public health problems. • Decreased economic value of the landscape near wind farms due to visual impacts.

2.2.3 Resource (mineral & fossil) availability

A complete and extensive process is the conversion of energy systems, as is the quest for material alternatives for fossil energy resources. Storage systems, energy efficiency improvements and energy grid adaptation are just a few of the steps necessary to overcome the challenges ahead. On a global scale that means the power mix will only change very little and significant changes will take decades rather than years to make in the proportions of various types of energy resources. The experience gained in Germany– for example, the conversion of energy infrastructure –also underscores the long times involved in the process of transformation, even with a social consensus on the issue of the future orientation of the country's energy policy already reached in the favorable light. The dependence on long-term fossil fuels is too firm to be resolved in just a few years [13].

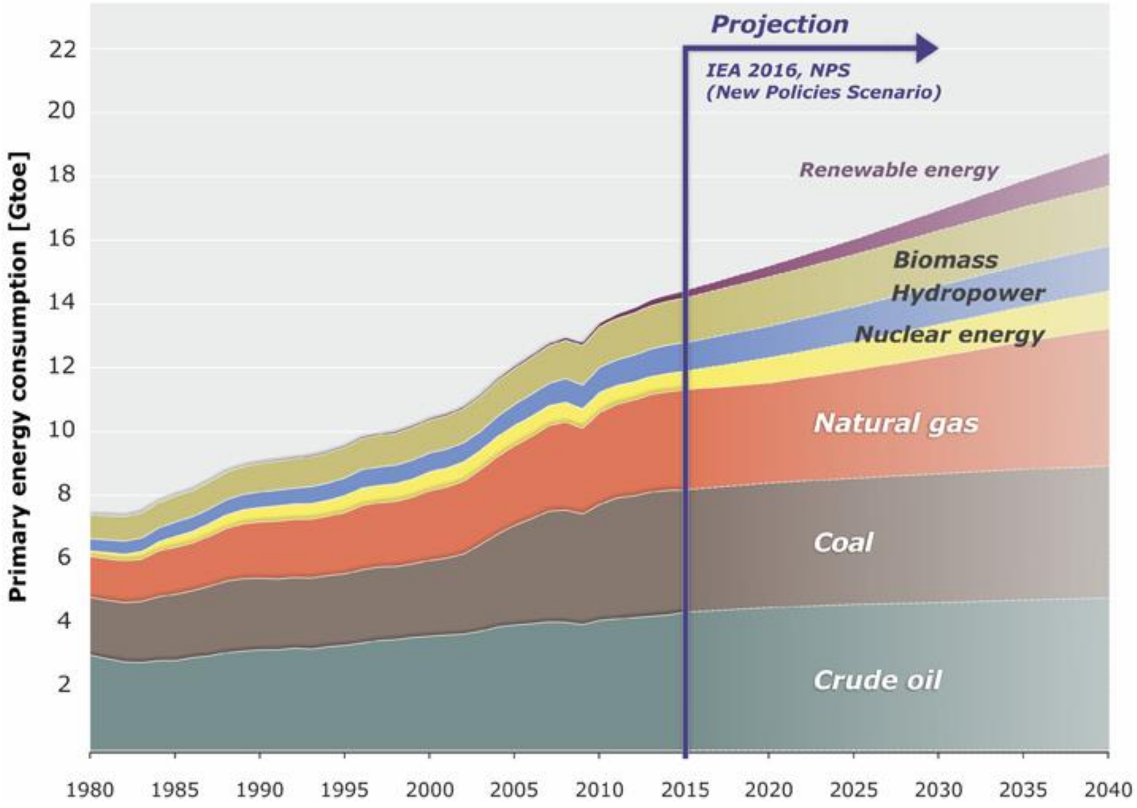


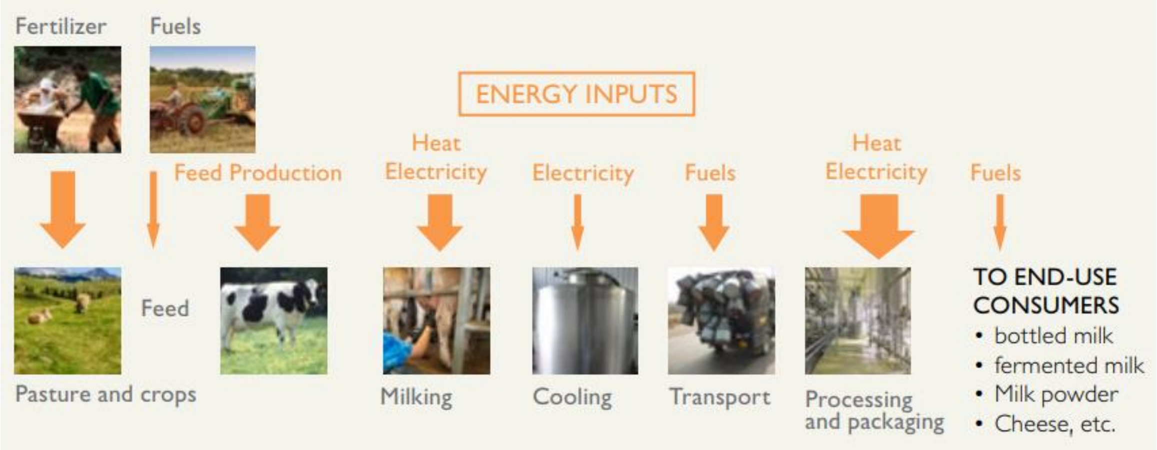
Figure 2.2.1: Development in global primary energy consumption per energy resource, and a possible scenario for future developments [13]

A reliable and economical supply of primary energy provides the basis for our prosperity and is critical for the development of working economies. In the coming decades, the world's populations will continue to grow and thus the demand for primary energy will grow. In the face of these challenges, fossil fuels will also be part of the world's energy supply. This is why, while declining proportions and improving efficiency will be achieved, fossil energy resources will still be essential for global production of energy in the foreseeable future to allow expansion of renewable energies and implement the mix of energy changes without disruption [13].

2.3 Energy use in milk value chain

The world food supply chains are challenging in terms of energy utilization, as stated in the "Opportunities for Agri - Food Chains to Becoming Energy - Smart" report published by the UN Food and Agriculture Organization in 2015. Over decades, food production, processing and disclosure were very dependent on fossil fuel input (except farmers who get the use of only manual labor and possibly power of animals for producing food, then cooked on cookers with inefficient biomass, for their families). As the global populations grow, food demand has also increased steadily and the demand for higher diets of protein has increased steadily. As a result of this, the agri - food industry has become an important greenhouse gas (GHG) producer [14].

Like all economic activity industries, the dairy sector is concerned with reducing its energy use as much as possible to reduce costs and play a responsible role in the global effort to control the impact on the global environment. Milk manufacturers have also become more aware of the importance of energy consumption. This is one of many processors' higher costs and components that can best be changed to reduce technology improvements and more controls on management [14].



Note: *Arrow widths indicate typical comparative levels of demand for energy inputs.*

Figure 2.3.1: Energy inputs at different stages of the milk value chain [14]

Systems differ whether animals are fed on pastures, drilling or preserved feed or concentrates are transported into livestock buildings. The demand for energy and water increased significantly with irrigation. The milk can be consumed fresh locally or processed and packaged in various ways for local or distant domestic or export markets [14].

Any milk value chain has a variety of energy intensive technologies that each offer the chance of decreasing GHG emissions.

1. ***Conservation*** agriculture is an approach to ecosystems management to improve and sustain continuous productivity through minimisation of mechanical disturbance of the soil, permanent moisture coverage and rotational diversification of crop species. Less tillage fuel, less irrigation power and less indirect weed control power per product unit can cause lower energy use. Any GHG and cost savings, however, are compensated if crop productivity results are reduced [14].

2. The drinking, irrigation and food processing purposes of ***water pumps*** consumes a large quantity of energy, typically using either electricity or diesel to power pumps on internal fuel engines. The popularity of the solar and wind energy pumps is growing and where good solar and wind energy sources exist, they should be promoted. Irrigation energy requirements can be reduced by:

    - where possible, use gravity supply;
    - efficient electric motor designs;
    - size pumping systems according to the actual water needs of the crop;
    - select efficient, properly matched water pump designs to meet the challenge;
    - regular maintenance of the pump;
    - use low - head sprinklers or drip irrigation systems in rows of crops;
    - soil moisture monitoring for water application rates;
    - selecting appropriate crop varieties resistant to drought;
    - use weather predictions when rotating water in various fields;
    - different irrigation rates across the field to match soil and humidity conditions through use of Global Positioning Systems (GPS) based automatic regulating systems;
    - Conservation of soil moisture by mulch, tree protection belts, etc.; and
    - Maintenance in good working order (so minimizing system failures), all equipment, water sources, input screens, etc. [14].

3. ***Heat*** generated by combustion of gases, coal, oil, biomass, or electrical resistance heaters, is normally produced for hot water and pasteurized milk and other processes. The energy demands are reduced by heat exchangers, for example, taking heat out of milk into preheating water and making more use of thermal energy by reducing thermal losses within a system. Heat can be supplied in all cases through solar heat, geothermal or contemporary bio-energy plants, or through efficient heat pump designs [14].

4. ***Cold storage and cooling*** are widely used to preserve quality after milking and processing as well as to reduce losses in the supply chain. Cooling systems reliably rely on energy supply systems, but new technologies such as solar absorption chillers are being introduced on the market. Small and large scales can be used as other sources of renewable electricity. For cold stores, energy demand can be reduced by increasing insulation, maintaining doors closed and reducing the heat load at the end of the cold chain processing stages [14].

5. The same power output can be produced by ***tractors and machinery*** using less energy, where the engines are maintained, the pressure of the pneumatic is correct, unnecessary ballast is removed and tractor performance optimization is achieved through proper gear selection and throttle selection and hydraulic systems. Up to ten percent fuel can be saved by a skilled operator while 20 percent sitting on the tractor and so the soil damage can be reduced by compacting or sliding [14].

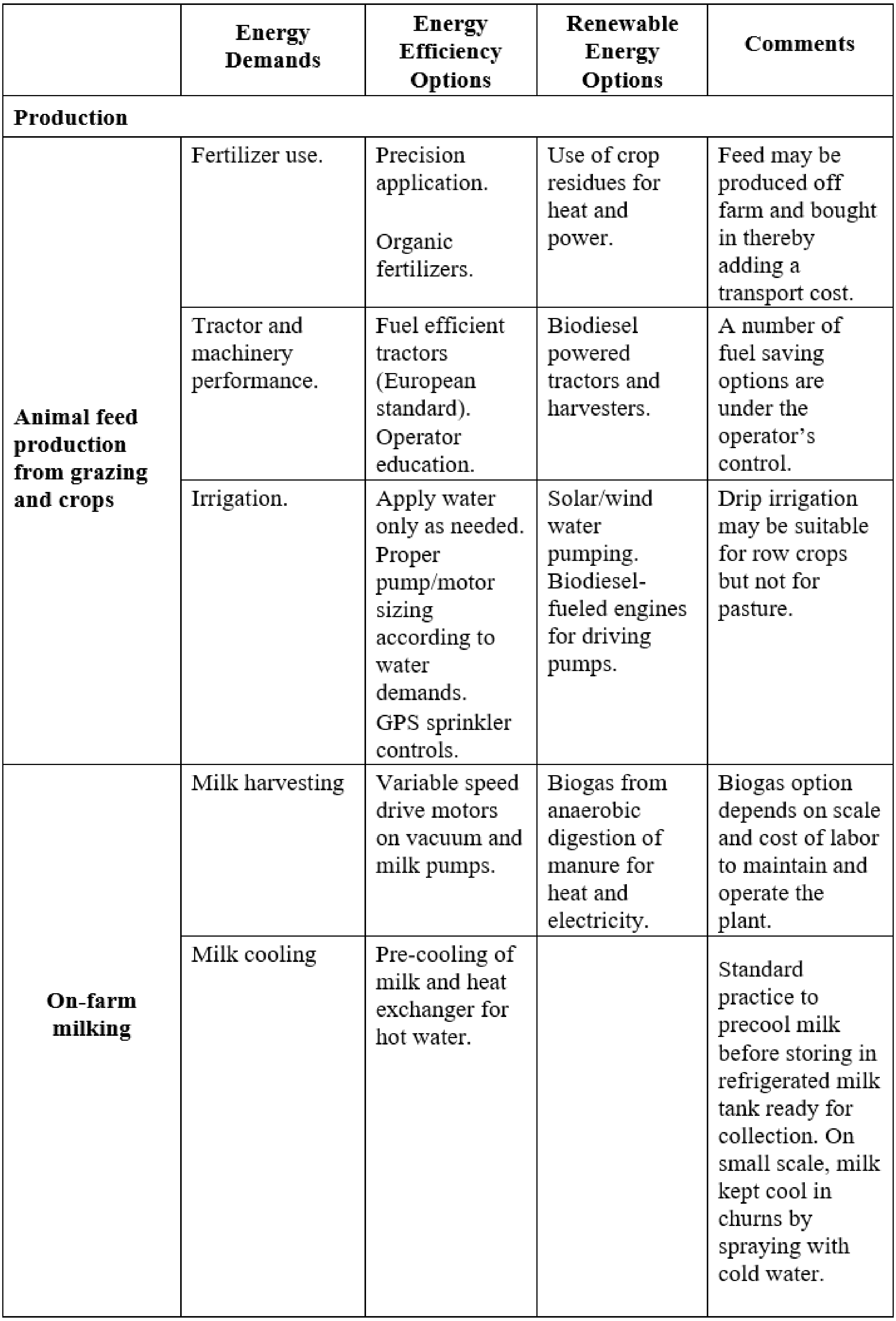
6. During manufacturing processes, ***fertilizers*** (including nitrogen, phosphorous, NPK and potash blends) have highly integrated energy, which can be reduced through improved production efficiencies, but also through more precise application methods. Recommendations for energy reductions in the use of fertilizers include:
   - cultivating legume plants that fix nitrogen to green crops;
   - choose NPK fertilizer after soil or leaf analysis of the desired nutrient value;
   - applying the soil or the leaf analysis results to calibrated rate;
   - apply less when the crop responds to increased productivity;
   - use fluid fertilizers directly in irrigation water, including via injection;
   - use of organic manures, including effluent from food processing plants and biogas sludge plants where possible; and
   - using GPS controlled equipment precision agriculture techniques and an soil type variations assessment [14].

7. Raw milk and finished product ***transport and distribution*** vary with distance and markets. Air-freighting of fresh foods around the world is heavily dependent on energy in order to satisfy the demand for off-season products in comparison with local markets that supply fresh food where possible. The transportation, with low carbon footprints, of food commodities, like milk powder in bulk may be relatively low. Improving roads can contribute to energy and time saving to bring fresh products into markets in rural areas of developing countries, thus improving local livelihoods [14].

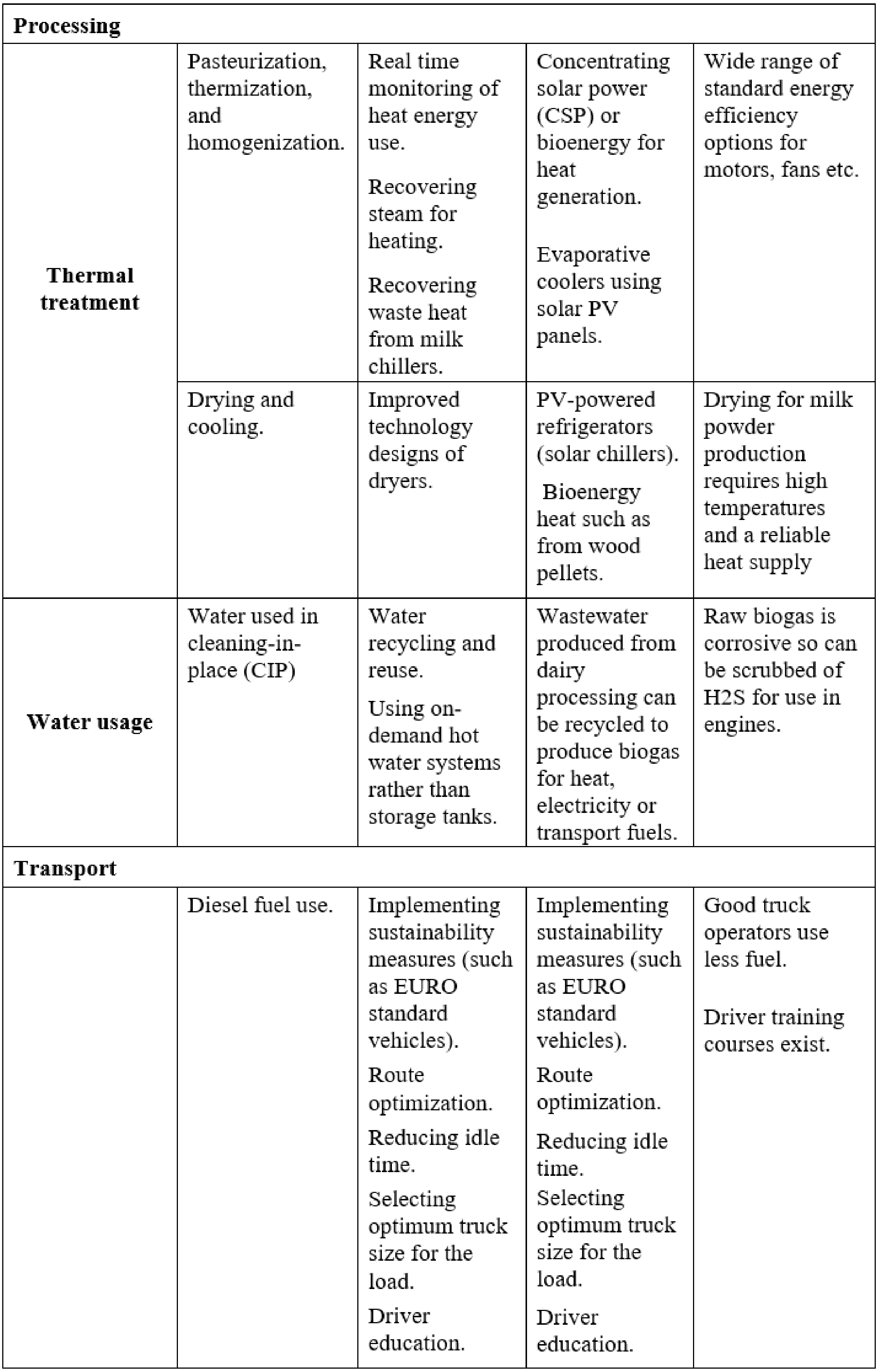
8. Dairy ***processing*** in a small to medium-sized or large-scale enterprise requires power for heating, cooling, lighting, packaging and storage. Globally, the energy required for 'beyond the farm gate' is threefold the energy consumed by 'behind the farm gate.' An energy audit of a trained specialist in many processing plants would identify economic opportunity to reduce energy demand while increasing performance and quality. [14].

9. In all the value-added chains where good resources exist in the region, ***renewable energy*** could replace fossil fuel energy (heat and electricity) inputs. This can be done using renewables as a renewable power grid, or by installing on the farm or processing plants solar photovoltaic, solar thermal, wind energy or heat and electricity bioenergy. Since biological waste is usually produced at both the farms and the processors, investments in anaerobic digestion plants have been used extensively to produce biogas for the supply of heat, energy or transportation fuels [14].

Table 2.3.1: Summary of low carbon mitigation options specific to milk production [14]



	Energy Demands	**Energy Efficiency Options**	**Renewable Energy Options**	**Comments**
Production				
Animal feed production from grazing and crops	Fertilizer use.	Precision application. Organic fertilizers.	Use of crop residues for heat and power.	Feed may be produced off farm and bought in thereby adding a transport cost.
	Tractor and machinery performance.	Fuel efficient tractors (European standard). Operator education.	Biodiesel powered tractors and harvesters.	A number of fuel saving options are under the operator's control.
	Irrigation.	Apply water only as needed. Proper pump/motor sizing according to water demands. GPS sprinkler controls.	Solar/wind water pumping. Biodiesel-fueled engines for driving pumps.	Drip irrigation may be suitable for row crops but not for pasture.
On-farm milking	Milk harvesting	Variable speed drive motors on vacuum and milk pumps.	Biogas from anaerobic digestion of manure for heat and electricity.	Biogas option depends on scale and cost of labor to maintain and operate the plant.
	Milk cooling	Pre-cooling of milk and heat exchanger for hot water.		Standard practice to precool milk before storing in refrigerated milk tank ready for collection. On small scale, milk kept cool in churns by spraying with cold water.



Processing				
Thermal treatment	Pasteurization, thermization, and homogenization.	Real time monitoring of heat energy use. Recovering steam for heating. Recovering waste heat from milk chillers.	Concentrating solar power (CSP) or bioenergy for heat generation. Evaporative coolers using solar PV panels.	Wide range of standard energy efficiency options for motors, fans etc.
	Drying and cooling.	Improved technology designs of dryers.	PV-powered refrigerators (solar chillers). Bioenergy heat such as from wood pellets.	Drying for milk powder production requires high temperatures and a reliable heat supply
Water usage	Water used in cleaning-in-place (CIP)	Water recycling and reuse. Using on-demand hot water systems rather than storage tanks.	Wastewater produced from dairy processing can be recycled to produce biogas for heat, electricity or transport fuels.	Raw biogas is corrosive so can be scrubbed of H2S for use in engines.
Transport				
	Diesel fuel use.	Implementing sustainability measures (such as EURO standard vehicles). Route optimization. Reducing idle time. Selecting optimum truck size for the load. Driver education.	Implementing sustainability measures (such as EURO standard vehicles). Route optimization. Reducing idle time. Selecting optimum truck size for the load. Driver education.	Good truck operators use less fuel. Driver training courses exist.

2.3.1 Comparison of energy use in milk products

The production of milk is resource intensive throughout the value chain in terms of energy inputs and consumption of water. In the post - harvest periods of milk production there are particularly wide differences in energy use. To maintain quality and reduce health hazards at a small scale, fresh dairy can simply be pasteurised (heated at a temperature of 60 degrees Celsius for 2 minutes) prior to sale onto local markets or cheese makers, whereas on a broader scale, fresh milk is usually cooled at about 4 degrees Celsius immediately after produce. [14].

The energy use in dairy products tends to rise substantially in regions and countries with a established value chain while raw milk move in line with the end - consumer (Fig. 2.3.2) [14].

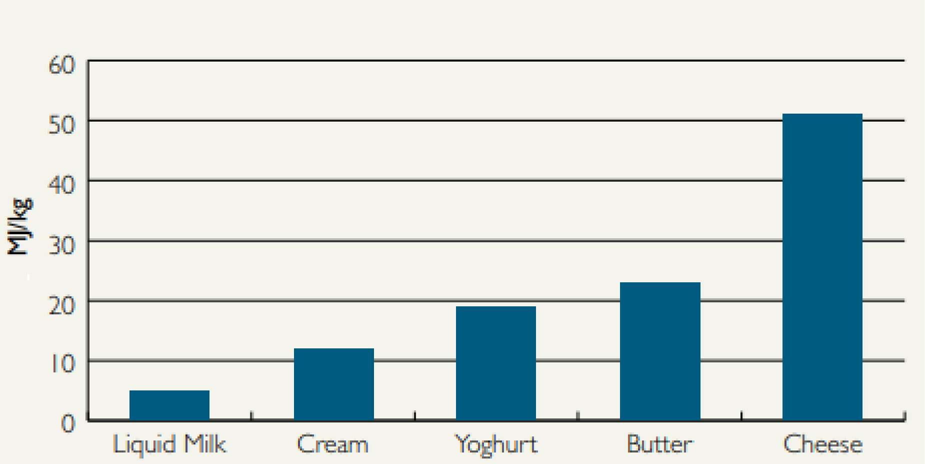


Figure 2.3.2: Comparison of energy consumption in selected dairy products (UK) [14]

Due to various processing, packaging and storage technologies employed, the energy utilization of dairy product production may vary significantly. Due to differences in their production processes and physical characteristics, even within a group of products such as cheese, which consumes around one quart of the total consumption of milk production energy (Fig. 2.3.3) [14].

