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REGIONE AUTÒNOMA DE SARDIGNA
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FSE 2007-2013
POR SARDEGNA
obiettivo competitività regionale e occupazione

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UNIVERSITÀ DEGLI STUDI DI SASSARI

SCUOLA DI DOTTORATO DI RICERCA
Scienze e Biotecnologie
dei Sistemi Agrari e Forestali
e delle Produzioni Alimentari

Indirizzo: Scienze e Tecnologie Zootecniche

Ciclo XXVI

A Life Cycle Assessment (LCA) Approach to Evaluate Energy Intensity and Related Environmental Impact in Dairy Farms

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Abstract

The usage of fossil fuels on a large scale started with the Industrial Revolution and it has been constantly raising since then, as well as the resulting emission of carbon dioxide (CO_2) into the environment. The objective of this study was to determine, through a partial life cycle assessment approach, the energy demands and the resulting Carbon Footprint in milk dairy production. The main study, which involved 285 Italian dairy farms, showed an average diesel consumption of 0.040 kg and 0.075 kWh of electricity per kg of milk produced. Total annual carbon dioxide emission, related to the energy use corresponded to 0.156 kg CO_2-eq per kg of milk. Final results showed that 79% of the on-farm energy emissions were due to the use of diesel and 20% for the electricity supply. The results obtained from the study were used to develop two linear models for predicting diesel and electricity consumption in dairy farms. Moreover, 4 conventional and 4 organic farms, located in California, USA, were analyzed to define the use of direct energy and the related environmental load. The results for conventional and organic farms showed annual diesel consumption about 0.0071 and 0.0164 kg per kg of milk sold, respectively. The electricity purchased accounted for 0.043 and 0.189 kWh per kg of milk, for conventional and organic respectively. Emissions of carbon dioxide associated to the energy usage were: 0.035 kg CO_2-eq per kg of milk per conventional farms and 0.103 kg CO_2-eq per kg of milk for the organic system.

Riassunto

L'utilizzo su larga scala di fonti fossili ebbe inizio con la rivoluzione industriale nel XVIII° secolo e con essa anche le relative emissioni di anidride carbonica (CO_2) nell'ambiente. L'obiettivo di questo lavoro era quello di determinare, tramite le metodologie dell'analisi del ciclo di vita, i fabbisogni energetici e il relativo valore di carbon footprint nel settore della produzione del latte. Lo studio principale, che ha coinvolto 285 aziende italiane da latte, mostra un consumo medio di gasolio pari a 0.040 kg e 0.075 kWh per il consumo elettrico per kg di latte prodotto. Il totale annuo delle emissioni di CO_2, relative all'uso dell'energia, corrisponde a 0.156 kg CO_2-eq per kg di latte. I risultati finali mostrano, inoltre che il 79% delle emissioni a livello aziendale sono dovute all'uso del gasolio e il 20% all'utilizzo dell'elettricità. Dai risultati ottenuti dal presente studio, sono stati sviluppati due modelli lineari per la stima dei consumi di elettricità e gasolio nelle aziende da latte. Inoltre, sono state analizzate 4 aziende convenzionali e 4 aziende biologiche da latte situate in California, USA, per definire il consumo di energia diretta e il relativo impatto ambientale. I risultati per le aziende convenzionali e biologiche hanno mostrato che il consumo annuale di gasolio è pari a 0.0071 e 0.0164 kg per kg di latte prodotto, mentre il consumo dell'energia elettrica corrisponde a 0.043 and 0.189 kWh per kg di latte, rispettivamente per le aziende convenzionali e biologiche. Le emissioni di anidride carbonica relative al consumo energetico sono: 0.035 kg CO_2-eq per kg di latte per le aziende convenzionali e 0.103 kg CO_2-eq per kg di latte per le biologiche.

CONTENTS

CHAPTER I

INTRODUCTION

1.1 From Carbon Cycle to Global Warming

Carbon is the fourth most abundant element in the universe and represents one of the strongest materials on the planet. Carbon, like water, moves continuously in the earth system and it represents one of the earth's primary biogeochemical cycle, in which carbon is exchanged among the biosphere, geosphere, hydrosphere, and atmosphere of the earth (Figure 1).

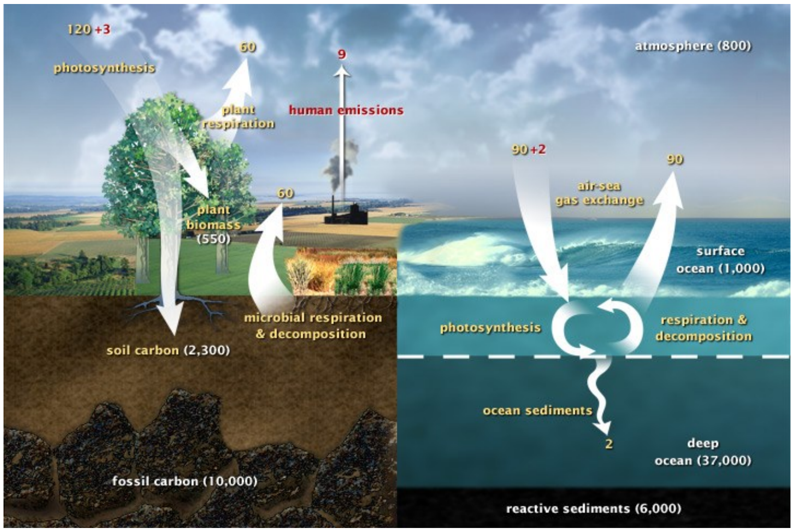


Figure 1. *Carbon cycle (Nasa 2011)*

According to the National Aeronautics and Space Administration (NASA, 2011), carbon flows between reservoir in an exchange called the carbon cycle, which has slow and fast components. Any change in the cycle that shifts carbon out of one reservoir puts more carbon in the other reservoirs.

In the slow carbon cycle through a series of chemical reactions, carbon takes between 100 and 200 million years to move between rocks, soil, ocean, and atmosphere. The fast carbon cycle is represented by the movement of carbon through life forms on earth. Carbon plays an important role in biology, since its ability to form complex organic molecules. Long carbon chains contain a high quantity of energy that is released, when the chains are break into apart. The energy released during the breakage of carbon molecules represents an important source of fuel for all living beings.

Plants and phytoplankton are the main components of the fast carbon cycle. Both plants and phytoplankton absorb carbon dioxide from the atmosphere and, through the energy from the sun, combine CO_2 and water to form sugar (CH_2O) and oxygen. The chemical reaction, called photosynthesis, is shown below:

$CO_2 + H_2O + \text{energy} = CH_2O + O_2$

To move carbon from a plant and return it to the atmosphere chemical reactions occur. Plants and humans (respiration, metabolism), break down the sugar to produce the energy they need to grow