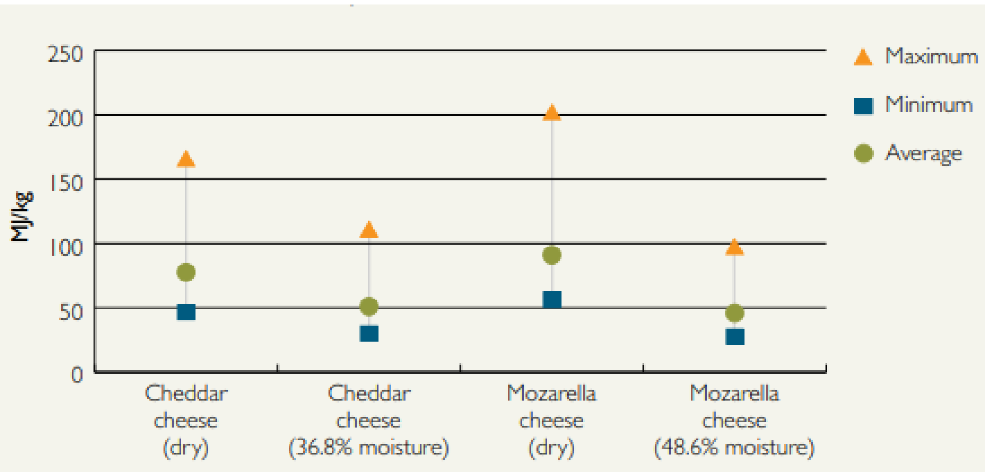


Figure 2.3.3: Energy input ranges (MJ/kg) for production of dry and wet cheddar and mozzarella cheese in the US [14]

2.3.2 Factors affecting to the variations of energy use in milk value chain

Milk and milk products are manufactured using two main subsystems: the milk production and manufacturing of agricultural feed. The use of of synthetic fertilizers and mechanized farming is part of intensive feed production. On a dairy farm, animal milking is the main activity. Milking is done by hand on small farms (approximately 80% of all farms in developing countries). The milk is stored in cans and chilled before being stored or sold directly to the consumer. On medium - sized farms, milking is performed by a vacuum pump and vessel, which is used to collect milk, teat cups attached to the vessel by means of hoses, and a vacuum and atmospheric pressing pulsation alternatively applied to the teat cups. Milk is transferred then from the tin pail cans to the milk mill. The milk entered directly into a pipeline in large dairy farms that would transfer it to a cold storage tank. It is subsequently transferred to cold trucks for further processing [14].

Because of these variations, a global energy use estimate would be misrepresenting. It is, however, useful to explore the areas where fossil fuel inputs per milk production unit might be lowered either through increasing the efficiency of resource use and use of renewable energy, or both, based on the general milk-product value chain (Fig. 2.3.1). Depending on the the the final product (such as the packaged milk, cheese, milk powder etc.) activity in the processing and packaging stages of a value chain can significantly change. This can affect the demand for energy [14].

Fossil fuel, in particular diesel for tractors, and harvest machinery and natural gas to produce fertilizers, is heavily used in animal feed manufacturing. Animal feed is produced in most industrialized regions with high fertilizer use and high energy usage in intensive cultivating systems. High levels of feed include concentrates, forage plants, imported hay and silage. Although the information on energy consumption in feed production is poor, Carbon Dioxide releases from diesel and natural gas combustion for feed production and transmission as well as for blending of focused feed vary with production, processing and transportation distance (Fig. 2.3.1). At the feed production stage the consumption of energy in industrialized countries is higher and more intensive, compared to developing countries in which milk production usually focuses on open grazing systems feed production and processing [14].

In drying and transport of animal feed, energy is also consumed. In the total energy demand of milk and milk products, local collections and transport infrastructure also play a major role. Milk collection and transportation costs often account for more than 30% of dairy costs (FAO, 2015). Most milk is collected by bulk tankers in industrialized countries and transported in great quantities to the processing plant. For developing countries, the bulk of milk is manufactured in remote rural areas by small - scale producers and is transported primarily by bicycle, animal, vehicle or foot into local markets or to small processing plants (FAO 2015). The methods for processing, packaging and transportation of milk products may vary, due to differences in the extent that the value chain is developed in a country or region. The share of raw milk being processed is high in industrialized countries (Table 2.3.2) and therefore energy is high, while comparatively low energy use is achieved in less developed countries [14].

Table 2.3.2: Share of milk sent from the farm to the processing by region

Region	Share of raw milk sent to dairy (%)
Sri Lanka	54 *[7]*
Source of below information: [14, Table 3.1]	
Asia	62
Other European countries	78
South America	82
EU27	89
North America	96
Oceania	100

An indication of energy demand in the value chain for cheese production in the US and the production of milk in the UK confirms the highest energy requirements for feed production (Fig. 2.3.4).

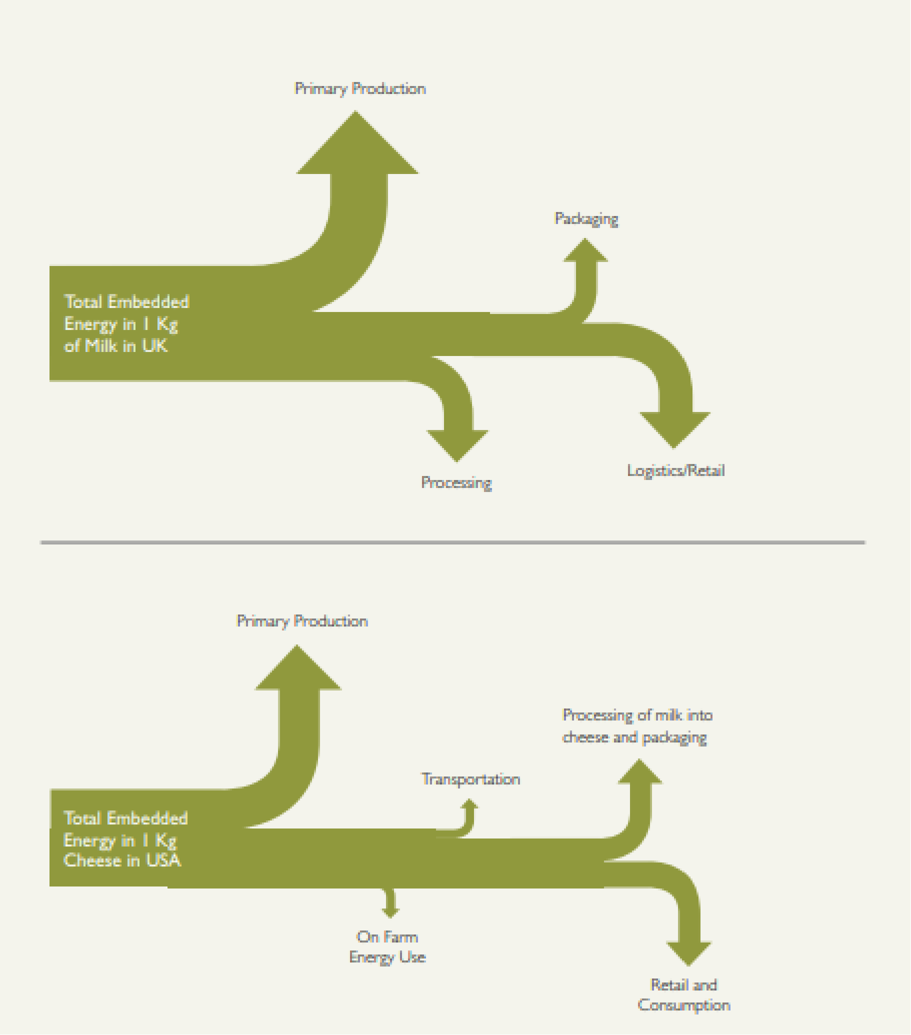


Figure 2.3.4: Width of the arrows indicate the energy use in cheese production in the USA (top) and in milk production in the UK (bottom) [14]

2.3.3 Breakdown of energy use

At each step, the quantity of energy and water used depend on local practices, mechanization and production systems. In Australia, for example, milk processing uses 63% of the total heat-energy input, 24% for electricity and the rest as transport fuels (Fig. 2.3.5). This section explains how energy is consumed in every phase to identify potential ways to improve energy efficiency and how innovative or renewable energy technologies can be used to reduce fossil fuels dependency. [14].

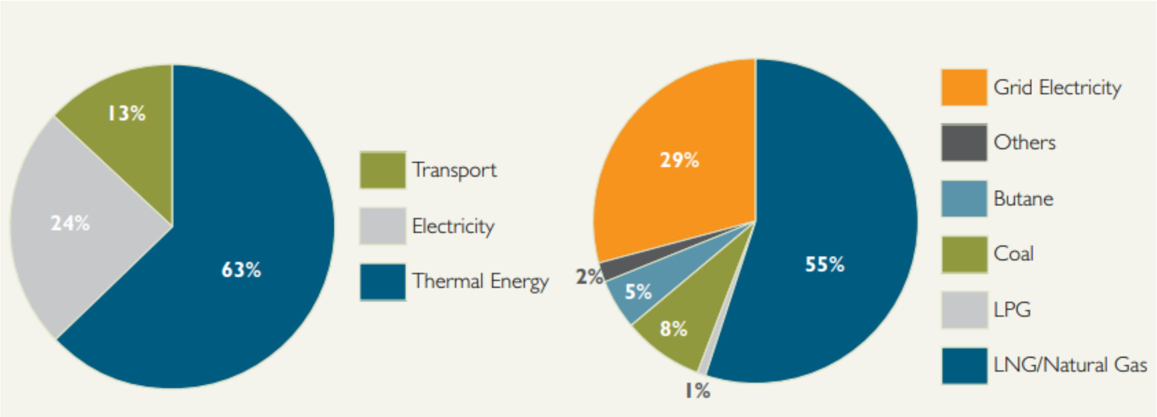


Figure 2.3.5: Energy use in the Australian dairy industry and fuel breakdown [14]

Table 2.3.3.: Primary energy use in average Finnish conventional and organic milk (GJ per 1000 L of milk) and percentage shares [14]

	Conventional Milk	Organic Milk	Conventional Milk	Organic Milk
Pre-farm total	**3.48**	**0.93**	**49%**	**20%**
Electricity*	0.11	0.06		
Fuels; purchased fodder	0.22	0.15		
Fuels; fertilizers	3.15	0.72		
On-farm total	**1.29**	**1.53**	**18%**	**32%**
Electricity	0.85	0.84		
Fuels	0.45	0.68		
Post-farm total	**1.99**	**1.99**	**28%**	**42%**
Dairy processing - electricity	0.59	0.59		
Dairy processing - fuels	0.4	0.4		
Packaging - fuels and electricity	1	1		
Transport fuels	**0.28**	**0.31**	**4%**	**7%**
Grand total	**7.05**	**4.75**	**100%**	**100%**

*Contains production of pesticides, processing of oil-seed rape, agricultural lime production, feed mill, drying of grains (fodder purchased); in the production of bread: agricultural lime production, salt, yeast, package and pesticide

2.3.4 Summary of key energy interventions

Some hotspots with the milk value chain can be identified from the above debate where interventions are needed to reduce energy and water use. In the animal feed production stage, the biggest demand for energy is in fact up to 40%* of energy, mainly through manufacture and application of fertilizers. Reduction of chemical fertilizers in organic milk production can significantly minimize overall energy consumption [14].

The use of organic matter (crop residue, manure, etc.) in the supply of nutrients can replace chemical fertilizers. Gronroos et al. (2006) reported that the total energy use between organic and conventional dairy production systems (Fig. 2.3.6) decreased to 4.75 MJ/kg in organic milk due to the reduced use of chemical fertilizer in conventional milk, ***i.e.:*** 7.05 MJ/kg. Approximately 45%of the energy spent on the production and application of fertilizers in traditional milk production systems, three times that of organic milk production [14].

Milk processing consumes between 20% and 30 percent of total dairy value chain energy consumption. Dairy pasteurization and chilling are important processes, since production and nutrition losses are prevented. Improvement of energy efficiency in machinery and waste control are practical solutions and the use of renewables to offset all direct use of fossil fuels. The main challenges will be to find ways of producing clean thermal energy (e.g. solar energy), have least environmental and GHG effects, improve production efficiency and reduce energy and losses of products [14].

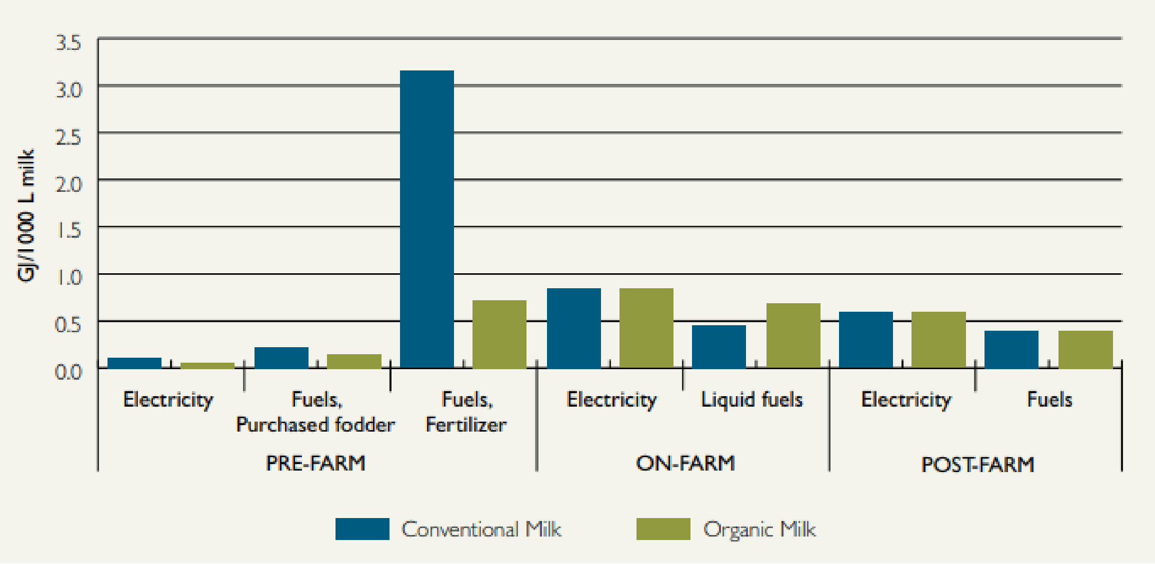


Figure 2.3.6: Comparison of energy use in production of conventional and organic milk (GJ/1000 L milk) [14]

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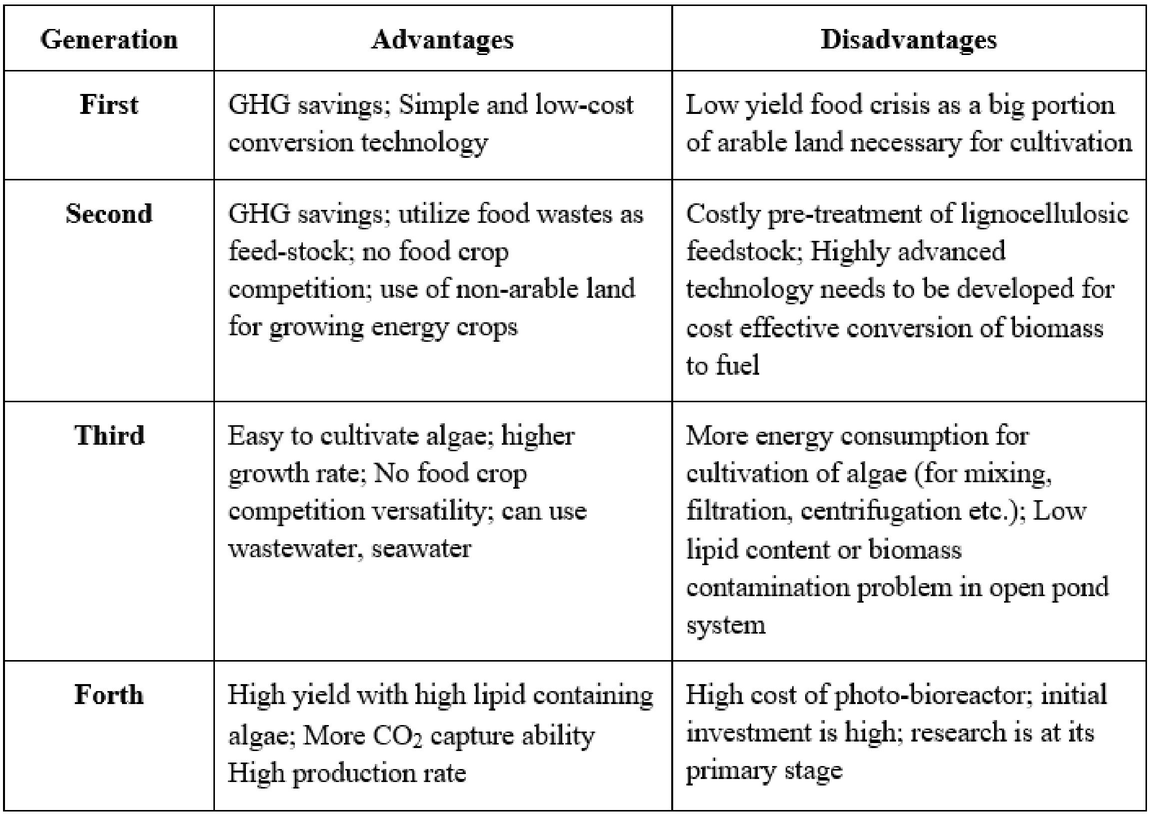
* This is the estimate in industrialized countries for intensive systems. The dependence on open grassing and the lack of concentrates in the feed mix may be much lower in developing countries.

2.4 Existing LCA studies on alternative transport fuels

The common alternative fuels available consist of ethanol, hybrid-electric, hydrogen, compressed natural gas, bio – diesel, liquefied propane and fuel cell. Biofuels are generally referred to as solid, gaseous or fluid biomass fuel. It can be classified these biofuels into four different generations, for example in the first, second, third and fourth biofuel generations based on bio - mass feedstock (for example sugar cane or oils, lignocellulosic biomass, for example wood or algae). Biofuels obtained from various feedstock generations offer unique benefits and challenges (summarized in Table 2.4.1). Biofuels may be produced in various forms (for example, gaseous or liquid), and may be used with various motors, for example in internal combustion engine vehicles or fuel cells. [2].

Table 2.4.1: Advantages and disadvantages of biofuel options [2]



Generation	Advantages	Disadvantages
First	GHG savings; Simple and low-cost conversion technology	Low yield food crisis as a big portion of arable land necessary for cultivation
Second	GHG savings; utilize food wastes as feed-stock; no food crop competition; use of non-arable land for growing energy crops	Costly pre-treatment of lignocellulosic feedstock; Highly advanced technology needs to be developed for cost effective conversion of biomass to fuel
Third	Easy to cultivate algae; higher growth rate; No food crop competition versatility; can use wastewater, seawater	More energy consumption for cultivation of algae (for mixing, filtration, centrifugation etc.); Low lipid content or biomass contamination problem in open pond system
Forth	High yield with high lipid containing algae; More CO_2 capture ability High production rate	High cost of photo-bioreactor; initial investment is high; research is at its primary stage

2.4.1 Environmental impacts of biofuels

Biofuels like biodiesel and ethanol are two (2) different alternative fuel types with a potential to minimize dependency on the import of petroleum fuel while minimizing atmospheric GHG releases [2].

The benefits of air quality of biodiesel in traditional diesel engines are:

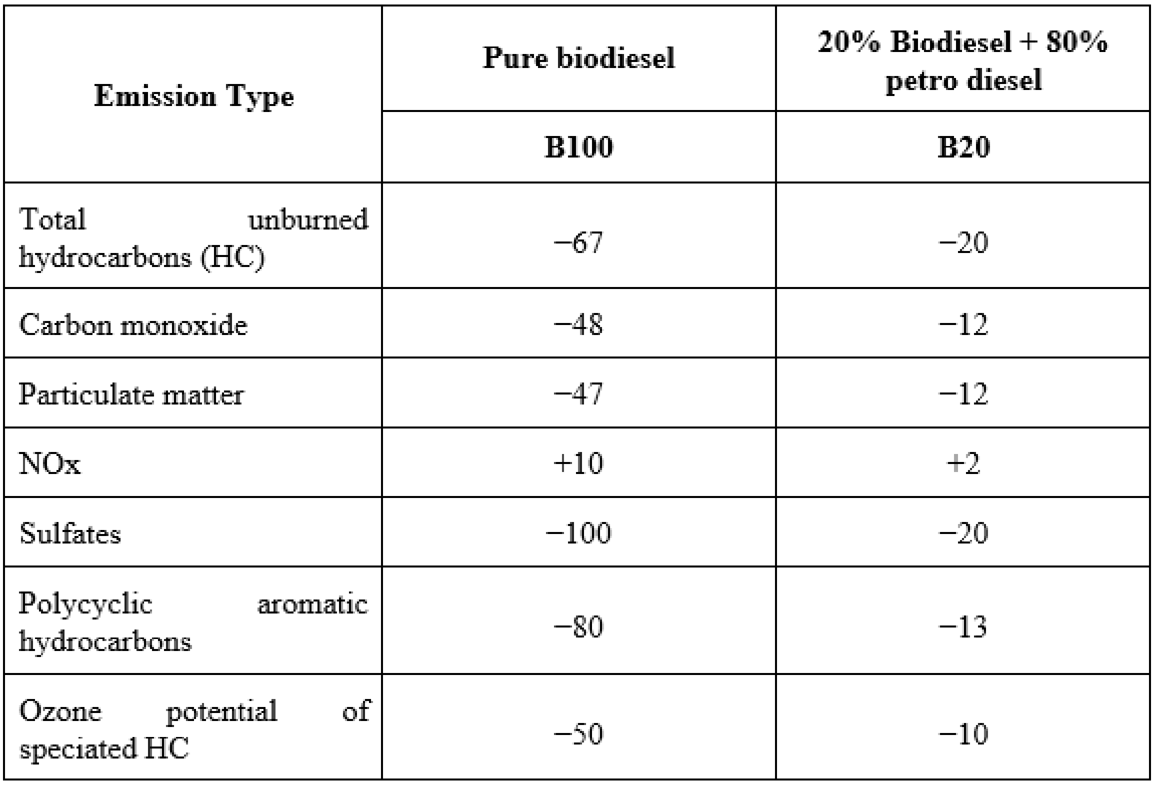
(1) By switching from traditional Diesel to biodiesel, carbon monoxide (CO), unburnt hydrocarbons, nitrated polycyclic aromatic hydrocarbons, sulfates, polycyclic aromatic hydrocarbons releases can be reduced significantly [2].

(2) The increase in the share of biodiesel mixed into diesel fuel increases the reduction of emissions. Conversely, the use of Biodiesel increases NOx emissions in conventional motor vehicles. A significant problem in areas outside of ozone could be the increase in NOx emissions with an increase of the biodiesel concentration. It has been found, when used with biodiesel blends (B20 and B100), that the NOx emissions rose from 1.86 to 2.23 for the same model compression-ignition vehicles. [2].

(3) The oxygenated diesel fuel mix is potentially useful for reducing particulate matter (PM) emissions, and these fuels may be alternative to diesel fuel. In addition, the use of ethanol mixtures led to CO and HC emissions reductions on the tail pipe of vehicles. This is probably because the ethanol fuel contains a higher oxygen content [2].

(4) The use of the E10 ethanol fuel blender was found to result in significant CO emission reductions (- 16 %) without significant changes in formaldehyde, CO_2, NO_x, N_2O or CH_4 releases. The results were obtained in statistical analyses. Likewise, the use of ethanol mixed E85 fuel resulted in substantial decreases (-45 percent) in NOx emissions without noteworthy CO and CO2 emission changes. [2].

Table 2.4.2: Comparison of percentage emissions from biodiesel vs. conventional diesel [2]



Emission Type	Pure biodiesel	20% Biodiesel + 80% petro diesel
	B100	B20
Total unburned hydrocarbons (HC)	−67	−20
Carbon monoxide	−48	−12
Particulate matter	−47	−12
NOx	+10	+2
Sulfates	−100	−20
Polycyclic aromatic hydrocarbons	−80	−13
Ozone potential of speciated HC	−50	−10

In addition, it benefits the air quality by using the low sulphur biological fuel blends and such biofuel blends do not make remarkable damages to the air quality e.g. emissions from carbon monoxides in ethanol and biodiesel mixtures are reduced by 25 - 50%. The advantages of particulate emissions reducing to as much as 50% and hydrocarbons by approximately two thirds are also offered by bio diesel blends. The research also discusses, however, that manufacturing and consumption of biofuels (biodiesel and ethanol) lead to improved emissions of NOx due basically to fertilizer emissions. [2].

A sustainability assessment of different fuel / vehicle options for classification of the best combinations of powertrains and fuel types with less emissions in the life cycle has shown the sustainability challenges associated with the use of existing ethanol combinations (e.g. E10 for ICEV and E85 for flexible-fuel vehicles). The results show the following important results. [2]:

1. From ethanol mixed fuels in the life cycle, the well - to - tank emissions dominate emissions.
2. Greater cellulosic (for example, grasses and trees ') efficiency (80 - 95 per cent) is based on the considered inputs of fossil fuels, i.e. efficiency depends on fuel manufacturing method and above all the input of petroleum fuel into the manufacturing of ethanol.
3. GHG emissions of up to 15 g CO2 equivalent / MJ ethanol, despite the fact that the costs are higher (according to the assessed studies).
4. Corn and fossil - fuel ethanol would be low-priced but far away from sustainable; if they were produced using existing methods, they would have high GHG emissions. For example, the well - to - wheel emissions of GHG (CO2 equiv / km) vary from 0 g CO2 equiv / km (E85 fuel based on cellulose) to 160 g CO2 equiv / km (E85 fuel made from corn).

Similarly it is useful to reduce overall GHG emissions by shifting to the next generation feedstocks (by manufacturing next generation feedstocks over conventional corn and soy beans). An assessment of the life cycle releases of GHGs from Municipal Solid Waste (MSW) has recognized that GHG emissions of MSW - based ethanol are lower than the conventional maize grain ethanol (approx. 60–80 per cent), and that pre - sorted products of marketable aluminum, glass, stain and plastic materials are able to reduce emissions of GHG of around 50 per cent compared to conventional maize grain ethanol [2].

2.4.2 Production technologies of fuel

1) **Diesel (Low sulphur diesel):** A product resulting from the distillation of crude oil is also recognized as automotive diesel oil. Diesel is a middle distillate, reflecting its weight in comparison to heavier fuel oil and lighter oil. *(Australian Government Department of Industry Innovation and Science) [2]*.
2) **Gasoline:** Gasoline is a product that comes from crude oil distillation. Its main use is to power cars and smaller commercial vehicles to passengers. In Australia the two most common types of oil grades are unleaded petrol and premium unleaded petrol. *(Australian Government Department of Industry Innovation and Science) [2]*.
3) **Biodiesel from Rape Methyl Ester (RME):** The RME biological diesel is made of Rape oil and is imported from the EU. It is generated by a chemical process of trans - esterification. This process creates two (2) produces called methyl esters (the chemical name of biodiesel) and glycerin (a product of value usually used for soaps and other products) *(Bio fuels Association of Australia, 2015) [2]*.

4) **Ethanol from sugarcane molasses:** Sugar cane molasses are used to produce Ethanol by fermentation, using a sugar mill, which uses the collocated distillery that produces molasse - fermented fuel ethanol and dunder (stillage) as a co - product. The sugar factory should be based on traditional technology and employs the steam and power supplied by the factory. In addition, it should be mentioned that the Molasses described here is a sugar co - product containing the residual sugars which can not be recovered further. Stillage is not also considered as an economic by - product is being used on sugar cane farms [2].

5) **LPG :** Liquid Petroleum Gas (LPG) is mainly known as propane. LPG is mainly a mixture of hydrocarbon gases, mainly propane (C_3H_8) and butane (C_4H_{10}). These gasses can occur either separately or together. These gasses liquefy under pressure, which is also called liquefied oil. LPG may occur naturally in petroleum and gas fields with other hydrocarbons, for example wet natural gas, or in the production of other petrol produce using the distillation tower it may be obtained from oil refineries with heated crude oil. The distillation tower side extracts fractions of the flow from the bottom to the top at various heights. Each point of extraction is controlled by temperature, for extracting a certain fraction of kerosene, naphtha, petrol, diesel, heavy gas oil and light gas oil. These are then forwarded to a single stream to be stored or processed further. LPG can be used as propane, butane and isobutene separated into its three primary components. It is stored pressurized as a liquid in cylinders or tanks [2].

6) **CNG :** The gas used in vehicles for natural gas is the same used in households for heating and cooking. Compressed Natural Gas (CNG) generates less than 1 percent of its total volume at standard atmospheric pressure after compressing conventional natural gas (composed mostly of CH4, Methane). Subject to the pressures 2,900–3,600 psi (200–48 bar), generally metallic cylinders of cylindrical shape are used to store and distribute these gases. [2].

7) **Hydrogen (Liquid hydrogen):** Hydrogen may be produced in various sources including fossil fuels, biomass and certain waste industrial chemicals and used in fuel cells or other engines or turbines for the supply of electricity. Coal, natural gas (NG), biomass and water have the highest potential among all hydrogen sources in Australia. Electrolysis technique, which is based on intermittent consumption of renewable energy and off-peak power from nuclear, hydro- or thermal power stations, is applied to use water resources in hydrogen production. Water electrolysis is globally seen by the compatibility of existing and future energy generation technologies and a large amount of renewable technology (solar, biomass, hydro, wind, tidal, wave, geothermal, etc.) as one of the key technologies for the production of hydrogen. [2].

8) **Electricity (Low Voltage, NSW):** Almost 90% of the power generation of Sri Lanka depends on the fossil fuel burning – coal and oil. The stored chemical energy is used for the heating and steam generation of water. The steam is subsequently forced under high pressure by an electric generator turbine. The entire process consists of converting chemical energy into kinetic energy into electrical energy. Similarly, the Kinetic energy of falling water pushes turbine blades into an hydroelectric power station to produce electricity, and the Kinetic energy of wind pushes wind turbine blades to produce electricity. The electricity generated at a generating plant is converted from low to high voltage to enable efficient transmission on the transmission system [2].

2.4.3: Calorific values and TTW efficiencies of vehicle powertrains

In the equation below, we mention the equation for calculating the Tank-to-Wheel efficiency as reported. The efficiency of the Tank - to - Wheel (TTW) is the ratio of fuel energy at the tank to the energy at the wheel to drive the vehicle [2].

$$\text{TTW Efficiency} = \frac{\text{Energy of fuel available at the wheel}}{\text{Energy of fuel in the vehicle tank}}$$

Table 2.4.3: Calorific values and TTW efficiencies of vehicle powertrains. [2]

S.No.	Fuel type	Net Calorific Value (MJ/kg)	TTW efficiency (η)
1	Diesel	42	0.295
2	Gasoline	43	0.22
3	Biodiesel	36.5	0.295
4	Ethanol	26.9	0.22
5	LPG	46.4	0.15-0.27
6	CNG	44.24	0.14-0.26
7	Hydrogen	119.93	0.46
8	Electric (BEV)	NA	0.77

2.4.4 Single score results in mPt/MJ

In order to integrate various impacts together, the technique of reporting single score results was utilized by *Ashish Sharma (2016)* while applying the weighting factors according to the Recipe end-point (H) methodology [2].

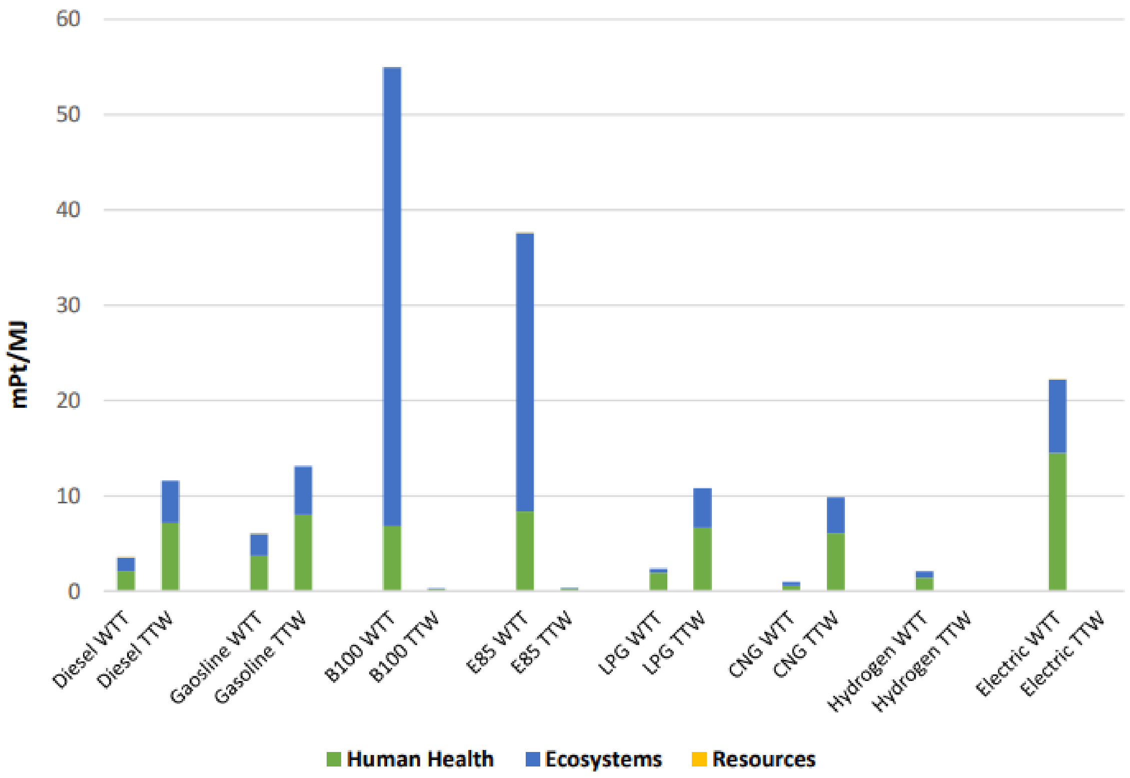


Figure 2.4.1: Single score results (mPt/MJ) for selected fuel types for WTT and TTW life cycle stages [2]

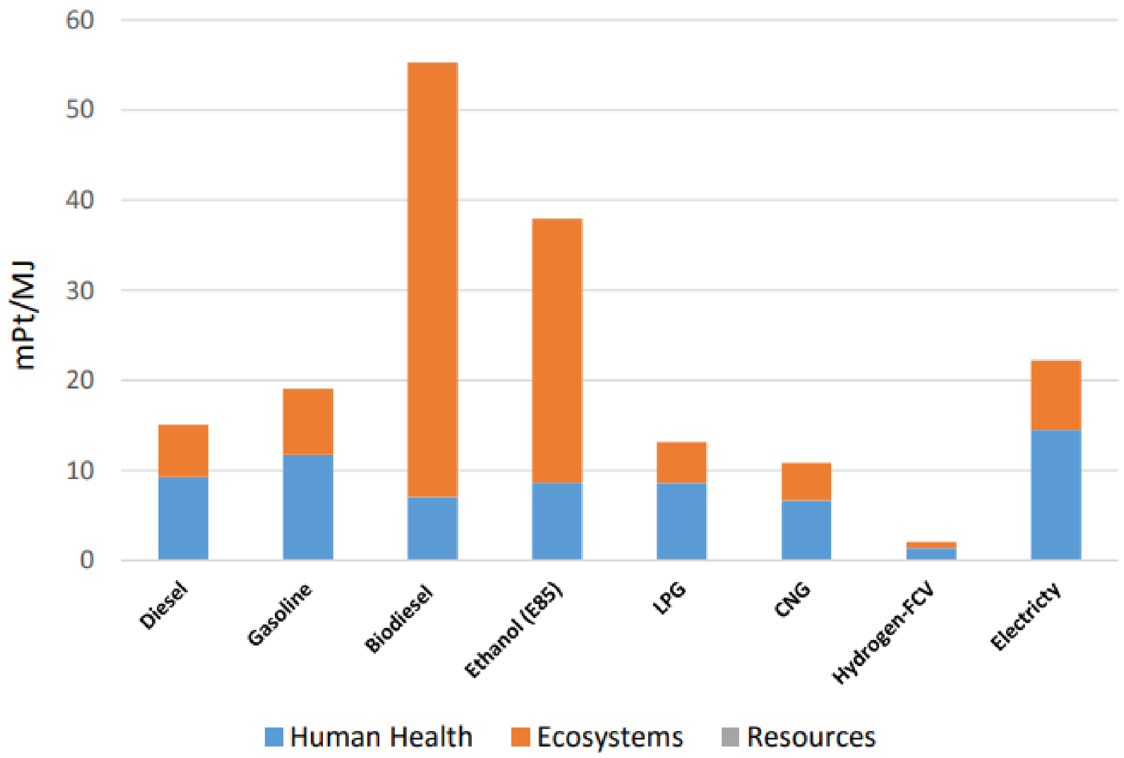


Figure 2.4.2: Single score results (mPt/MJ) for total life cycle of selected fuel types [2]

The results of the single - score overall life cycle (mPt / MJ units), followed by electricity, diesel, LPG, ethanol (E85), gasoline, CNG and lowest hydrogen fuel, can be shown from figures 2.4.1 and Figure 2.4.2. In addition, the division of the results into WTT and TTW shows that the maximum scoring impacts for biodiesel, E85, electricity, petrol, diesel, LPG, hydrogen FCV and minimum for CNG are the single scoring effects for WTT stage. The highest results for gasoline, Diesel, LPG, CNG, ethanol (E85), biodiesel and minimum for hydrogen FCV, electricity are given in the context of the TTW Life cycle stage. Therefore, conventional fules (diesel and gasoline), in contrast to alternative fules, which are less affected during the operation phase of vehicles or in the TTW life cycle, have the most impact during vehicle operation.

2.5 Framework for energy use in LCA and their reporting

Energy utilization is a common category of impact in LCA, an established method of evaluation and management of the environment. The use of energy in the life cycle — also called embodied, imbedded or embedded energy use — indicates the amount of energy a product or service needs to produce over a lifetime. Energy importance for the support of human well - being and severely restricted resources of energy around the world, is the main reason for the energy consumption categorization. Energy use and other types of impact— like potential for toxicity, global warming and acidification— are frequently evaluated in order to give an explanation for various kinds of impacts to the environment. In a study on LCA that can be later stated as "life cycle energy analysis," the only impact category that is considered could also be energy use. This method is actually elder than the procedure of LCA. It was originated by Hannon (1972) and Makhijani and Lichtenberg (1972) who carried out energy analyzes of products. One reason for using energy as the only category of impact in LCA could be that the energy use is the most important category of impact. An other likely reason is that indicators of energy use have made known to be excellent proxy indicators for general impacts to the environmental [15].

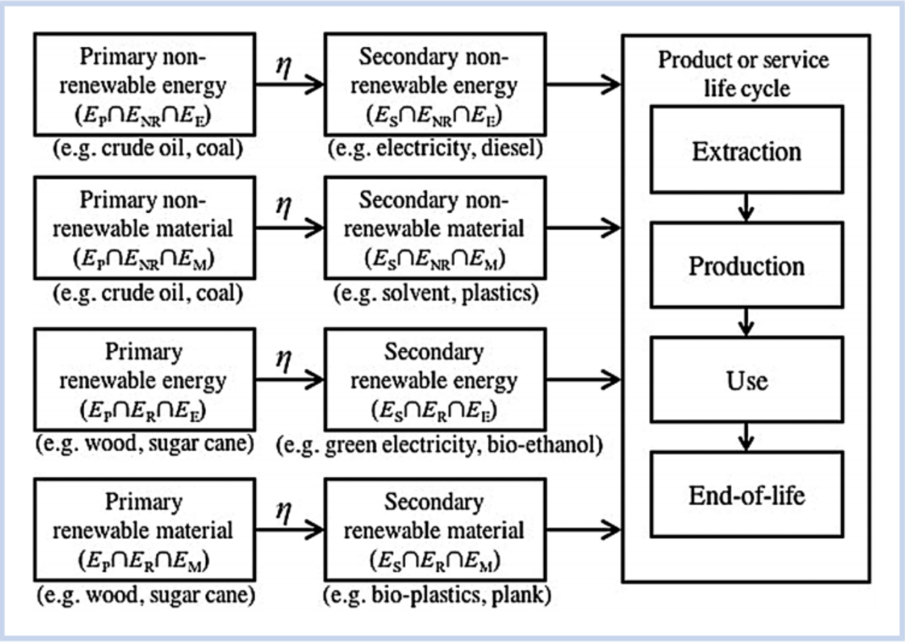


Figure 2.5.1: Graphical illustration of a framework for energy use indicators in LCA [15]

Where, E_P, E_S, E_R, E_{NR}, E_E, E_M, η symbolize life cycle primary energy use, life cycle secondary energy use, life cycle renewable energy use, life cycle nonrenewable energy use, life cycle energy use intended for energy purposes, life cycle energy use intended for material purposes, and the primary-to-secondary energy conversion factor, respectively.

When building an indicator to show the energy consumption according to the suggested framework, three main choices must be made:

1) Primary or secondary energy accounting,

2) Renewable and/or non - renewable energy consumption, and

3) Including energy for energy and/or material purposes [15].

Below, two main players discuss the choices which seem most relevant:

National policy agencies and companies that focus on their products and production. Government agencies' role consists in considering social effects as a whole, protecting their citizens and providing business with adequate conditions and rules (e.g. in energy supply). Instead, companies usually concentrate on their production processes less and sometimes outspread to much of the life cycles of their products. Whether or not the primary and secondary energy choices include losses from primary to secondary energy conversion in the research, should be determined. It would be more comprehensive to choose primary energy and thus include such potential significant losses. This approach addresses concerns regarding the inadequate accessibility of energy resources (if considering non - renewable energy) and the potential of limited total generation (if also considered for renewable energy). For most LCA studies of actors, primary energy is therefore likely the most relevant choice. The purpose to select secondary energy, and not the loss of primary - secondary energy, could be that these losses are local and not linked to the production system's performance. Accordingly, secondary energy use may become more appropriate if companies need to comparison the life - cycle energy consumption of their goods to that manufactured by rival companies. This is why that avoids the impacts of various energy systems and concentrates on the primary manufacturing system. In terms of marketing, an enterprise could not be regarded as convenient and even biased to have the shortcomings of an inefficient (low η) energy generation background system [15].

The selection between renewables and/or non - renewables depends on the importance of renewable energy consumption. It is clear that the use of non - renewable energy is challenging as energy can’t be refilled. In many LCA studies, therefore, the inclusion of nonrenewable energy usage appears to be relevant. The current worldwide increase in renewable energy means, on the other, that renewable and non - renewable energy are to be integrated into the assessment of life cycle energy use, by government and company institutions [15].

In most LCA studies, which include energy used for energy and/or material purposes would probably occur in the majority of LCA studies. However, it is less obvious whether energy is to be included for material purposes. When energy is included in material inputs like wooden planks and fossil solvents, it offers a broader view on energy usage. Energy incorporated into materials is also extracted out of nature, like energy intended for energy drives. Furthermore, in many instances the energy integrated into the materials can also be cast-off for energy drives. It can actually be used for end - of - life energy generation (e.g. for waste plastics incineration). The use of energy for material and energy purposes and especially for players dealing with the restricted energy accessibility in the society (e.g.: governments), therefore makes sense [15].

2.5.1 Is cumulative fossil energy demand (CED) a useful indicator for the environmental performance of products?

In a research done by Mark A.J. Huijbregts Et al., a regression analysis of impacts to the environment from the 1218 fossil CEDs is examined in the context of fossil Cumulatives Energy Demand as a measure of environmental performance of processes and products, divided into products in the product types of ‘waste management’, transport’, material production’, ‘energy production’ and ‘material production’. Their findings illustrates that fossil CEDs are well correlated to all sets of products but treatment of waste in most categories: global warming, acidification, acidification, eutrophication, human toxicity (variance from 46% to 100%), ozone depletion and formation of tropospheric ozone depletion. They come to a conclusion that petroleum fuels are a driving force of several impacts on the environment and indicate many environmental problems. That can thus aid as an environmental dash-board indicator. The utility of fossil CED as an indigenous measure of environmental impacts is however restricted by considerable uncertainty in the fossil product - specific impact values (over 10 for most impact categories ; 95 % confidence interval). One of the main reasons for this great uncertainty are emissions and land utilization related to non - fossil fuels such as waste disposal, radionuclide emissions and agricultural and forestry grounds [16].

2.6 Existing LCA studies of dairy sector

In the following table, it is summarized several major studies based on the presence of the environmental or sustainability indicators (socio-economic).

Some studies analyze the effects on the environment of milk products and milk. These analyzes are based on detailed calculations of a product specific model. Environmental impacts, including the input of raw milk, are analyzed from cradle to gate. Environmental effects are evaluated by the intermediate and final methods. Detailed dairy models enable the input and output to be allocated to single milk products for each subprocess and thus to a great extent avoid allocation.

The analysis done on the dairy model illustrates that the main impact in all categories is raw milk manufacturing. The second largest impact in many impact types is on packaging for the consumer.

In some studies, their scope has been extended to the socio - economic cycle assessments which take account of the socio - economic performance of products during their different life cycles.

The environmental assessment of the life cycle also includes consideration for the environmental impact in certain studies, the use of energy and water, where all internal processing streams, such as steam, cold water, electricity etc., have been modeled.

Table 2.6.1: Summary of the selected studies differentiated based on the methodological approach, data sources used and type of indicators considered

Study (Year)	LCA included	Methodology used	Softwares / instruments used	Database used	Environmental indicators	Economic indicators	Social indicators
Regula Keller et al. (2016) [17]	√	Use water & energy, in addition to various process phases in a dairy model. All internal processing streams for individual products are modeled in addition to electricity, cold water (cooling) and steam.	SimaPro	ILCD at midpoint level	√	X	X
Ali Daneshi et al. (2014) [6]	√	An abiotic energy assessment at a cradle- to - factory gate life cycle for one year between 2011 and 2012.	Simapro v7.3 and Ms. Excel	Ecoinvent 2.0	√	X	X
Food & Agriculture Org., UN (2010) [18]	√	A full LCA for the global dairy industry, which uses consistent calculation procedures, modeling approaches, data and parameters for each sector production system.	Geographical Information System (GIS) grids (raster layers), Bern Model for Global Warming Potentials (GWP) with a time horizon of 100 years based on the 4th Assessment Report of the IPCC (IPCC, 2007)	EcoInvent, 2009	√	X	X

Sara González et al. (2013) [19]	√	Standard Life Cycle Assessment Framework (LCA), collected on - site in the dairy factory with inventory data and completed with the literature and databases. For the distribution of environmental burdens between products, a mass allocation approach was considered.	Simapro 7.3.2	Ecoinvent, CML method (2001), The cumulative non - renewable energy and nuclear energy demand (CED) analysis was conducted.	√	X	X
Dairy Farmers of Canada (2012) [20]	√	The scope was confined for LCA environmental impacts to the main sources, from "cradle to farm-gate" and transport to processing plants. At Social - LCA, the socioeconomic performance of the product is assessed from "cradle to grave" at its various stages in lifetime.	NA	IMPACT World+	√	√	√

2.7 Dairy supply chain of Sri Lanka

In Sri Lanka, milk collection and marketing are performed by complicated systems with various actors. The formal / processed market of dairy comprises small primary dairy cooperatives, larger local cooperatives, district-level dairy cooperatives, unions of dairy cooperatives, collection point networks and milk chilling centers (MCCs) managed by cooperatives or the large-scale dairy processors. Also small local processors play a role in the production of modern dairy products. Small private dairy collectors, small local dairy processors, small retailers, and dairy producers, who directly sell to restaurants and hotels or to consumers engage in the informal market [21].

2.7.1 Milk collection and marketing

The system of formal milk collection in Sri Lanka consists of collecting small amounts of milk from many small farms spread over relatively long distances. Producers who are unable to directly sell to end users or retail outlets must either rely on private (informal) milk collectors, cooperative dairy collectors or formal dairy - processing centers. The distance from major urban markets depends on milk production density, and doesn't effect on market access. The formal milk industry is made up of public or private companies and small processors. "Informal" or "raw milk markets" include direct sales to individual consumers and private milk collectors, who then sell milk to MCCs or to individual customers and institutions. (The term "informal market" here describes the dairy products of raw milk and indigenous processes, and can be officially endorsed at some level.) [21]

In the majority of households, milk was sold through their collection centres, representing about 54% of all the total volume of milk reported to MCC by the farmers surveyed [7]. Secondly, cooperative collection centers were important, which in turn sell to certain large - scale dairy producers or some other outlet such as direct marketing informally of raw milk. Less than 2% of the families sampled used more than one MCC. Tests are made on a daily basis for either individual milk or bulk dairy farms, a 15-day average or average 7-15 day bulk milk tests. However, even when daily or individual testing is not performed, farm - gate prices reflect clearly the general fat and SNF level on every visited system so that, despite higher transport cost, prices are significantly higher in dry areas than in others. This offers a good incentive to increase the consumption in the areas of large production where high-fat genotype animals prevail [21].

Figure 2.7.1: A private milk collector in formal milk supply chain

Informal milk sales and collection

Direct sales to neighbors, shops and restaurants are an important and convenient markets for many producers to sell milk. Although this can involve a certain amount of higher transaction costs when looking for buyers the farmers can exercise some control over prices, delivery and payment conditions by way of establishing regular buyers and informal agreements. The survey reported that producers' households disposed of 15% milk in this way. These domestic (raw) milk markets also have an important function in areas where such markets are available, especially in neighborhoods and nearby cities (sometimes known as "town milk"). These are directly served to farmers, private collectors and some cooperatives that supply milk to restaurants and hotels, door to door and small processors. While exact figures do not exist on this market, informed respondents suggested that this market in some areas might be relatively important. Private (small) milk collectors are a group of entrepreneurs of the private sector (also known as middlemen) that collect milk and deliver milk to the market (shops, hotels, consumer home delivery, large processors and MCCs). They work with push bikes, motorcycles and small lorries, and even where dairy companies are powerful they play an important part in many systems. They provide a seemingly efficient way to bulk and supply milk to collection or chilling centers, although they appear to offer a lower price for farming than is generally available through farming systems. In return they provide services such as collecting, delivering and selling concentrate feed and non - interest advances and loans to farmers. They range from 7 - 8 liters per day (bike operators) to 2000 liters per day (vehicle operators). Research shows that these private collectors have limited capital and often offer producers non - price benefits. These small - scale milk collectors return a monthly job, while also creating jobs for a full - time worker. These intermediaries often provide farmers with other services like small loans. [21]

Formal milk collection

The organization of dairy supplies usually follows density of milk production, as is evident in Sri Lanka too. The highest production per sq. km is in Nuwara - Eliya (113 liters). Central Province has the highest milk collection reported. The Eastern province has the highest proportion of animals and buffalos. Though the share of cattle and buffalos in the Central Province is comparably low, because of the more favorable climate and higher grades of dairy animals, it contributes significantly to the overall milk collection. Due to rainfall and temperature, a significant amount of seasonal activity is observed in milk collection. The variance over the year is approximately 40% [7].

Dairy Collection Centers (DCCs): These are primary collection points with enough milk producers to guarantee minimum milk collection of approximately 100 liters / day. They are managed by farms, manufacturers or larger dairy cooperatives themselves. DCC's main function is to receive milk from producers and to transmit the milk to the MCC. As mentioned above, most DCCs test for fat and SNF in milk. [21]

Most milk is generally collected only morning, but milk is also collected at night in areas with a higher production density. Similarly, evening milk is often marketed or simply consumed by farmers in informal markets [21]

Milk Chilling Centers (MCCs): They are secondary points of collection. Currently 287 MCCs are operating in a large network with hundreds of collection points in 2015 as published in the statistical bulletin on livestock published by the Dept. of animal production and health [7]. In addition, some large farms provide direct milk to the MCCs. The smaller ones often have power failures and many have old equipment. The costs of milk collection in areas with low production density are apparently high. For efficient large - scale operators, average collection cost is around Rs 65 - 80/L (up to the MCC). The competition for farm milk leads to tensions in certain areas, especially where private collectors are being evacuated by large - scale dairy collector networks and supplies of the same dairy co-operatives and private collectors. Suppliers appear to be not loyal to any specific purchaser of milk. Suppliers are willing to transfer to other purchasers if prices change [21].

Figure 2.7.2: A typical milk chilling center of a large scale dairy manufacturer

Figure 2.7.3: A refrigeration system used in a MCC

Figure 2.7.4: A typical main route tanker used for raw milk transportation

2.7.2 Milk processing

Milk industry in Sri Lanka includes (a) processing of liquid milk for locally manufactured milk and (b) plants which repackage using imported milk powder, while some dairy manufacturers produce yogurt and ice - cream using a mixture of local and imported milk powders [21].

Small private processing has played a small but helpful role in increasing the commercialization of milk products. Curd, produced by the farmers, and modern products, such as ice cream, yogurt sweetened, etc.

Figure 2.7.5: Processing and filling equipment used in a large scale dairy factory

2.8 Modeling LCIA using openLCA

According to ISO 14040 standard, there are three phases of LCA. The first phase of this project involves defining goals and scope, followed by an inventory analysis of the life cycle. Understanding of results is the final stage of the LCA [2].

2.8.1 Steps of life cycle impact assessment (LCIA)

In LCIA, the primary flows from the life cycle inventory are translated into their future contribution to the environmental effects (classification) considered in the LCA, which makes it useful to answer the questions presented in the goal definition at the interpretation stage [2].

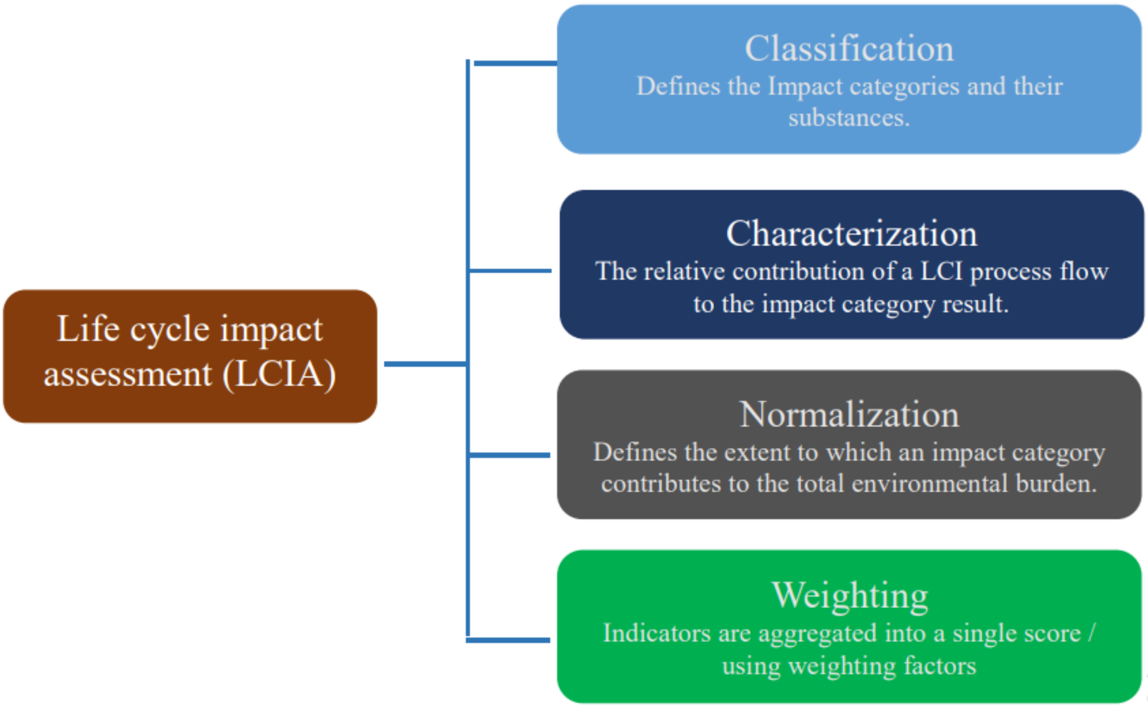


Figure 2.8.1: Modelling life cycle impact assessment (LCIA) using openLCA [2]

Characterization is used to specify a substance's comparative severity with a similar substance. This applies to a selected category of pollutants such as greenhouse gases, energy use or radioactive substances. Conditions from the prevailing scientific literature are demonstrated by the characterization factors. For example, as shown by figures from the Intergovernmental Panel on Climate Change (IPCC), a similar example from this category could be radiative forcing methane to 25 times as much as that of carbon dioxide (CO2), the radiative forcing of methane. The quantity to be characterized is traditionally indicated by reference. This reference is CO2 equivalent for GHGs. This value is 25 for methane, meaning that 1 kg of methane has the same radiative forcing as 25 kg of CO2. The LCI results will also be compared against each impact category for the purposes of characterization factors and the substance’s contribution to the impact category will be listed and multiplied then by a characterization factor specific to that impact category to show the substances' relative contribution. The basic requirement for the use of these characteristics is that such factors include the legislative recommendations [2].

Normalization method for comparison of results

The impact indicator data found, are normalized to relate the life cycle effects of the various stages of the process and sources of energy. ISO 14044 defines normalization as a step which is optional in LCA following the characterization stage. Two normalization methods, namely internal and external, are commonly used in life cycle assessment. Case - specific normalization is carried out with internal normalization when the scores of impacts are divided by the highest value in the same category of impact or the total of the scores of impacts. An other way is to take a choosen alternative as a basis and follow an approach of "divide by baseline". In contrast, a normalization factor is required by the external normalization method, which is well-defined depending on the overall impacts in a category of indicator under a reference system which is selected, that can be for a system or per person or region during a specified time-frame (e.g. average annual impact of a European citizen ***OR*** average yearly environmental load in a country is divided by the number of inhabitants living in that country). Then, all impacts are shown in the same unit [3].

The benefit of internal normalization is that data outside the case study are not required [3].

Table 2.8.1: An example for normalization of characterized results [22]

	Climate Change		**Acidification**	
Characterized results	2.49	kg CO2-eq.	0.0168	mol H+-eq.
Normalization factor	6.803	kg CO2-eq / person·yr	49.44	mol H+-eq. / person·yr
Normalized results	3.66E-04	person·yr	3.40E-04	person·yr

Weighing

Here, a value judgment is applied to the results stating how important each impact is. After weighing, the calculated environmental impacts can be aggregated and displayed as a single score. Weighing is a controversial step since this value judgment may be different per individual/organization [22].

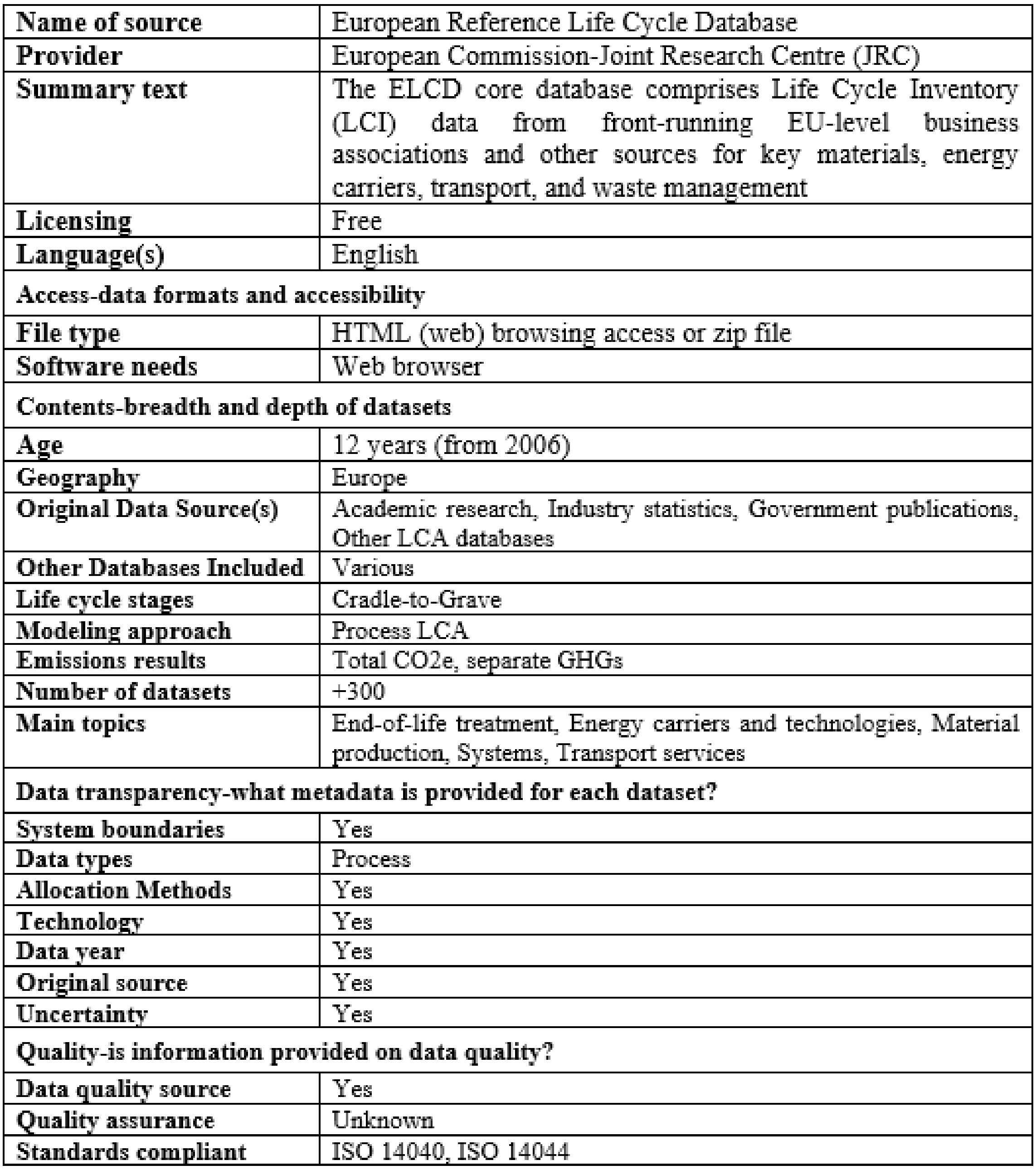
Options for determining weighing factors are distance to target (scientific or policy targets), monetization (e.g. willingness to pay), panel weighing (average opinion of a group) [22].

2.8.2 ELCD database (version 3.2, from October 2015) for LCA

ELCD (European Life Cycle Database) has been composed of Life Cycle Inventory (LCI) data from leading European business groups and other sources for energy carriers, key materials, waste management and transport since its first issue in 2006. The data sets are supplied and approved by the named association of the industry [23].

The ELCD is published means of a newly developed information technology infrastructure ready for the Life Cycle Data Network registry as the "JRC ELCD Node". This Information Technology infrastructure is based on the Soda4LCA application (advanced by the Karlsruhe Institute of Technology (KIT), OkworX consulting and JRC) and on an added application advanced by JRC [24].

Table 2.8.2: Detail summary of ELCD database [25]



Name of source	European Reference Life Cycle Database
Provider	European Commission-Joint Research Centre (JRC)
Summary text	The ELCD core database comprises Life Cycle Inventory (LCI) data from front-running EU-level business associations and other sources for key materials, energy carriers, transport, and waste management
Licensing	Free
Language(s)	English
Access-data formats and accessibility	
File type	HTML (web) browsing access or zip file
Software needs	Web browser
Contents-breadth and depth of datasets	
Age	12 years (from 2006)
Geography	Europe
Original Data Source(s)	Academic research, Industry statistics, Government publications, Other LCA databases
Other Databases Included	Various
Life cycle stages	Cradle-to-Grave
Modeling approach	Process LCA
Emissions results	Total CO2e, separate GHGs
Number of datasets	+300
Main topics	End-of-life treatment, Energy carriers and technologies, Material production, Systems, Transport services
Data transparency-what metadata is provided for each dataset?	
System boundaries	Yes
Data types	Process
Allocation Methods	Yes
Technology	Yes
Data year	Yes
Original source	Yes
Uncertainty	Yes
Quality-is information provided on data quality?	
Data quality source	Yes
Quality assurance	Unknown
Standards compliant	ISO 14040, ISO 14044

2.8.3 ReCiPe methodology (version 1.11-December 2014) for LCIA

The development of the Recipe methodology was done with the help of many developers in the LCA sector such as PRé consultants , CML, RIVM, , Nijmegen, CE Delft, and Radboud University. This approach is treated to be a reappraisal to the CML 2002 and EI99. The indicator values are measured in a manner similar to EI99. This method links end-point and mid-point modelling approaches. Eighteen (18) categories of midpoint: human toxicity, natural land transformation, urban land occupation, particulate matter formation, marine eco-toxicity, mineral resource depletion, agricultural land occupation, climate change, terrestrial eco-toxicity, water depletion, ozone depletion, freshwater eutrophication, fossil fuel depletion, freshwater eco-toxicity, marine eutrophication, photochemical oxidant formation, terrestrial acidification, ionizing radiation [26].

At the level of endpoint, three (3) categories of endpoint are taken into account, which in this study, are the similar demarcated environmental protection areas: resources availability, eco system diversity and damage to human health. The year 2000 was selected as the year of reference for characterization and normalization and information was collected at a European level. But, in 2010 , some changes were applied regarding the midpoint normalization factors. The panel approach measures the weighting in this method. Europe has regional validity [26].

However, as with other LCIA methodologies, there are some problems that are global, such as climate change, depletion of the ozone layer and resources. Figure 2.8.2 illustrates ReCiPe methodology impact categories & pathways [26].

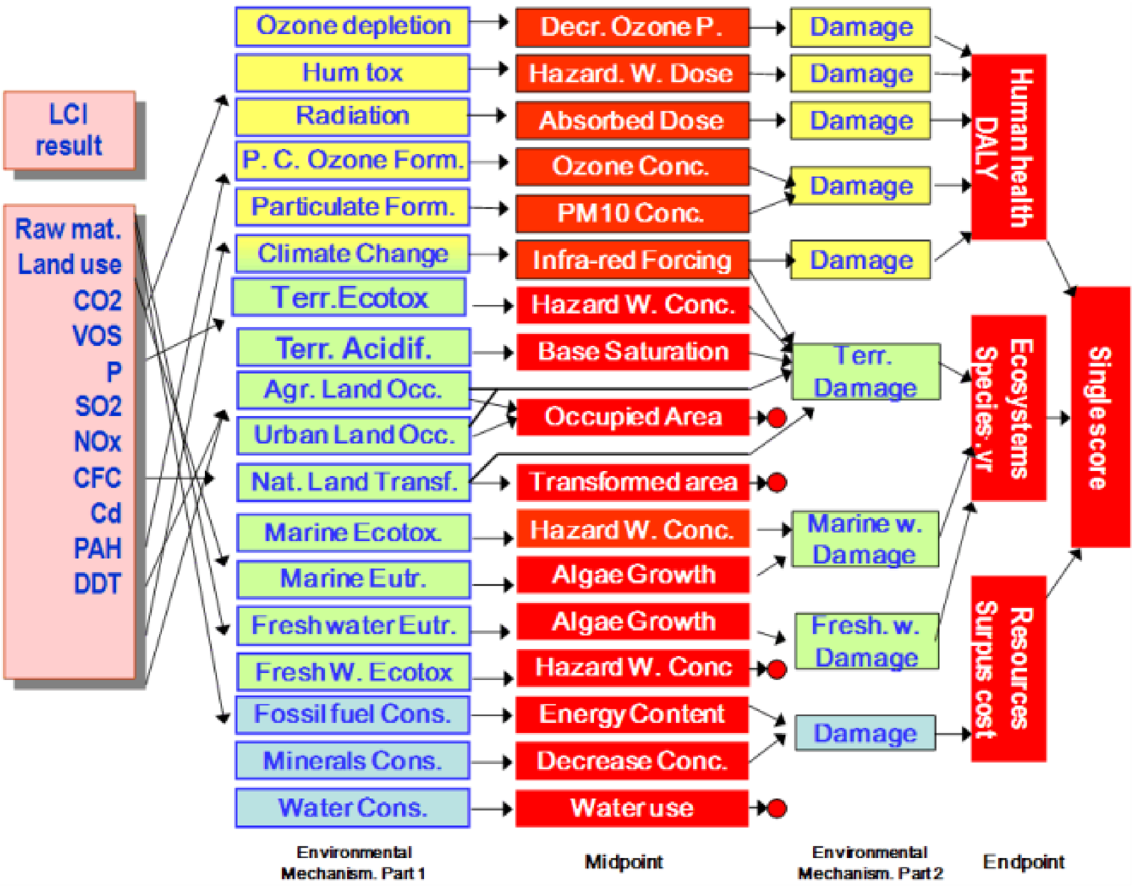


Figure 2.8.2: Impact categories and pathways covered by the ReCiPe methodology [26]

3. METHODOLOGY

To begin with, a literature survey was led to discover the key stages of Sri Lanka's formal milk supply chain. After evaluating the environmental effects of the life cycle related to energy consumption, the methodology has been advanced. A case study was subsequently performed using data obtained from a large dairy manufacturer in Sri Lanka, where a LCA was carried out in view of a full calendar year (taking into account the total raw milk intake and energy consumption in that year including specific consumption of energy and sources of energy). A last, an impact assessment was done on the likely differences in environmental presentations with regard to various energy supply scenarios. The details were used to make guidelines for the dairy industry in Sri Lanka. The study details were well defined in the following segments in the research.

3.1 Life cycle assessment methodology

Life cycle assessment can be defined in ISO 14040 in four phases. These four phases were led by the LCA connected to the existing study. First, it is necessary to outline the goal and scope. The main criteria for defining an LCA's goal are the application expected and use of results, target audience, and the details why the reseach was conducted. An LCA's scope includes the product system, procedures, selection of impact groups, and expectations. There might be some various definitions of system boundaries, such as gate - to - gate (between intermediate process phases), cradle - to - gate (to intermediate process from raw material extraction) and cradle - to - grave (end - of - life raw material extraction). The inputs and outputs of the product system were gathered and quantified, in the second phase. At this point, for each stage of the process, the resources, energy, and waste must be documented along with transport related activities from and to individual phases of the process. This is the stage in which the case study area - specific data must be brought in. The life cycle account data is used in the third phase to evaluate the product system's environmental impacts. This is identified as the evaluation of impacts of the life cycle. Different categories of impacts are used to represent the environmental impacts of the life cycle, based on the objective and scope. The methodology's fourth and final phase was interpretation. The results that brought the LCA findings to be interpreted should be in line with the defined goal and scope. These may be aimed at decision - makers and other stakeholders in the form of conclusions and recommendations [3].

3.2 Life cycle assessment

3.2.1 Goal and scope definition

In this study, the author made an analysis of the gate - to - gate life cycle and a comparison of different situations of energy supply. The life cycle analysis was carried out with the open LCA software developed by GreenDelta GmbH, Germany, following the standardized LCA procedure ISO 14040. Data collection is depending on the life cycle inventory database ELCD 3.2 produced by the European Commission's Joint Research Center (JRC) and secondary data were collected from many technical reports, government reports, websites, dairy sector in Sri Lanka, Richlife Dairies Ltd and literature survey in particular. The impacts of the environmental cycle were evaluated using a methodology called Recipe midpoint (H) life cycle impact assessment (LCIA).

Table 3.2.1: Goal and scope definition

Goal	
Application	Life cycle impacts of energy use in dairy supply chain
Target audience	Sri Lankan dairy industry
Expectation and use of results	Improving energy performance and sustainability in Sri Lankan dairy supply chain, by filling the data gaps on life cycle impacts of Sri Lankan dairy industry
Scope	
Approach	Gate-to-gate
System boundary	MCC operation (Raw milk collection, testing, chilling and pumping) , Raw milk transportation, Dairy factory operation (Milk Processing, Filling and Storing) and Finished goods transportation (from factory to distribution points) in terms of energy use intended for energy purposes

3.2.2 Functional unit

In general, all related inputs and outputs in the LCI (Life Cycle Inventory) stage and the final impact values in the LCIA (Life Cycle Inventory Assessment) stage related to the reference flow known as the functional unit (FU), will be critical for LCA studies. The Functional Unit has a important effect on the results of particular environmental impacts as they are essential for effective decision - making, and industry [2]. Functional unit was defined as the "1 liter of raw milk input into the system", for this study.

3.2.3 Defining life cycle boundaries of the present study

The boundary of the system has been chosen and designated covering whole supply chain of a large- scale dairy producer, in order to stipulate the space of unit methods have also been taken into account in the analysis. From the definition of scope explained in LCA, the “gate-to-gate” approach has been tracked and followed for the study. The focus of the LCA can be taken out on the major phases of dairy supply chain of a typical large-scale dairy manufacturer in Sri Lanka, as this includes the concerned areas relating to energy use intended for energy purposes. Though the overall life cycle energy consumption of a dairy product generally comprises all the processes from animal feed manufacture to eventual disposal of used packaging materials, the designated process steps within the system boundary of the LCA have been recognized as the top most direct concern for a large-scale dairy manufacturer. With As such, the effect assessment was carried out solely for the MCC process (raw milk collection, testing, chilling and pumping), raw milk transport, milk processing (milk processing, filling and storage) and finished goods transport (from factory to distribution points) phases of the Sri Lankan dairy industry.

The LCA system boundary for this research was well-defined as illustrated in Figure 3.2.1. The analysis did not take into account packaging materials, chemicals and other raw materials including milk powder. Solid waste and drainage releases from the system were therefore not considered as the purpose of this research was to investigate the life cycle impact of energy (including fuel) use.

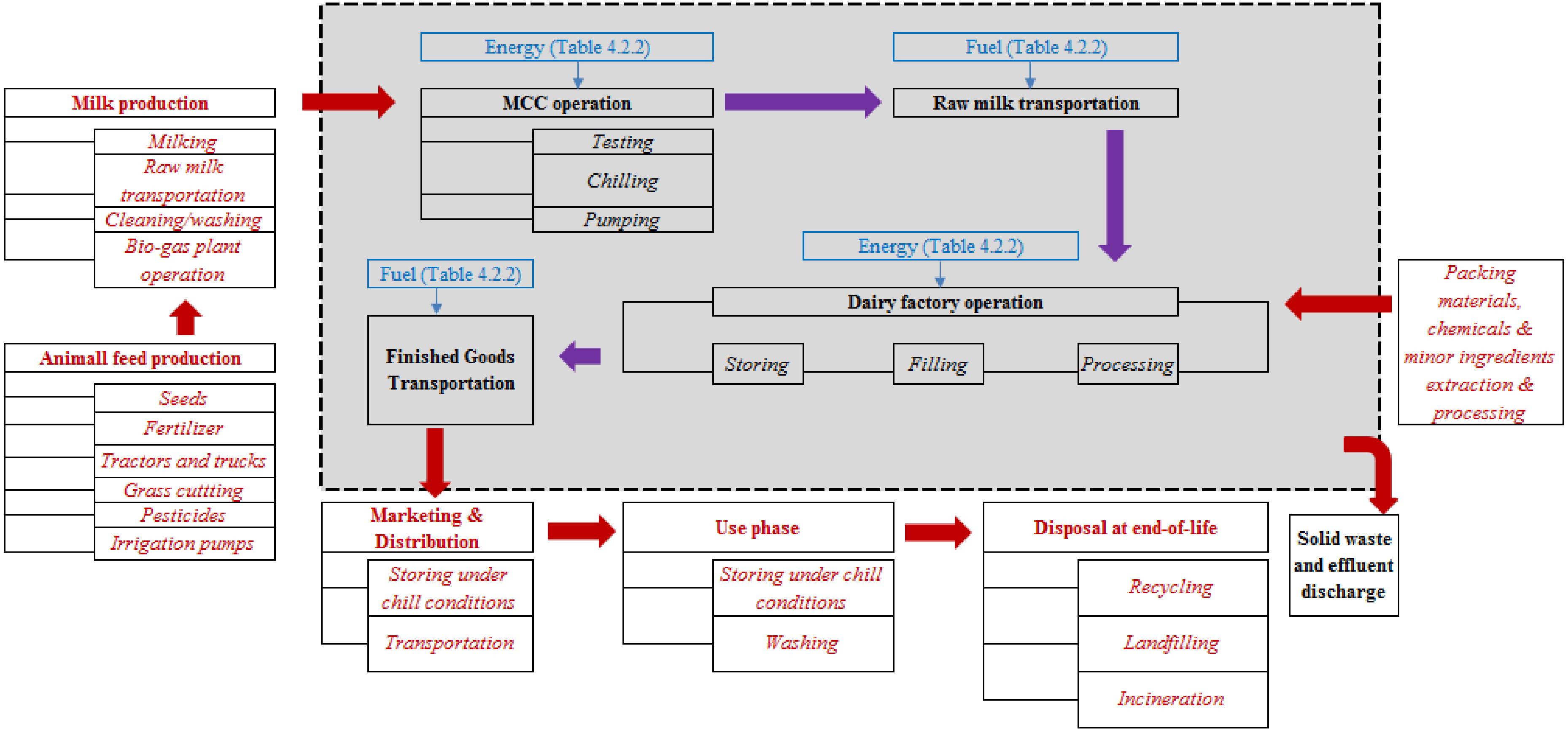


Figure 3.2.1.: LCA system boundary for the dairy supply chain

3.2.4 Life cycle inventory analysis (LCI)

The definition of the goal and scope of the study has been offered the primary plan for directing the life cycle inventory stage of an LCA. When implementing the plan for the life cycle inventory analysis, the functioning phases have been drawn in Figure 3.2.2 (abstracted from ISO 14044:2006) have been achieved as appropriate. (It should be noted that some iterative steps are not shown in Figure 3.2.2.)

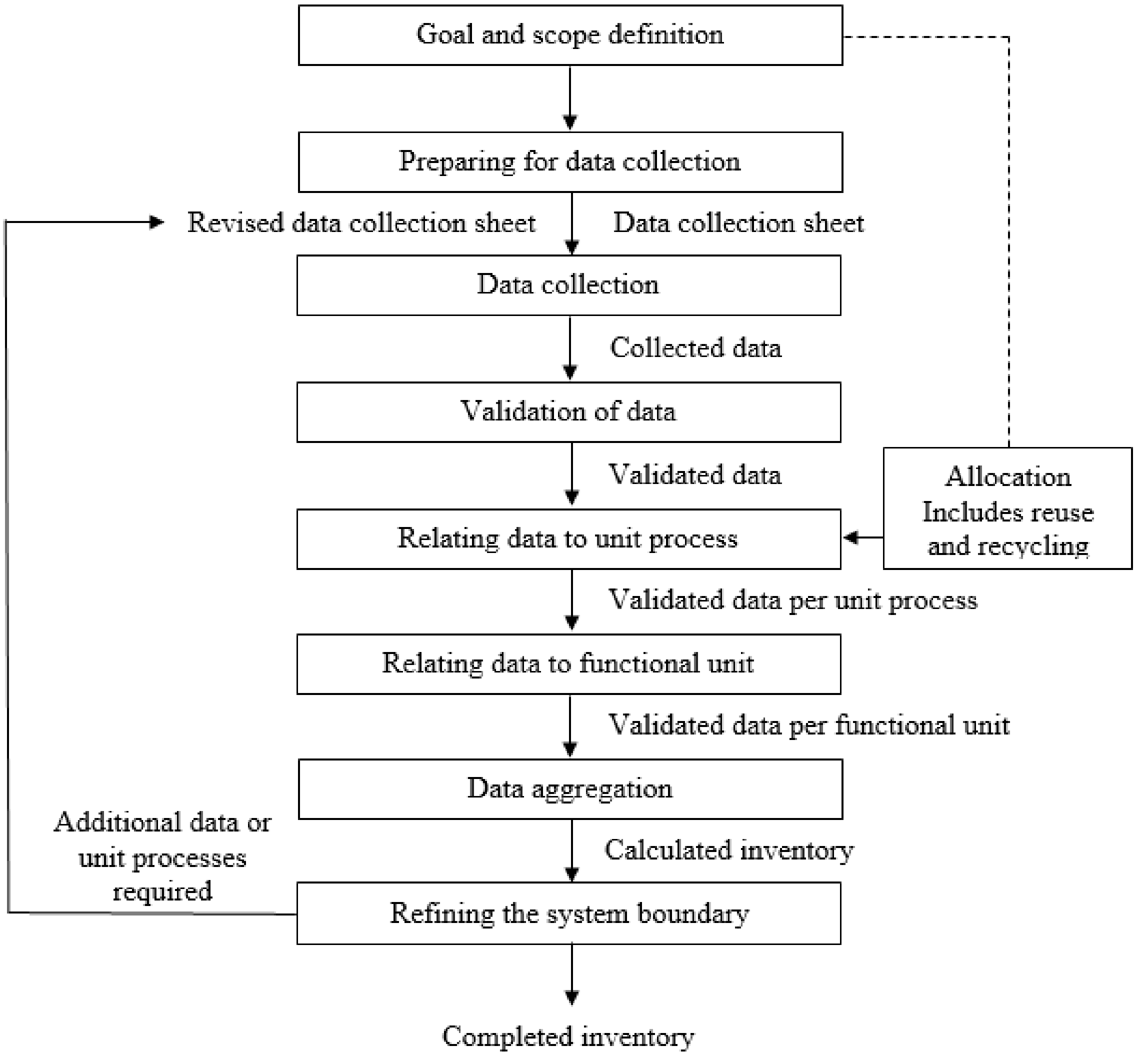


Figure 3.2.2: Simplified procedure for inventory analysis [27]

3.2.5 Life cycle impact assessment

After defining the system boundary, a large - scale Sri Lankan dairy manufacturer's process phases of the supply chain (i.e. from MCC operation to transportation of finished items to distribution points) were analyzed for their energy use. The impact of the life cycle of various sources of energy that were used in the generation of electricity and thermal energy, and fuel, were measured by means of the ReCiPe (version 1.11) Midpoint Hierarchist (H) method (Hierarchist method is depending on the most common policy principles in relation to time-frame and several other issues and it uses the medium time-frame. For example: a 100-year time frame for global warming, GWP100) in openLCA software with data from the ELCD database (version 3.2) to report characterization results. ReCiPe can be taken as the technique that has been coordinated to demonstrate principles and choices, and that essentially consists of categories of midpoint and endpoint impact. The Midpoint Pointers embody the basic flows and other exchanges considered by the type of impact. To explain the environmental impacts, The ReCiPe method uses Eighteen (18) impact categories at the mid-point level. The level of the mid-point was oriented towards damage and the ambiguity that accompanies the results is lower. They are usually more precise than end-point ones (that are used in terms of public - related terms to show the "damage" / total effect). As the aim of this research was to measure and compare the impacts of energy consumption to the environmental in different process steps and scenarios and not to understand the results of LCA, mid-point indicators were choosen as environmental performance parameters. Correspondingly, the LCA has also been steered on the transport in view of an alternative eco-friendly fuel type, i.e.: Solar PV in Electrical vehicles, as identified from the literature review.

For each process step, the impacts were accumulated using the data on energy consumption, and thus allocated in the case study to one liter of raw milk intake. The actual energy use was considered in the analysis of the considered large - scale dairy manufacturer and the Sri Lankan electricity

3.2.6 Normalization method for comparison of results

In this research, an external normalization process was conducted. Normalization factors were obtained from an Excel file published in ReCiPe website with latest updates (last update: 6 Feb 2015). These normalization factors have been calculated using the Europe and World reference inventories in SimaPro. For this study, the normalization factors calculated using the World reference inventory (with population data of year 2000) was considered.

4. ANALYSIS

4.1 Case study

The total energy (primary, secondary, non-renewable and renewable) use (intended for energy purposes and not for material purposes) against the raw milk intake to the supply chain of one of the large-scale dairy manufacturers in Sri Lanka, within a full calendar year, was choosen to attend in this case study.

The company maintains a milk collection network which consists of Eight (8) milk chilling centers located at milk pockets dispersed in different areas of the country including one at the main processing plant in Wadduwa (Please, refer **Annexure I** for the details on MCC locations and their capacities).

A fleet of vehicles, comprising of Seven (7) main route tankers with different capacities with another Five (5) hired vehicles (small Lorries), is available for raw milk collection. These small Lorries are used to collect milk directly from the farmers/ farmer groups operating under five different MCCs. Tankers are used to collect raw milk from the MCCs. At Chilling Centers, the amount of milk varies from day to another and depends on season. But, the supply for a specific day is identified before the main-route tankers leave the factory (Since, there is a communication between Chilling Center & Factory). Hence, the Transport Executive of the company decides and communicates the number of tankers, their capacities, time of departure, time of arrival etc. by the evening of each day so as the arrival of tankers to the factory (with raw milk collected) can be planned before 6.00 AM of the following day. The tankers collect milk from the Chilling Centers daily / once in two days and bring it to the factory. Full quantity of milk of each Chilling center must be collected. In a certain time, all vehicles must complete their journey. Normally, Two (2) tankers leave from the factory in each day to cover all the MCCs.

Processing of raw milk and converting them in to different value-added products such as Yogurt, Curd, UHT milk, Cheese, Stirred yogurt and pasteurized milk, is carried out in the main processing plant (factory) located at Molligoda, Wadduwa of Kaluthara district. The factory has a capacity of processing 50,000 liters per day, approximately. The finished products are then stored within the same facility under different conditions. Cool rooms are maintained for Yogurt, Curd, Cheese and pasteurized milk. UHT milk is stored in a dry-store. Also, there are Three (3) vehicles based in the factory; 2 diesel vans for staff transport and one motorcycle for miscellaneous purposes.

Finally, the finished goods transportation is carried out by the company up to the Peliyagoda warehouse and dealers' points / distribution agencies located in different areas of the country, with Five (5) diesel motor Lorries. (Please, refer **Annexure II** for the details of the vehicles used in the supply chain)

4.2 Data for the analysis

In addition to the details on the consumption of raw milk to the supply chain during the full calendar year under consideration, in 2015, data on energy use, sources and efficiency were essential for developing the inventory of the life cycle for analysis. In addition, the analysis considered a reasonable set of alternative energy supply sources to compare different scenarios.

4.2.1 Raw milk input to the supply chain

In Table 4.2.1, the total raw milk input from all the MCCs to the supply chain of Richlife Dairies Ltd., in 2015, is given. There are seasonal and regional changes in milk supply, their fat and SNF content [28]. Seasonal variation in milk supply is nearly 45%. When analyzing milk supply, fat and SNF data of each MCC in couple of years, it was noticed the same pattern is iterated in each year. Also, the pattern of varying the product mix (which is largely effected to the energy use as understood from the literature survey) is also almost the same in every year with minor exceptions. But, for this analysis, those variations were not considered because all the MCCs were taken into account as a single process in the LCA and the aggregated data in a full calendar was considered for the analysis.

Table 4.2.1: Raw milk input to the supply chain in 2015
[Source: Selected large scale dairy manufacturer]

Month	Quantity / Liters
January	400,897.1
February	464,210.1
March	487,041.7
April	405,521.5
May	429,701.5
June	391,945.0
July	454,206.1
August	482,474.8
September	394,373.8
October	425,867.8
November	338,513.9
December	335,488.3
Total / Liters	**5,010,241.7**

4.2.2 Energy use and sources

The energy consumption within the border of the LCA was mainly considered by electrical and heat energy in the MCCs and milk plants and by transport fuel, according to the case study.

Table 4.2.2 illustrates the actual energy use in year 2015 under each phase of the supply chain and their resources. Electricity usage was taken from electricity bills. Diesel, Petrol, furnace oil and fire wood usage was taken from log books maintained in respective locations. (e.g.: actual Diesel consumption of generators was taken from the log book maintained in the generator room).

The energy sources used in the dairy supply chain were finally apportioned for one liter of raw milk input to the supply chain.

In 2015, the thermal energy was mainly (nearly 70%) supplied through bio-mass. But, in 2014, 100% it came through furnace oil and in 2016, 100% it came through bio-mass.

In the "Sri Lankan Energy Balance" issued by the "Sri Lankan Sustainable Energy Authority," the information for generating electricity was taken into account to find the grid power generation mix as described in Table 4.2.3.

Table 4.2.2: Energy use in each phase of the supply chain and their sources

<table>
<tr><th>Phase</th><th>Energy Use</th><th>Source</th><th colspan="2">Quantity Used in 2015</th><th>Unit</th><th>Per Liter Consumption</th></tr>
<tr><td rowspan="2">MCC Operation
(Raw milk collection, testing, chilling and pumping)</td><td>Electricity</td><td>National Grid</td><td colspan="2">205,781</td><td>kW h</td><td>4.107E-02</td></tr>
<tr><td>Electricity (from the Generator)</td><td>Auto Diesel</td><td colspan="2">3,325</td><td>Ltr</td><td>6.637E-04</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Raw Milk Transportation</td><td>In milk transport vehicles (Milk collection vans and Main route tankers)</td><td>Auto Diesel</td><td colspan="2">62,680</td><td>Ltr</td><td>1.251E-02</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td rowspan="6">Dairy Factory
(Milk Processing, Filling and Storing)</td><td>Electricity</td><td>National Grid</td><td colspan="2">1,687,137</td><td>kW h</td><td>3.367E-01</td></tr>
<tr><td>Staff transport vehicles</td><td rowspan="2">Auto Diesel</td><td>4,849.20</td><td rowspan="2">10,604.20</td><td rowspan="2">Ltr</td><td rowspan="2">2.117E-03</td></tr>
<tr><td>Electricity (from the Generator)</td><td>5,755.00</td></tr>
<tr><td>Motorcycle</td><td>Petrol</td><td colspan="2">76.25</td><td>Ltr</td><td>1.522E-05</td></tr>
<tr><td>Furnace oil boilers (1.Wembly, 2.Sheng Chung)</td><td>Furnace fuel oil</td><td colspan="2">142,807.00</td><td>Ltr</td><td>2.850E-02</td></tr>
<tr><td>Biomass boiler (Thermax, Combtoc CB40)</td><td>Fire wood</td><td colspan="2">331,722.00</td><td>kg</td><td>6.621E-02</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td>Finished Goods Transportation
(From Factory to Distribution points)</td><td>In transport vehicles</td><td>Auto Diesel</td><td colspan="2">10,086.70</td><td>Ltr</td><td>2.013E-03</td></tr>
</table>

Table 4.2.3: Electricity generation mix for Sri Lanka in 2015

Source			**Generation /(GW h) [9]**		**% Share**		**Per Ltr Consumption of Electricity from the National Grid / kW h (Business-as-usual in 2015)**	
							MCC Operation	**Dairy Factory**
Major Hydro				4904.4	37.14%		1.525E-02	1.250E-01
Thermal	Coal			4447.2	33.67%		1.383E-02	1.134E-01
	Oil	Auto Diesel	441.1	2349.2	3.34%		1.372E-03	1.125E-02
		HSFO 380 cst (FO 3500)	373		2.82%		1.160E-03	9.511E-03
		Naphtha	540.3		4.09%		1.680E-03	1.378E-02
		HSFO 180 cst (FO 1500)	323.4		2.45%		1.006E-03	8.246E-03
		LSFO 180 cst	671.4		5.08%		2.088E-03	1.712E-02
Renewable	Mini Hydro			1064.7	8.06%		3.311E-03	2.715E-02
	Biomass			57.3	0.43%		1.782E-04	1.461E-03
	Solar PV			40.7	0.31%		1.266E-04	1.038E-03
	Wind			343.2	2.60%		1.067E-03	8.751E-03
Total				**13206.7**	**100.00%**		**4.107E-02**	**3.367E-01**

4.2.3 Alternative energy supply scenarios

Different scenarios of energy supply for all phases were explored to evaluate the impact of substituting conventional sources of energy for sustainable solutions. In previous studies, scenario-based assessment of energy utilization and the consequent impacts to the environmental and comparison between various sources of energy have been considered [3]. The food industry in Sri Lanka is currently on the way heading to non-conventional sources of energy whereby main food manufacturers invest for their energy needs in solar and biomass. Some of the initiatives which are common for the industry include installing solar photovoltaic technology in its production plants and substituting oil-based boilers with biomass fired ones.

The energy supplies scenario taken into account in the study is detailed in Table 4.2.4. Each scenario included data for evaluating the life cycle impacts of various sources of energy in Table 4.2.5. The aggregated impact indicator values for all the stages were used for comparing the life cycle impacts of energy supply in “business-as-usual” scenario (Scenario 1) in 2015, with the ‘Early case’ before 2015 (Scenario 2) before introducing the biomass fired boiler (i.e.: 100% run with Furnace oil) for thermal energy supply in factory operation phase, ‘Current case’ after 2015 (i.e.: 100% run with biomass for thermal energy supply-Scenario 3) and two (2) replacement scenarios (hypothetical states that can be tried in future-Scenario 4 &5). The forth considers 50% replacement of Solar PV for electricity and transportation, with 100% use of biomass for thermal energy and, the fifth scenario considers 100% replacement of Solar PV for electricity and transportation, with 100% use of biomass for thermal energy. In other words, the final scenario looks at the consequences of the entire replacement of conventional sources with renewable energies.

Table 4.2.4: Energy supply scenarios

#	Scenario	Electricity	Thermal Energy	Transportation fuel
1	**Business as Usual-In 2015**	Grid electricity, Diesel generator in power cuts (100% conventional supply)	70% from bio-mass and the rest from furnace fuel oil	100% from fossil fuel (auto Diesel and Petrol)
2	**Early state-Before 2015**	Grid electricity, Diesel generator in power cuts (100% conventional supply)	100% from furnace fuel oil	100% from fossil fuel (auto Diesel and Petrol)
3	**Current state-After 2015**	Grid electricity, Diesel generator in power cuts (100% conventional supply)	100% from bio-mass	100% from fossil fuel (auto Diesel and Petrol)
4	**Future State 1**	50% from Solar PV and the rest from conventional supply	100% from bio-mass	50% from fossil fuel and the rest from Solar PV
5	**Future State 2**	100% from Solar PV	100% from bio-mass	100% from Solar PV

Table 4.2.5: Energy use per functional unit under different scenarios

Phase	Source	Use	UOM	Scenario 1 (Business as Usual-In 2015)	Scenario 2 (Early state-Before 2015)	Scenario 3 (Current state-After 2015)	Scenario 4 (Future State 1)	Scenario 5 (Future State 2)
MCC Operation	Hydro	Electricity	kW h	1.856E-02	1.856E-02	1.856E-02	9.282E-03	0.000E+00
	Coal	Electricity	kW h	1.383E-02	1.383E-02	1.383E-02	6.915E-03	0.000E+00
	Auto Diesel	Electricity	kW h	1.372E-03	1.372E-03	1.372E-03	6.859E-04	0.000E+00
	Auto Diesel-Generator	Electricity	Ltr	6.637E-04	6.637E-04	6.637E-04	3.318E-04	0.000E+00
	HSFO 380 cst (FO 3500)	Electricity	kW h	1.160E-03	1.160E-03	1.160E-03	5.800E-04	0.000E+00
	Naphtha	Electricity	kW h	1.680E-03	1.680E-03	1.680E-03	8.402E-04	0.000E+00
	HSFO 180 cst (FO 1500)	Electricity	kW h	1.006E-03	1.006E-03	1.006E-03	5.029E-04	0.000E+00
	LSFO 180 cst	Electricity	kW h	2.088E-03	2.088E-03	2.088E-03	1.044E-03	0.000E+00
	Biomass	Electricity	kW h	1.782E-04	1.782E-04	1.782E-04	8.910E-05	0.000E+00
	Solar PV	Electricity	kW h	1.266E-04	1.266E-04	1.266E-04	2.162E-02	4.311E-02
	Wind	Electricity	kW h	1.067E-03	1.067E-03	1.067E-03	5.337E-04	0.000E+00
Raw Milk Transportation	Auto Diesel	Vehicle Fuel	Ltr	1.251E-02	1.251E-02	1.251E-02	6.255E-03	0.000E+00
	Solar PV	Vehicle Fuel	kW h	0.000E+00	0.000E+00	0.000E+00	2.139E-02	4.278E-02
Dairy Factory Operation	Hydro	Electricity	kW h	1.522E-01	1.522E-01	1.522E-01	7.610E-02	0.000E+00
	Coal	Electricity	kW h	1.134E-01	1.134E-01	1.134E-01	5.670E-02	0.000E+00
	Auto Diesel	Electricity	kW h	1.125E-02	1.125E-02	1.125E-02	5.623E-03	0.000E+00
	Auto Diesel-Generator and Vehicles	Fuel + Electricity	Ltr	2.117E-03	2.117E-03	2.117E-03	1.058E-03	0.000E+00
	Petrol	Vehicle Fuel	Ltr	1.522E-05	1.522E-05	1.522E-05	7.609E-06	0.000E+00
	Solar PV	Vehicle Fuel	kW h	0.000E+00	0.000E+00	0.000E+00	1.678E-03	3.356E-03
	HSFO 380 cst (FO 3500)	Electricity	kW h	9.511E-03	9.511E-03	9.511E-03	4.755E-03	0.000E+00
	Naphtha	Electricity	kW h	1.378E-02	1.378E-02	1.378E-02	6.888E-03	0.000E+00
	HSFO 180 cst (FO 1500)	Electricity	kW h	8.246E-03	8.246E-03	8.246E-03	4.123E-03	0.000E+00
	LSFO 180 cst	Electricity	kW h	1.712E-02	1.712E-02	1.712E-02	8.560E-03	0.000E+00
	Biomass	Electricity	kW h	1.461E-03	1.461E-03	1.461E-03	7.305E-04	0.000E+00
	Biomass	Thermal	kg	6.621E-02	0.000E+00	2.495E-01	2.495E-01	2.495E-01
	Furnace oil	Thermal	Ltr	2.850E-02	3.383E-02	0.000E+00	0.000E+00	0.000E+00
	Solar PV	Electricity	kW h	1.038E-03	1.038E-03	1.038E-03	1.707E-01	3.403E-01
	Wind	Electricity	kW h	8.751E-03	8.751E-03	8.751E-03	4.375E-03	0.000E+00
FG Transportation	Auto Diesel	Vehicle Fuel	Ltr	2.013E-03	2.013E-03	2.013E-03	1.007E-03	0.000E+00
	Solar PV	Vehicle Fuel	kW h	0.000E+00	0.000E+00	0.000E+00	3.442E-03	6.884E-03

In Table 4.2.5, when calculating the Furnace oil use of the factory for the supply of thermal power under Scenario 2, it was considered a period of Three (3) consecutive months of 2015 in which the factory ran 100% with furnace fuel only. From January to March in 2015, 46352 Liters of furnace oil had been used in the factory before starting the biomass boiler operation. The furnace oil use per functional unit within this period (3.383E-02 Liter/Liter of raw milk input) was then assumed to be the same under Scenario 2 as well.

Also, when calculating the biomass use of the factory for thermal power supply under Scenario 3, it was considered a period of 2015 in which the factory ran 100% with biomass only. For that, 27 days in November 2015 considered and got the average biomass use per functional unit as 2.495E-01 kg/Ltr of raw milk input. This value was assumed to be same under Scenario 3 as well.

Also, under Scenario 4 & 5, when expressing the Solar PV energy use of Electric vehicles (EVs) in transportation phases (raw milk transportation and finished goods transportation), derived from the actual diesel usage, it was taken the typical value of TTW efficiency of a Diesel IC engine as 20% and a BEV as 60% based on the information provided in www.fueleconomy.gov (official website of the office of energy efficiency & renewable energy of United States) [29].

Further, under Scenario 4 & 5, when expressing the Solar PV energy use to replace auto Diesel for electricity generation, in MCCs and the factory, using the generators, it was taken the typical value of efficiency of a Diesel generator as 30% [30].

As mentioned already, the vehicles (5 small Lorries) operating under 5 different MCCs, were considered under Raw milk transportation phase and not under MCC operation phase. As such, their energy use (auto Diesel as a fuel) was added to the same of main route tankers and taken into account for calculation of auto Diesel use per functional unit in raw milk transportation.

4.2.4 Arranging life cycle data for openLCA with conversion factors

Energy use data listed in Table: 4.2.5 were re-arranged in Table 4.2.8 to make the LCA modelling in openLCA more ease with the data feeding facilities/options provided in that. Following changes were done there, using the information provided in www.ceypetco.gov.lk on densities of different petroleum fuels, the data provided in ‘Sri Lanka Energy Balance 2015’ report by the ‘Sri Lanka Sustainable Energy Authority’ on total petroleum fuel use in power generation and power generation data provided in Table 4.2.3.

1.) Diesel and Petrol usage of vehicles and electricity generators used in MCCs and the factory expressed in Liters, was converted to ‘kg’.

2.) Electricity from Hydro, Solar & Wind power sources expressed in ‘kW h’, was converted to ‘MJ’.

3.) With regard to the electricity obtained from the national grid, electricity usage equivalent to each and every petroleum fuel was expressed in ‘kg’ of respective fuel type used in power generation.

4.) With regard to the electricity obtained from the national grid, electricity usage equivalent to biomass, was also expressed in ‘kg’ taking the typical value of efficiency of a biomass power generation plant as 25% (*source: The final report on 'Replacing grid electricity with sustainable biomass based power' published by Sri*

Lanka Carbon Fund, United Dendro Energy, Obayashi Corporation (Japan), Hokuden Sogo Corporation (Japan) with EX Research Institute Ltd., in 2013.) [31] and the conversion factors provided in Annexure 01. (*Source: 'Sri Lanka Energy Balance 2015' report issued by the 'Sri Lanka Sustainable Energy Authority'*)

Biomass requirement to produce 1 kW h of electricity for the national grid was found accordingly, as 2.263E-01 kg.

Table 4.2.6: Densities of petroleum fuels [32]

Fuel type	Average Density at 15 ^{0}C / kg m^{-3}
Auto Diesel	840
HSFO 380 cst (FO 3500)	970
Naphtha	685
HSFO 180 cst (FO 1500)	970
LSFO 180 cst	970
Petrol 92 Octane	752

Table 4.2.7: Petroleum fuels use in power generation in 2015 [9]

Fuel type	Total petroleum fuel usage in power generation				Petroleum fuel use per kW h in kg
	Quantity	UOM	Quantity	UOM	
Fuel Oil (HSFO 180 CST, FO 1500)	70.8	million liters	6.868E07	kg	2.124E-01
Coal	1,880.0	million kg	1.880E09	kg	4.227E-01
Residual Oil (HSFO 380 CST, FO 3500)	83.6	million liters	8.109E07	kg	2.174E-01
Diesel	98.6	million liters	8.282E07	kg	1.878E-01
LSFO 180 CST	152.3	million liters	1.477E08	kg	2.200E-01
Naphtha	144.7	million liters	9.912E07	kg	1.835E-01

Table 4.2.8: Life cycle data arranged for openLCA

Phase	Source	Use	UOM	Scenario 1 (Business as Usual-In 2015)	Scenario 2 (Early state-Before 2015)	Scenario 3 (Current state-After 2015)	Scenario 4 (Future State 1)	Scenario 5 (Future State 2)
MCC Operation	Hydro	Electricity	MJ	6.683E-02	6.683E-02	6.683E-02	3.341E-02	0.000E+00
	Coal	Electricity	kg	5.847E-03	5.847E-03	5.847E-03	2.923E-03	0.000E+00
	Auto Diesel	Electricity	kg	2.576E-04	2.576E-04	2.576E-04	1.288E-04	0.000E+00
	Auto Diesel-Generator	Electricity	kg	5.575E-04	5.575E-04	5.575E-04	2.788E-04	0.000E+00
	HSFO 380 cst (FO 3500)	Electricity	kg	2.522E-04	2.522E-04	2.522E-04	1.261E-04	0.000E+00
	Naphtha	Electricity	kg	3.083E-04	3.083E-04	3.083E-04	1.541E-04	0.000E+00
	HSFO 180 cst (FO 1500)	Electricity	kg	2.136E-04	2.136E-04	2.136E-04	1.068E-04	0.000E+00
	LSFO 180 cst	Electricity	kg	4.594E-04	4.594E-04	4.594E-04	2.297E-04	0.000E+00
	Biomass	Electricity	kg	4.032E-05	4.032E-05	4.032E-05	2.016E-05	0.000E+00
	Solar PV	Electricity	MJ	4.557E-04	4.557E-04	4.557E-04	7.783E-02	1.552E-01
	Wind	Electricity	MJ	3.842E-03	3.842E-03	3.842E-03	1.921E-03	0.000E+00
Raw Milk Transportation	Auto Diesel	Vehicle Fuel	kg	1.051E-02	1.051E-02	1.051E-02	5.254E-03	0.000E+00
	Solar PV	Vehicle Fuel	MJ	0.000E+00	0.000E+00	0.000E+00	7.700E-02	1.540E-01
Dairy Factory	Hydro	Electricity	MJ	5.479E-01	5.479E-01	5.479E-01	2.740E-01	0.000E+00
	Coal	Electricity	kg	4.794E-02	4.794E-02	4.794E-02	2.397E-02	0.000E+00
	Auto Diesel	Electricity	kg	2.112E-03	2.112E-03	2.112E-03	1.056E-03	0.000E+00
	Auto Diesel-Generator and Vehicles	Fuel + Electricity	kg	1.778E-03	1.778E-03	1.778E-03	8.889E-04	0.000E+00
	Petrol	Vehicle Fuel	kg	1.145E-05	1.145E-05	1.145E-05	5.726E-06	0.000E+00
	Solar PV	Vehicle Fuel	MJ	0.000E+00	0.000E+00	0.000E+00	6.041E-03	1.208E-02
	HSFO 380 cst (FO 3500)	Electricity	kg	2.068E-03	2.068E-03	2.068E-03	1.034E-03	0.000E+00
	Naphtha	Electricity	kg	2.527E-03	2.527E-03	2.527E-03	1.264E-03	0.000E+00
	HSFO 180 cst (FO 1500)	Electricity	kg	1.751E-03	1.751E-03	1.751E-03	8.755E-04	0.000E+00
	LSFO 180 cst	Electricity	kg	3.767E-03	3.767E-03	3.767E-03	1.883E-03	0.000E+00
	Biomass	Electricity	kg	3.306E-04	3.306E-04	3.306E-04	1.653E-04	0.000E+00
	Biomass	Thermal	kg	6.621E-02	0.000E+00	2.495E-01	2.495E-01	2.495E-01
	Furnace oil	Thermal	kg	2.765E-02	3.282E-02	0.000E+00	0.000E+00	0.000E+00
	Solar PV	Electricity	MJ	3.736E-03	3.736E-03	3.736E-03	6.144E-01	1.225E+00
	Wind	Electricity	MJ	3.150E-02	3.150E-02	3.150E-02	1.575E-02	0.000E+00
FG Transportation	Auto Diesel	Vehicle Fuel	kg	1.691E-03	1.691E-03	1.691E-03	8.456E-04	0.000E+00
	Solar PV	Vehicle Fuel	MJ	0.000E+00	0.000E+00	0.000E+00	1.239E-02	2.478E-02

When feeding the usage of Naphtha in to openLCA as an elementary flow, it was included under Gasoline (Petrol) because the conversion factor of Naphtha given in Annexure III is the same as of Gasoline (Petrol). Also, the electricity obtained from Solar PV for the national grid and for the vehicles as an alternative fuel, was fed as a resource in air ‘converted’.

4.2.5 Additional LCIA data quality analysis carried out

In the context of additional LCIA data quality analytics, outlined in ISO 14044:2006, it has been used to better realize the noteworthiness and responsibilities of the LCIA results. These techniques were important for the identification of significant differences and negligible LCI outcomes.

Gravity analysis

It is a statistical process which identifies the data that contribute most to the result of the indicator. These items can be examined with greater priority to ensure sound decisions are taken [27].

This method was used to compare different energy supply scenarios under each impact category and identify the impact categories having the greatest contribution in ‘Business-as-usual’ scenario. Also, this method was used to identify the phases having the highest contribution to each indicator result in ‘Business-as-usual’ scenario.

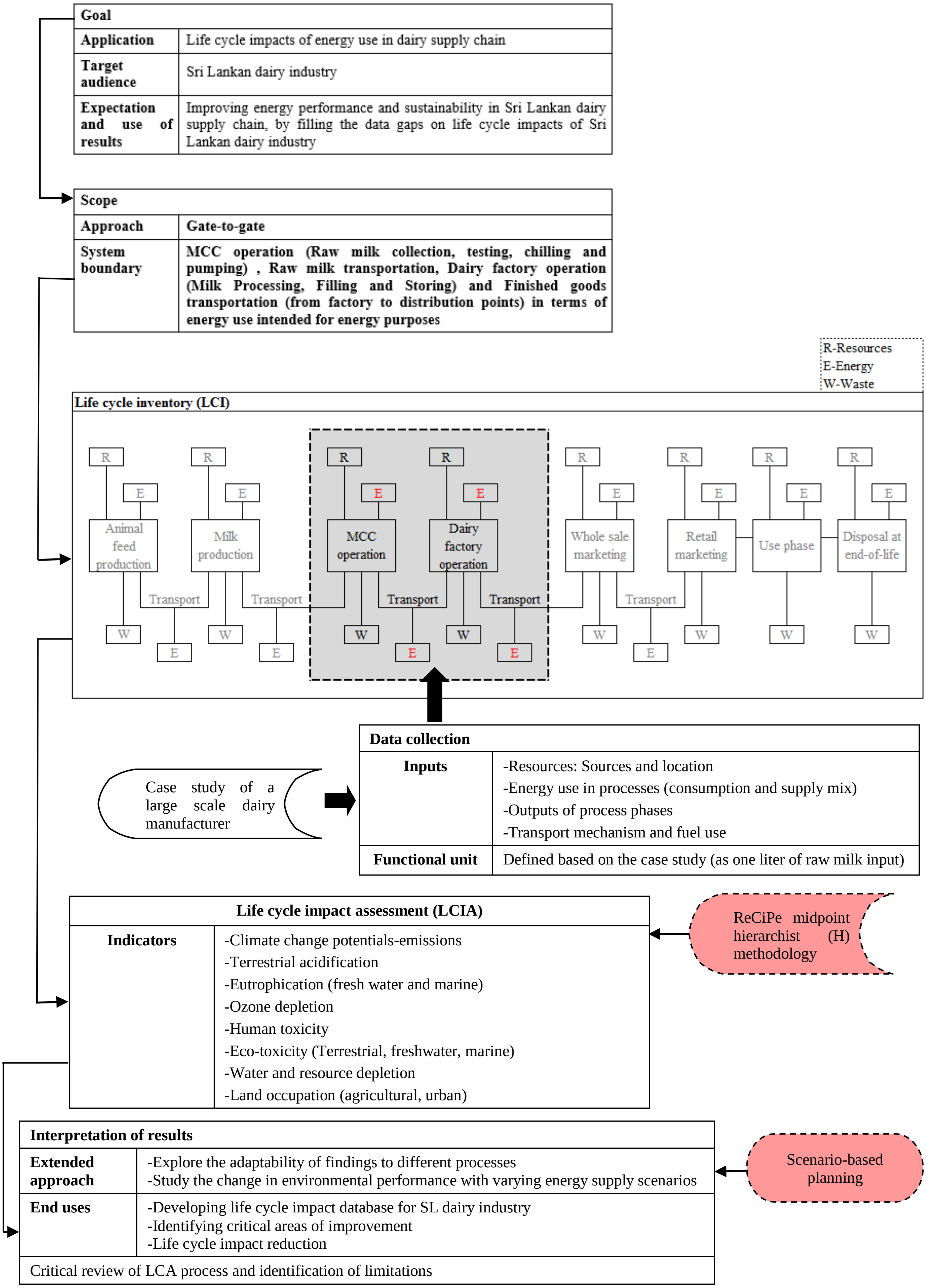
Sensitivity analysis

This is a procedure for determining how data changes and methodological choices affect the LCIA results [27].

In this study, this technique was used to determine the effect of change in normalization factor used for Water depletion, for the normalized results of Scenario 1 (Business-as-usual case). Because, since, the source excel file (downloaded from ReCiPe website) used to get normalization factors, had not provided normalization factors for Water depletion under any case listed. Therefore, the author had to refer the ‘Normalization method and data for environmental footprints’ published by JRC of European commission and use the factor recommended for EU-27 based on domestic inventory taking the reference year as 2013 [33].

4.3 Environmental performance assessment

A method for the environmental assessment of the use of energy in the dairy industry depending on the thinking of life cycle, was detailed in the previous section. Figure 4.3.1 summarizes the method suggested for the milk industry of Sri Lanka depending on the research. The objective and scope were defined to meet the requirements of the target audience, i.e. The dairy sector in Sri Lanka and government agencies that regulate industrial practices. In this study, energy use was examined in the key stage of processes in a typical larger dairy manufacturer's supply chain. In evaluating the possible benefits for the industry of alternative energy scenarios, a scenario - based approach was followed.



Goal	
Application	Life cycle impacts of energy use in dairy supply chain
Target audience	Sri Lankan dairy industry
Expectation and use of results	Improving energy performance and sustainability in Sri Lankan dairy supply chain, by filling the data gaps on life cycle impacts of Sri Lankan dairy industry

Scope	
Approach	**Gate-to-gate**
System boundary	**MCC operation (Raw milk collection, testing, chilling and pumping) , Raw milk transportation, Dairy factory operation (Milk Processing, Filling and Storing) and Finished goods transportation (from factory to distribution points) in terms of energy use intended for energy purposes**

Data collection	
Inputs	-Resources: Sources and location -Energy use in processes (consumption and supply mix) -Outputs of process phases -Transport mechanism and fuel use
Functional unit	Defined based on the case study (as one liter of raw milk input)

Life cycle impact assessment (LCIA)	
Indicators	-Climate change potentials-emissions -Terrestrial acidification -Eutrophication (fresh water and marine) -Ozone depletion -Human toxicity -Eco-toxicity (Terrestrial, freshwater, marine) -Water and resource depletion -Land occupation (agricultural, urban)

Interpretation of results	
Extended approach	-Explore the adaptability of findings to different processes -Study the change in environmental performance with varying energy supply scenarios
End uses	-Developing life cycle impact database for SL dairy industry -Identifying critical areas of improvement -Life cycle impact reduction
Critical review of LCA process and identification of limitations	

Figure 4.3.1: LCA methodology for dairy industry (Architecture was adopted from [03])

5. RESULTS & DISCUSSION

In this study, a Gate - to - Gate approach was used to investigate the life cycle effects of energy consumption in the dairy sector of Sri Lanka. In order to identify the environmental costs related to one liter of milk input in the dairy supply chain, impacts on life cycle have been assessed per liter. For life - cycle evaluation, a methodology has been established and an analysis of alternative energy supply scenarios has been conducted for every phase of the SL dairy sector. In addition to supporting the development of a database on life cycle in the dairy industry of SL, results could be used to identify the most pivotal areas to enhance the impact of the dairy supply chain on the life cycle and to propose the most suitable sustainability measures.

Energy supplies prevail in the milk sector in Sri Lanka, where fossil fuel fuels are based. As the analysis below shows, there are substantial impacts of the life cycle linked with petroleum fuel energy. This approach can therefore be extended to other Sri Lankan milk manufacturers, quantifying and measuring the impacts of the life cycle in different scenarios of energy.

The industrial sector creates a high environmental burden in its various sectors around the world. In the manufacturng industry, the strategies to reduce the effects to the environment therefore need to be explored. The energy source and the features of the manufacturing process steps have a remarkable effect on the impact of an industry on the environment. Information which goes further than material or direct energy use should therefore be taken into account when assessing these consequences. For recognizing the most significant areas of attention, the evaluation of products for the sustainability must be stretched upstream and downstream across the value chain. Various strategies can be used in manufacturing facilities for reducing the environmental impacts of energy consumption. One way forward to this target is by managing energy used in the industrial sector, where the facility and processes implement the practces of energy efficiency and reduction of demand. Energy waste can be reduced to optimize consumption through infrastructure changes through the use of energy efficient facilities and by modifying industrial processes to improve efficiency. Alternative, lower environmental energy sources can simultaneously be used to satisfy industrial energy needs [3].

The main share of the power mix in Sri Lanka is provided by conventional sources of fossil fuel. Coal and petroleum power generation is about 51,5 %. This is due in part to the high level of environmental consequences associated with Sri Lankan dairy manufacture processes, which rely heavily on electricity from the national grid to supply their energy requirements. In addition, fossil fuels such as furnace oil also provide a substantial portion of the thermal energy supply.

In this study, five (5) different scenarios of energy supply have been established and studied for comparing the effects of energy consumption in milk manufacturing on the environmental life cycle. The scenarios for energy supply were designed to explore potential effects of full biomass thermal energy substitution, complete substitution of grid electricity supplies through Solar PV, complete electricity substitution for vehicle fuel, partial thermal, electricity and car fuel substitution and, finally, a complete energy substitution. Also, in Scenario 2, it was investigated the environmental impact before introducing biomass for thermal energy.

5.1 Characterized results

Table 5.1.1: Life cycle impacts of the dairy supply chain

Impact Category	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Unit
Agricultural land occupation	4.028E-03	4.028E-03	4.028E-03	2.014E-03	0.000E+00	m2*a
Climate Change	2.838E-02	3.038E-02	1.768E-02	8.838E-03	0.000E+00	kg CO2 eq
Fossil depletion	1.023E-01	1.084E-01	6.926E-02	3.463E-02	0.000E+00	kg oil eq
Freshwater ecotoxicity	7.871E-06	8.308E-06	5.539E-06	2.769E-06	0.000E+00	kg 1,4-DB eq
Freshwater eutrophication	4.695E-07	5.282E-07	1.555E-07	7.774E-08	0.000E+00	kg P eq
Human toxicity	1.714E-03	1.781E-03	1.357E-03	6.783E-04	0.000E+00	kg 1,4-DB eq
Ionising radiation	4.521E-04	4.976E-04	2.091E-04	1.046E-04	0.000E+00	kg U235 eq
Marine ecotoxicity	6.624E-05	7.145E-05	3.839E-05	1.919E-05	0.000E+00	kg 1,4-DB eq
Marine eutrophication	6.696E-06	6.954E-06	5.317E-06	2.658E-06	0.000E+00	kg N eq
Metal depletion	1.514E-04	1.560E-04	1.266E-04	6.328E-05	0.000E+00	kg Fe eq
Natural land transformation	-2.411E-08	-2.411E-08	-2.411E-08	-1.205E-08	0.000E+00	m2
Ozone depletion	3.028E-10	3.402E-10	1.032E-10	5.158E-11	0.000E+00	kg CFC-11 eq
Particulate matter formation	3.899E-05	4.204E-05	2.266E-05	1.133E-05	0.000E+00	kg PM10 eq
Photochemical oxidant formation	9.808E-05	1.060E-04	5.583E-05	2.791E-05	0.000E+00	kg NMVOC
Terrestrial acidification	1.513E-04	1.630E-04	8.914E-05	4.456E-05	0.000E+00	kg SO2 eq
Terrestrial ecotoxicity	1.330E-06	1.392E-06	9.943E-07	4.971E-07	0.000E+00	kg 1,4-DB eq
Urban land occupation	1.734E-03	1.734E-03	1.734E-03	8.670E-04	0.000E+00	m2*a
Water depletion	3.412E-03	3.414E-03	3.404E-03	1.702E-03	0.000E+00	m3

Normalized scores were obtained for the Scenario 1 from Table 5.1.1 showing characterized results, and listed in Table 5.1.2 to identify the category indicators those having the greatest contribution to the environmental impact. As Table 5.1.2 depicts, Fossil depletion, Water depletion and Marine eco toxicity become the major impact categories.

Table 5.1.2: Significant impact categories of Scenario 1 ('Business-as-usual' case)

Impact category	Normalized value / (person/year)	% contribution
Fossil depletion	7.931E-05	45.5%
Water depletion	4.192E-05	24.1%
Marine ecotoxicity	2.690E-05	15.4%
Human toxicity	5.252E-06	3.0%
Climate Change	4.119E-06	2.4%
Terrestrial acidification	3.963E-06	2.3%
Particulate matter formation	2.773E-06	1.6%
Urban land occupation	2.238E-06	1.3%
Freshwater ecotoxicity	1.829E-06	1.0%
Photochemical oxidant formation	1.729E-06	1.0%
Freshwater eutrophication	1.620E-06	0.9%
Marine eutrophication	9.124E-07	0.5%
Agricultural land occupation	7.426E-07	0.4%
Ionising radiation	3.432E-07	0.2%
Metal depletion	3.400E-07	0.2%
Terrestrial ecotoxicity	2.243E-07	0.1%
Ozone depletion	8.047E-09	0.0%
Natural land transformation	-2.004E-09	0.0%

As explained in section 4.2.5, in this study, Sensitivity analysis technique was used to determine the effect of change in normalization factor used for Water depletion, for the normalized results of Scenario 1 (Business-as-usual case). Because, since, the source excel file (downloaded from ReCiPe website) used to get normalization factors, had not provided normalization factors for Water depletion under any case listed (i.e.: either in World or Europe reference data and either in ReCiPe midpoint E or H or I methods). Therefore, the author had to refer the 'Normalization method and data for environmental footprints' [33] published by the JRC of European commission and used the factor recommended for EU-27 based on domestic inventory.

Table 5.1.3: Results of the sensitivity analysis on change in normalization factor of water depletion

% change	Normalization factor	Normalized category indicator value (under Scenario 1)	% contribution to the total impact (under Scenario 1)	% change in % contribution to the total impact
20%	97.68	3.493E-05	20%	-17%
15%	93.61	3.645E-05	21%	-13%
10%	89.54	3.811E-05	22%	-9%
5%	85.47	3.993E-05	23%	-5%
0%	81.4	4.192E-05	24%	0%
-5%	77.33	4.413E-05	25%	5%
-10%	73.26	4.658E-05	27%	11%
-15%	69.19	4.932E-05	28%	18%
-20%	65.12	5.240E-05	30%	25%

As per the sensitivity analysis results shown in Table 5.1.3, with each 1% change in the value of normalization factors used for water depletion, percentage change in percentage contribution of water depletion to the total impact also varies by 1% (inversely proportionately), approximately. But, even with a +/- 20% change in the value of normalization factor used, the percentage contribution of water depletion to the total impact lies in between 20%-30% range and still stands as one of the three (3) major category indicators under Scenario 1.

5.2 Comparison of life cycle impacts in different process phases

Table 5.2.1 lists the impact values per functional unit (one liter of raw milk input), for all the 18 impact indicators to evaluate the impact of the milk industry on the environmental in ‘Business-as-usual’ case. In the representation, the normalized values in every impact type, was considered. (For each indicator, the total is set to 100% and the percentage contribution from every stage of the process is calculated accordingly.)

That can be realized that the dairy factory operation phase has the largest contribution, except in Four (4) cases (***i.e.:*** water depletion, natural land transformation, urban land occupation, agricultural land occupation), to the environmental impacts of one liter of raw milk throughout the selected process stages in the dairy life cycle. Except the water depletion, all other Three (3) impact categories here, are minor indicators. Therefore, this result gives us a hint to further investigate the impact of diesel (and petrol) on water depletion. As verified from the analysis results shown in openLCA under the ‘Contribution tree’ of Scenario 1, replacement of petroleum fuels used for vehicles with an alternative green energy source would greatly impact on environmental performance. Even the replacement of fuel oil with biomass, can’t influence on water depletion in such a great level.

But, biomass instead of fuel oil has a great impact on the majority of category indicators, especially on fossil depletion.

Table 5.2.1: Relative contribution to total impacts from each process phase (Sce. 1)

Impact category	MCC operation	Raw milk transportation	Dairy factory operation	Finished goods transportation
Climate change	5.1%	17.3%	74.9%	2.8%
Ozone depletion	3.3%	4.6%	91.5%	0.7%
Terrestrial acidification	4.1%	23.5%	68.6%	3.8%
Freshwater eutrophication	2.9%	7.0%	89.0%	1.1%
Marine eutrophication	4.6%	41.4%	47.3%	6.7%
Human toxicity	4.7%	40.4%	48.4%	6.5%
Photochemical oxidant formation	4.2%	21.0%	71.5%	3.4%
Particulate matter formation	4.2%	22.2%	70.0%	3.6%
Terrestrial ecotoxicity	4.4%	38.2%	51.2%	6.2%
Freshwater ecotoxicity	5.1%	26.2%	64.5%	4.2%
Marine ecotoxicity	4.0%	23.7%	68.6%	3.8%
Ionising radiation	3.9%	12.0%	82.2%	1.9%
Agricultural land occupation	4.9%	61.1%	24.1%	9.8%
Urban land occupation	5.0%	60.8%	24.5%	9.8%
Natural land transformation	5.8%	52.4%	33.4%	8.4%
Water depletion	5.7%	53.1%	32.7%	8.6%
Metal depletion	7.8%	13.5%	76.5%	2.2%
Fossil depletion	6.2%	12.0%	79.9%	1.9%

In contrast to dairy factory operation phase, the impact due to transportation is relatively low, but considerable. But, when comparing the raw milk transportation phase with the finished goods transportation phase, the impact because of finished goods transportation is insignificant for all the impact categories. (Contribution from raw milk transportation is six times larger than the finished goods transportation). The percentage contribution from each phase of the process is further illustrated in Figure 5.2.1, where over 50% of contribution from the milk production phase for most categories of impacts can be seen.

Marine eco toxicity and human toxicity are the next most significant category indicators in Scenario 1, after fossil depletion and water depletion. But, both the raw milk transportation phase and dairy factory operation phase contributes in approximately the same levels to these impact categories. By scrutinizing details provided in the 'Contribution tree' of openLCA analysis result report, it is clear that petroleum fuels have the greatest contribution to these impact categories. Out of all the petroleum fuels, diesel and furnace oil has the most significant contribution. But, it further reveals that diesel has the highest per liter contribution compared to furnace oil.

The huge gap in between the values of raw milk transportation and finished goods transportation highlights the need of paying attention to optimize the milk collection network of the company.

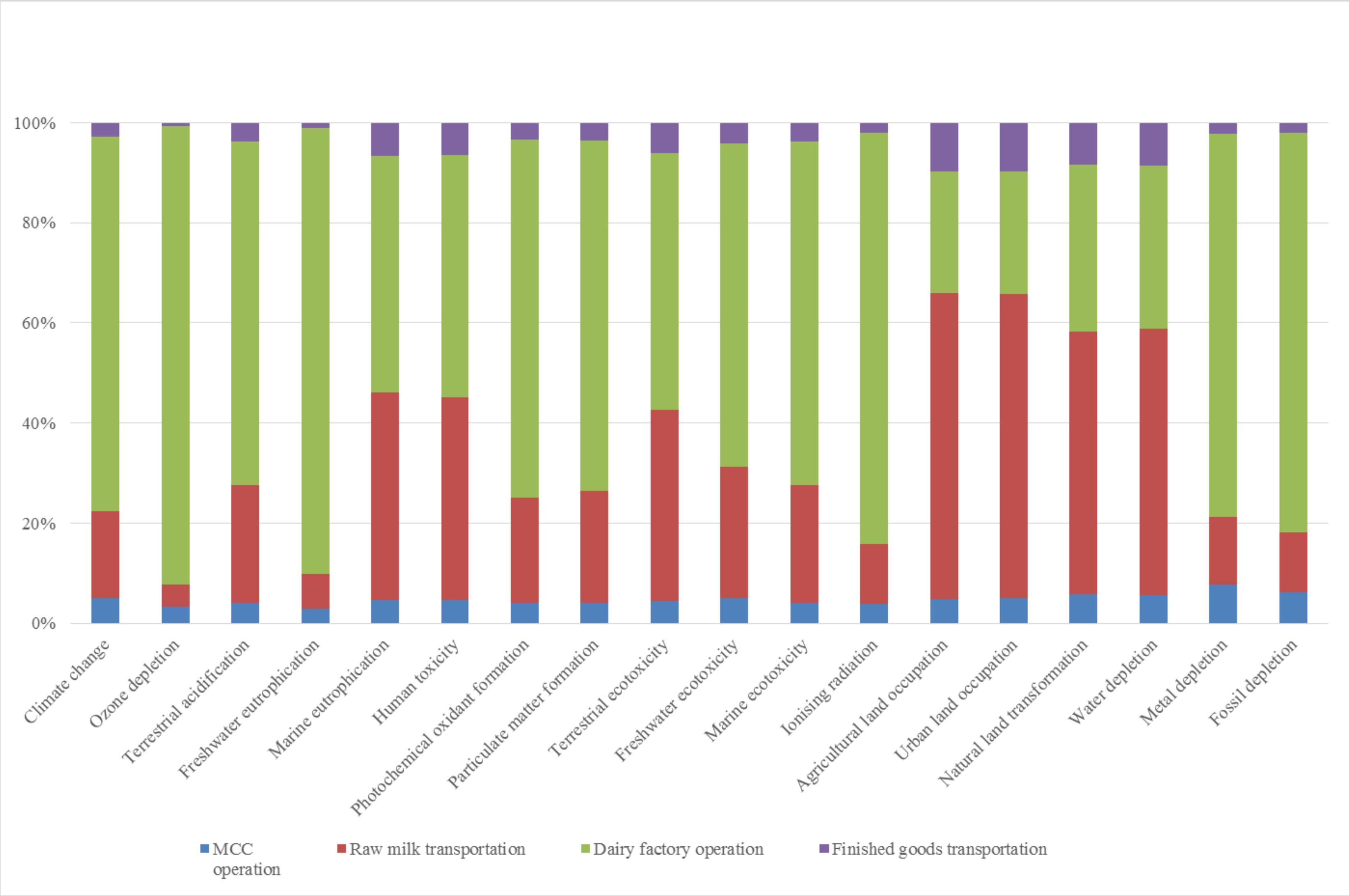


Figure 5.2.1: Relative contribution to total impacts from each process phase (Sce. 1)

5.2.1 Effect of replacement of furnace oil with biomass on change in relative contribution from each process phase, and cost

The best way to assess the effect of replacement of furnace oil with biomass on change in relative contribution from each process phase and cost, is comparing Scenario 2 (as detailed in Table 5.2.2 and Figure 5.2.2) and Scenario 3 (as detailed in Table 5.2.3 and Figure 5.2.3).

As per the Table 4.2.5,

Furnace oil consumption per liter of raw milk in Scenario 2 = 3.383E-02 Liter

Associated cost in Scenario 2 (price of 1 Ltr of furnace oil is LKR 80) =LKR 2.71 /Liter

Biomass consumption per liter of raw milk in Scenario 3 =2.495E-01 kg

Associated cost in Scenario 3 (price of 1 kg of fire wood is LKR 5.25) =LKR 1.31 /Liter

Percentage saving of cost =51.6%

Annualized saving of cost (calculated based on the total raw milk intake in 2015, that is, 5010241.7 Liters) = LKR 7 Million

Table 5.2.2: Relative contribution to total impacts from each process phase (Sce. 2)

Impact category	MCC operation	Raw milk transportation	Dairy factory operation	Finished goods transportation
Climate change	4.8%	16.1%	76.5%	2.6%
Ozone depletion	2.9%	4.1%	92.4%	0.7%
Terrestrial acidification	3.8%	21.9%	70.8%	3.5%
Freshwater eutrophication	2.6%	6.2%	90.2%	1.0%
Marine eutrophication	4.4%	39.9%	49.3%	6.4%
Human toxicity	4.5%	38.9%	50.3%	6.3%
Photochemical oxidant formation	3.8%	19.4%	73.7%	3.1%
Particulate matter formation	3.9%	20.6%	72.2%	3.3%
Terrestrial ecotoxicity	4.2%	36.5%	53.4%	5.9%
Freshwater ecotoxicity	4.8%	24.8%	66.4%	4.0%
Marine ecotoxicity	3.7%	21.9%	70.9%	3.5%
Ionising radiation	3.5%	10.9%	83.8%	1.8%
Agricultural land occupation	4.9%	61.1%	24.1%	9.8%
Urban land occupation	5.0%	60.8%	24.5%	9.8%
Natural land transformation	5.8%	52.4%	33.4%	8.4%
Water depletion	5.7%	53.1%	32.7%	8.5%
Metal depletion	7.5%	13.1%	77.2%	2.1%
Fossil depletion	5.8%	11.3%	81.0%	1.8%

Table 5.2.3: Relative contribution to total impacts from each process phase (Sce. 3)

Impact category	MCC operation	Raw milk transportation	Dairy factory operation	Finished goods transportation
Climate change	8.2%	27.7%	59.7%	4.5%
Ozone depletion	9.6%	13.4%	74.9%	2.2%
Terrestrial acidification	7.0%	40.0%	46.6%	6.4%
Freshwater eutrophication	8.8%	21.0%	66.8%	3.4%
Marine eutrophication	5.8%	52.2%	33.7%	8.4%
Human toxicity	5.9%	51.1%	34.8%	8.2%
Photochemical oxidant formation	7.3%	36.8%	50.0%	5.9%
Particulate matter formation	7.1%	38.3%	48.5%	6.2%
Terrestrial ecotoxicity	5.9%	51.1%	34.8%	8.2%
Freshwater ecotoxicity	7.2%	37.2%	49.6%	6.0%
Marine ecotoxicity	6.9%	40.8%	45.7%	6.6%
Ionising radiation	8.3%	26.0%	61.5%	4.2%
Agricultural land occupation	4.9%	61.1%	24.1%	9.8%
Urban land occupation	5.0%	60.8%	24.5%	9.8%
Natural land transformation	5.8%	52.4%	33.4%	8.4%
Water depletion	5.7%	53.3%	32.5%	8.6%
Metal depletion	9.3%	16.2%	71.9%	2.6%
Fossil depletion	9.2%	17.7%	70.3%	2.9%

As per the results shown in above two tables and below two figures, it is clear that the percentage share of raw milk transportation phase in Scenario 3 has been increased significantly compared to Scenario 2 except in four cases, that is, natural land transformation, water depletion, urban land occupation and agricultural land occupation. In those four cases, the relative contribution from each process phase remains unchanged. But, in all other cases percentage share of raw milk transportation phase is increased and factory operation phase is decreased notably.

As an example, the increase of percentage share of raw milk transportation phase in climate change is 72%, in ozone depletion is 230%, in freshwater eutrophication is 240%, in ionizing radiation is 138%, in photochemical oxidant formation is 90%, and in particulate matter formation and marine ecotoxicity is 86%.

These results highlight the importance of paying attention to improve the raw milk transportation phase in terms of energy use. It can be done in two ways. One is, by converting the vehicles used for raw milk transportation, to an alternative fuel. The second is a low / no cost solution. That is, optimizing the milk collection network. That can be done without any major investments on technology changes / innovations like conversion of vehicles for alternative fuels. Many researchers have found the ways to optimize milk collection networks using GIS application and simulation.

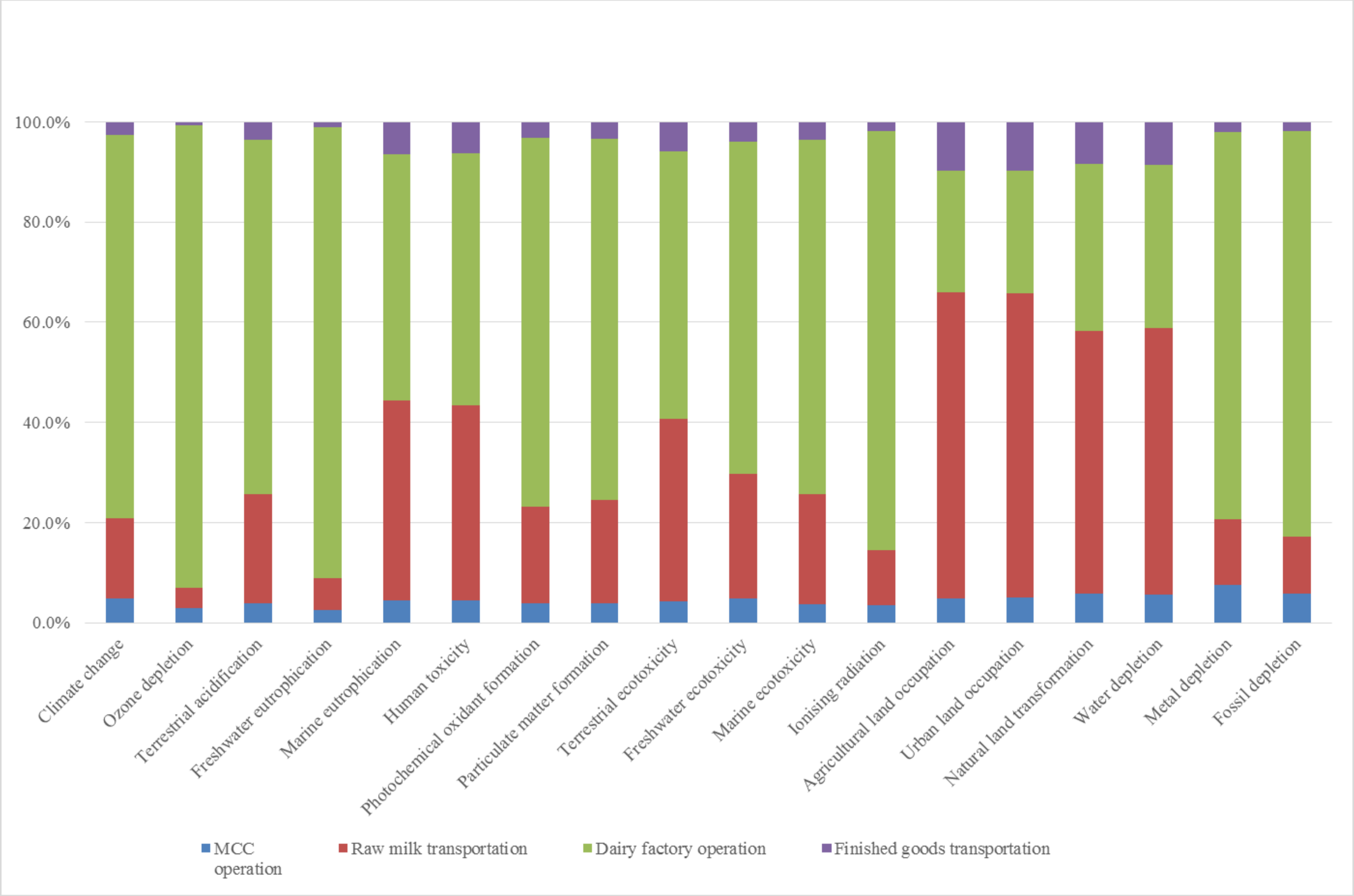


Figure 5.2.2: Relative contribution to total impacts from each process phase (Sce. 2)

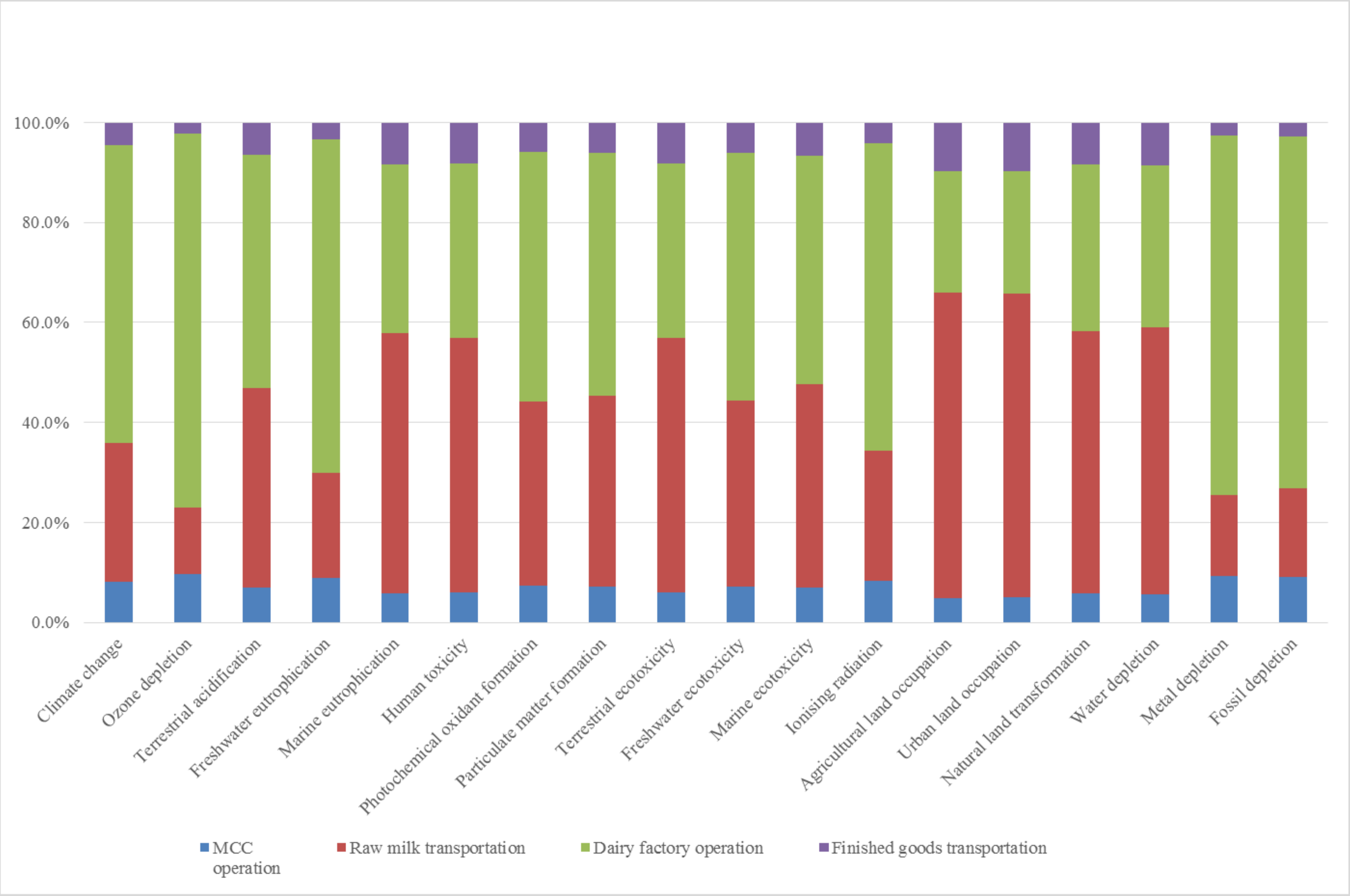


Figure 5.2.3: Relative contribution to total impacts from each process phase (Sce. 3)

5.3 Comparison of life cycle impacts under alternative energy scenarios

Table 5.3.1: Normalized impact category results

Impact Category	Scenario 1 (Business as Usual-In 2015)	Scenario 2 (Early state-Before 2015)	Scenario 3 (Current state-After 2015)	Scenario 4 (Future State 1)	Scenario 5 (Future State 2)	Normalization factor [ReCiPe Midpoint (H) World]	
						Value	Unit
Agricultural land occupation	7.426E-07	7.426E-07	7.426E-07	3.713E-07	0.000E+00	5.424E+03	m2*a/person/year
Climate Change	4.119E-06	4.409E-06	2.565E-06	1.283E-06	0.000E+00	6.891E+03	kg CO2 eq/person/year
Fossil depletion	7.931E-05	8.410E-05	5.371E-05	2.685E-05	0.000E+00	1.290E+03	kg oil eq/person/year
Freshwater ecotoxicity	1.829E-06	1.930E-06	1.287E-06	6.435E-07	0.000E+00	4.304E+00	kg 1,4-DB eq/person/year
Freshwater eutrophication	1.620E-06	1.822E-06	5.364E-07	2.682E-07	0.000E+00	2.899E-01	kg P eq/person/year
Human toxicity	5.252E-06	5.457E-06	4.158E-06	2.079E-06	0.000E+00	3.263E+02	kg 1,4-DB eq/person/year
Ionising radiation	3.432E-07	3.777E-07	1.587E-07	7.937E-08	0.000E+00	1.317E+03	kg U235 eq/person/year
Marine ecotoxicity	2.690E-05	2.901E-05	1.559E-05	7.794E-06	0.000E+00	2.462E+00	kg 1,4-DB eq/person/year
Marine eutrophication	9.124E-07	9.476E-07	7.245E-07	3.622E-07	0.000E+00	7.339E+00	kg N eq/person/year
Metal depletion	3.400E-07	3.504E-07	2.843E-07	1.421E-07	0.000E+00	4.452E+02	kg Fe eq/person/year
Natural land transformation	-2.004E-09	-2.004E-09	-2.004E-09	-1.002E-09	0.000E+00	1.203E+01	m2/person/year
Ozone depletion	8.047E-09	9.040E-09	2.741E-09	1.371E-09	0.000E+00	3.763E-02	kg CFC-11 eq/person/year
Particulate matter formation	2.773E-06	2.991E-06	1.612E-06	8.058E-07	0.000E+00	1.406E+01	kg PM10 eq/person/year
Photochemical oxidant formation	1.729E-06	1.868E-06	9.840E-07	4.920E-07	0.000E+00	5.674E+01	kg NMVOC/person/year
Terrestrial acidification	3.963E-06	4.268E-06	2.334E-06	1.167E-06	0.000E+00	3.819E+01	kg SO2 eq/person/year
Terrestrial ecotoxicity	2.243E-07	2.349E-07	1.677E-07	8.385E-08	0.000E+00	5.929E+00	kg 1,4-DB eq/person/year
Urban land occupation	2.238E-06	2.238E-06	2.238E-06	1.119E-06	0.000E+00	7.750E+02	m2*a/person/year
Water depletion	4.192E-05	4.194E-05	4.181E-05	2.090E-05	0.000E+00	8.140E+01	m3/person/year

Table 5.3.2: Comparison of impact categories under different energy supply scenarios

Climate Change	**Scenario 1** (Business as Usual-In 2015)	**Scenario 2** (Early state-Before 2015)	**Scenario 3** (Current state-After 2015)	**Scenario 4** (Future State 1)	**Scenario 5** (Future State 2)	**% reduction with the introduction of bio-mass boiler**
Agricultural land occupation	29%	29%	29%	14%	0%	0%
Climate Change	33%	36%	21%	10%	0%	42%
Fossil depletion	33%	34%	22%	11%	0%	36%
Freshwater ecotoxicity	32%	34%	23%	11%	0%	33%
Freshwater eutrophication	38%	43%	13%	6%	0%	71%
Human toxicity	31%	32%	25%	12%	0%	24%
Ionising radiation	36%	39%	17%	8%	0%	58%
Marine ecotoxicity	34%	37%	20%	10%	0%	46%
Marine eutrophication	31%	32%	25%	12%	0%	24%
Metal depletion	30%	31%	25%	13%	0%	19%
Natural land transformation	29%	29%	29%	14%	0%	0%
Ozone depletion	38%	43%	13%	6%	0%	70%
Particulate matter formation	34%	37%	20%	10%	0%	46%
Photochemical oxidant formation	34%	37%	19%	10%	0%	47%
Terrestrial acidification	34%	36%	20%	10%	0%	45%
Terrestrial ecotoxicity	32%	33%	24%	12%	0%	29%
Urban land occupation	29%	29%	29%	14%	0%	0%
Water depletion	29%	29%	29%	14%	0%	0%

Table 5.3.1 shows the total impacts of the energy consumption in the dairy supply chain on the life cycle of the different standardized energy supply scenarios.

For better understanding, in Table 5.3.2, a comparison of various energy supply scenarios has been done against each impact category. Here, specially, the impact of introducing a biomass fired boiler in 2015, was critically examined under each category indicator. There, the percentage reduction of category values was calculated considering the Scenario 2 (Early state-before 2015) and Scenario 3 (Current state-after 2015), because the Scenario 1 (business-as-usual) represents a transition period in terms of thermal energy supply, that is, from furnace oil to biomass.

The results of the introduction of the biomass fired boiler in 2015, which resulted in significant environmental improvements, can be noted in accordance with the figures in the latter column in Table 5.3.2.

Thermal energy supply in Scenario 4 & 5, is the same as of Scenario 3. Therefore, it is clear that the replacement of grid electricity and auto Diesel (in transport) with solar photovoltaic has the highest consequence on the reduction of impact to the environmental in Scenario 4 &5.

The graphics below show the relative outcomes of the indicator in each scenario (project variants). The maximum result for each indicator is set at 100 percent, with the other variants being shown in relation to these results.

As per these charts, there is not a significant improvement in ‘Business-as-usual’ case compared to the ‘Early case’ because the biomass boiler was introduced in April 2015, and again from June 2015 to Oct 2015, it was stopped to correct a noise level issue raised by the neighbors.

Altogether, the impacts are lowermost (almost zero) in Scenario 5, where all energy requirements are provided through alternative sources. Also, in Scenario 4, where 50% of electricity and petroleum fuels are replaced with Solar PV, all the indicators show a 50% reduction compared to the Scenario 3.

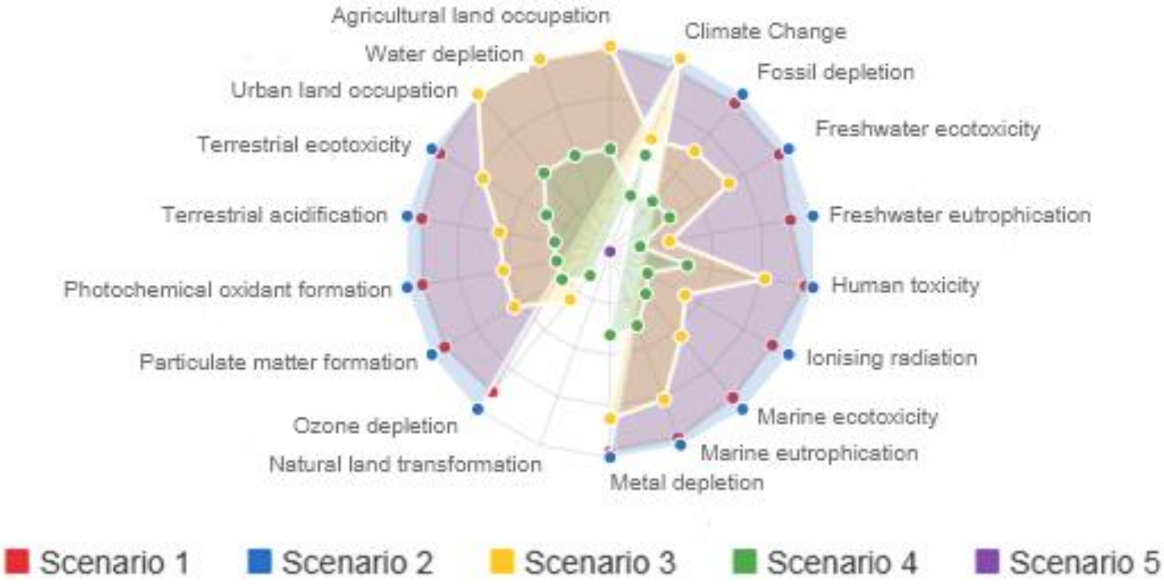


Figure 5.3.1: Comparison of impact categories under different energy supply scenarios (radar chart)

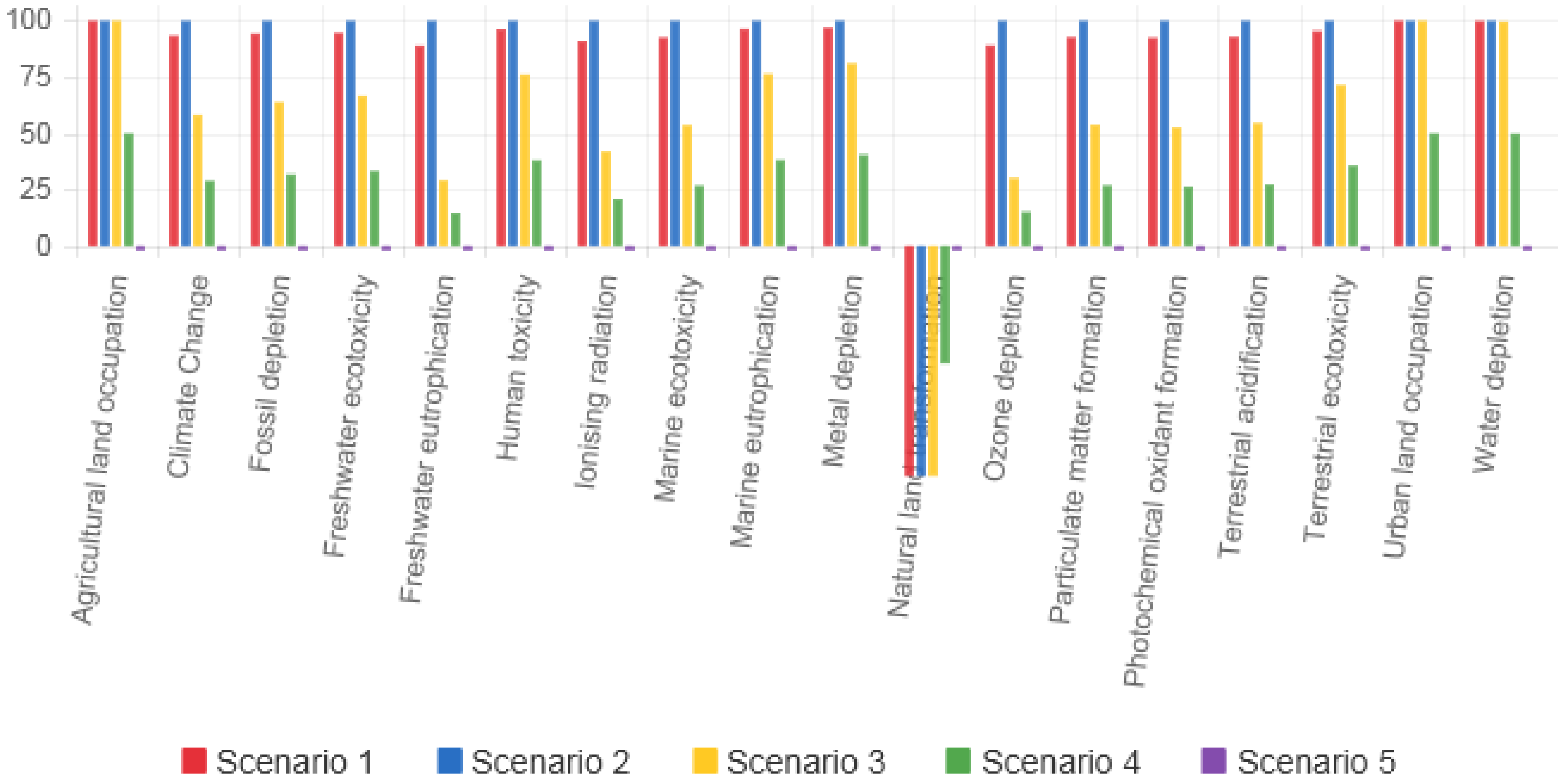


Figure 5.3.2: Comparison of impact categories under different energy supply scenarios (bar chart)

When separately evaluated for the environmental effects of the various milk supply chain process phase, it was found that a highest impact on the energy consumption in a dairy factory was observed in the dairy factory operation phase (64 %). This result is due to the fact that, in the process phases taken into consideration during the life cycle of dairy products, the highest specific energy use per liter of raw milk input occurs. A number of sub - processes, including processing, filling / packaging, storage (under chilled conditions and dry conditions), etc., require electric and thermal energy during this stage. In order to advance the sustainability performance of the value chain, the dairy manufacturers must focus their attention on this field. The special energy use of every activity needs to be recognized separately for identifying the most critical process steps of the plant operation. In contrast to the impacts of production activities, the environmental impacts caused by transport per liter of raw milk are lower. For example, as depicted in Figure 5.2.1, transportation is accountable for only 20% of the incremental climate change potential per liter of raw milk (measurement used is kilograms of CO_2 emitted), though factory operation phase is accountable for 75%. The rest 5% is concerned with MCC operation. Though the total life cycle impact of transportation (30.5%) is considerable, the contribution from finished goods transportation becomes negligible (4.2%) compared to the raw milk transportation phase (26.3%) when averaged per liter of raw milk input.

After conventional energy sources have been substituted by solar PV and biomass, the overall environmental footprint of energy use is significantly reduced. When comparing the Scenario 2 and Scenario 3, it is easy to understand the effect of introduction of biomass for thermal energy on environmental impacts. For an example, as a result of introducing bio-mass to replace furnace oil, Freshwater eutrophication is reduced by 71%, Ozone depletion is reduced by 70%, and Ionizing radiation is reduced by 58%. Also, the scores of category indicators like terrestrial acidification, ozone depletion and climate change etc. are decreased by 90% to 95% from the ‘business-as-usual’ case when conventional energy sources used for factory and MCC operations are fully substituted by the green energy sources. Compared to Solar PV, though biomass does not provide higher benifits as a substitution of thermal energy sources from fossil fuel, the effect on some categories of indicators, such as natural land transformation, agricultural land use, urban land use and water depletion, is reduced. The fossil depletion, the major environmental impact category can be reduced approximately by 36% by replacing the sources of thermal energy totally with biomass-fired boilers. Solar photovoltaic however contributes to much higher emission reductions than biomass, because the technology used in operating phases is zero emissions. These results suggest that dairy industries can achieve considerable environmental benefit by alternatives, especially low environmental emission sources such as solar energy, replacing conventional energy sources.

Although solar photovoltaics are treated to be a zero-emission technology which decreases considerably the impacts to the environmental over traditional petroleum energy sources, the disposal, manufacturing and resource extraction phases (of Solar PV) can still produce some effects, in particular because of the presence of Zn and Cd based materials. The life cycle effects of 100% solar PV supplies are still higher than zero, therefore. While direct emissions are less effective than solar photovoltaics, it can cause reduced environmental toxic matter releases compared with solar photovoltaics. In fact, in the eco - toxicity category based on the results of LCA, per unit energy of biomass is better than solar PV [3].

6. RECOMMENDATIONS & CONCLUSIONS

6.1 Recommendations

6.1.1 Benefits to stakeholders

The results of this research project can be applied by the dairy industry in analyzing its own performance in terms of sustainability and in taking actions to improve that performance. This approach is able to identify the critical areas that need attention to reduce the impact of the industry's life cycle. The measures of energy efficiency and reduction of demand may be taken at production sites, by splitting the high - impact processes like manufacturing into sub - activities. In addition, environmental and cost advantages could be achieved by optimizing the milk collection network. In addition, for the Sri Lankan dairy industry, it will be particularly useful the analysis of the impact to the environment because of using alternative sources of energy. This data can be used for the exploration of sustainability and to evaluate the feasibility of such strategies for the supply chain. The production of 'green' labelled products gives dairy producers on the local market a competitive advantage, where ‘green’ produces are becoming increasingly popular. The upstream integration of the supply chain became interesting as the dairy industry grew within the country. The results of the study will therefore be helpful for dairy manufacturers to expand their processing steps.

This research discovered that investment in alternative energy technologies could reduce the dairy industry's environmental burden. The present movement for renewable energy sources in the Sri Lankan milk industry should be promoted and encouraged to ensure that the industry is sustainable in terms of long - term energy and environment. Decision makers and authorities can use this information to formulate policies to promote sustainable domestic production. In many countries, together with Sri Lanka, carbon taxes and credits have served as tools in encouraging the use of green energy sources. However, although renewables are normally supposed to be null emissions when calculating carbon credits, an LCA approach shows that, if you look at the total life - cycle, they too are responsible for some emissions. (But, in this study, it is not reflected, because, for Scenario 4 & 5, solar energy ‘converted’ was used.) In order to assess how to incentivize and subsidize the implementation of renewable energy in the production industry, decision - makers will need to measure the environmental impacts of the energy use within the life – cycle, and actual reductions with alternative energy replacement. Backing from the government for technological innovation and regulations for efficient and effective use of resources can be encouraged to promote reduction of emissions and other effects [3].

In addition, the industrial sector of Sri Lanka and the economy can decrease the reliance on foreign energy by moving them away from petroleum - based fuel sources to renewable alternatives which are available locally. The industry sector accounts for 30.6% of Sri Lanka's total energy demand in 2015. Currently, more than 51% of the country’s primary energy supply is provided by petroleum and coal [9], and this results in the economy of Sri Lanka being severely hooked on fossil fuel prices in global markets. By studying strategies to decrease fossil fuel dependency, in addition to environmental benefits, one can gain an additional benifits of economic independence and long - term energy security.

6.1.2 Limitations and further work

The outcomes of this research have been based on a case study by a major milk manufacturer in Sri Lanka. For all the dairy manufacturers involved in the formal milk supply chain, the use of equipment, raw materials and processes in the dairy industry are almost the same in most aspects. The results are therefore accepted to some extent, but with some limitations, for the generalizability and adaptability. Moreover, where details were not available in the life cycle assessment, assumptions were made. The principal challenge to develop a Sri Lankan dairy industry's life cycle assessment framework is a lack of country - specific data, which is common in developing countries. Since Life Cycle Assessment is a new concept for the dairy industry in Sri Lanka, there are no reported studies on how to use the lifecycle approach to improve the sustainability of the formal milk supply chain. In addition, milk powder, chemicals and packaging materials are generally obtained from other countries / companies, and this information and solid waste and effluent disposals should be included in the development and impact assessments of the life cycle inventory (LCI). Due to the unavailability of the data, these data have not been accounted in the scope of the study. Furthermore, the scope of the current study did not take into account animal feed production, milk production, sales and marketing phases. The defined approach can, however, be used by adapting to the needs of case studies to evaluate the impact of a life cycle of the formal dairy supply chain in Sri Lanka. A full examination through an energy audit at the manufacturing facility is needed for identifying essential sub - activities in a certain process stage (e.g. plant operations, MCCs). In this way, a more detailed LCA can be identified for the specific energy consumption of each activity / product.

This research only focuses on the energy utilization of the milk supply chain from the MCC to the eventual distribution of final products to the distribution agents. Additional work must be carried out to quantify the use of resources and waste during processes. A review must take into account the upstream and downstream milk production activities, ranging from animal feed production, milk production, the making of milk ingredients and other inputs (including chemical products used for cleaning) to the possible disposal following consumption at the end of their lifetime, in order to recognize the full life cycle effects of the milk sector. For determining the complete environmental impacts of the product, such a study must also include the consequences of waste generation and resource use in every stage of the milk product life cycle. The assessment should also include an analysis of the potential lifecycle scenarios like waste disposal and recycling, to develop strategies to implement the lifecycle concepts of the cradle - to - cradle in the dairy industry.

In addition, a detailed Life Cycle Cost Assessment (LCCA) must be carried out in order to examine the full costs and advantages of implementing impact reduction strategies like substitution by alternative sources of energy. This approach can establish the economic viability of various energy scenarios. In conjunction with the environmental assessment, the economic impact assessment must be used to select for milk production organizations' best impact mitigation strategies for the purpose of improving the sustainable performance of their supply chains.

6.2 Conclusions

As a way to increase the performance of the formal milk supply chain, by performing an environmental impact evaluation on the consumption of energy in the dairy industry of Sri Lanka, it was found that the dairy factory operation phase results in the maximum environmental impacts (64.0%) in general, while MCC operation phase and finished goods transportation phase result on only a small portion of the impacts (5.5% and 4.2% respectively) in judgement. Raw milk transportation phase also plays an important role being the second highest (26.3%). As such, it can be concluded that the first Two (2) objectives of this study, that is, ‘To quantify environmental effects from energy use within the formal milk supply chain of Sri Lanka during the recognized stages’ and ‘To determine the most critical environmental impact processes’, were successfully met.

After conducting a comparison between different alternative energy scenarios for supplying the thermal and electricity requirements of the milk industry, it has been determined that the highest environmental impact is achieved with solar PV electricity generation. It was verified with the case study that the dairy sector can reduce the overall environmental impacts approximately by 30% and the cost on thermal energy supply by 51.6%, by replacing furnace oil with biomass for thermal energy supply. But, the use of solar photovoltaic as a substitution for conventional electric energy sources in dairy manufacturing sites and MCCs can decrease the total impact further by as much as 60%. These results verify the meeting of the third objective of the study, that is, ‘To study the effect on the sustainability performance of the formal milk supply chain of alternative energy supply scenarios’.

Substitution of conventional sources of fossil - fuel energy from renewable energy sources which are available locally will also support the country to achieve long - term economic advantages, while ensuring the security and independence in terms of energy.

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Annexure I: MCC locations and their capacities

MCC Location	Maximum Capacity / (Liters)
Dambulla	7,300
Nikaweratiya	7,200
Galaha	5,000
Norwood	6,000
Kirindiwela	3,100
Horana	1,200
Bandaragama	1,200
Wadduwa	560

Annexure II: Details of the vehicles used in the supply chain

Main route tankers used for raw milk transportation

Vehicle Number	Make	Engine Capacity	Bowser Capacity
LI 2196	Misubishi FUSO	3,907cc	6,800 L
LH 8119	TATA	3,883cc	9,500 L
LL 3471	TATA	3,883cc	9,500 L
LL 4653	Ashok Leyland	6,540cc	11,200 L
LL 3587	Ashok Leyland	6,540cc	9,900 L
LK 3705	TATA	6,540cc	9,900 L
LL 3221	Ashok Leyland	6,540cc	12,600 L

Vehicles used in the factory

Vehicle Number	Make	Fuel Type	Engine Capacity
HX-0691	Nissan Vanette	Diesel	2,180cc
HM-9287	Nissan Dual purpose van	Diesel	3,150cc
TY-9516	Honda motorcycle	Petrol	100cc

Vehicles used for finished goods transportation

Vehicle Number	Make	Fuel Type	Engine Capacity
GH-4873	Isuzu ELF Motor lorry	Diesel	4,330cc
LB-8958	Isuzu Motor lorry	Diesel	4,334 cc
68-2271	Isuzu Motor lorry	Diesel	3,630cc
LK-1597	JMC Motor lorry	Diesel	2,771cc
LK-1595	JMC Motor lorry	Diesel	2,771cc

Annexure III: Conversion to uniform energy units

For comparison, energy products expressed in their respective units used for ordinary transactions need to be converted to a common equivalent unit. Similar to most other countries, Sri Lanka used tonnes of oil equivalent (toe) as the common denominator for this purpose (1 toe = 10 GCal = 41,868,000 kJ). Sri Lanka is contemplating using Joules as the common unit in future. Shown below are the conversion factors used for converting each energy product to equivalent toe.

Conversion factors and calorific values

Primary Energy	**toe/t**	**kJ/t**
Bagasse	0.40	16,747,200
Charcoal	0.65	27,214,200
Coal	0.70	29,307,600
Crude Oil	1.03	43,124,040
Fuel wood	0.38	15,909,840
Hydro-electricity (thermal equivalent) (toe/GWh)	240.00	10,048,320,000

Products	**toe/t**	**kJ/t**
Aviation Gasoline	1.06	44,380,080
Aviation Turbine Fuel	1.05	43,961,400
Ethane	1.18	49,404,240
Fuel Oil	0.98	41,030,640
Gas Oil /Diesel Oil	1.05	43,961,400
Kerosene	1.05	43,961,400
LPG	1.06	44,380,080
Motor Gasoline (Petrol)	1.09	45,636,120
Naphtha	1.09	45,636,120
Refinery gas	1.15	48,148,200
Residual Oil	0.98	41,030,640
Solvent	0.89	37,262,520

Electricity		**kJ/t**
Electricity (kcal/kWh)	860	36,006,480,000
Electricity (toe/GWh)	86	3,600,648,000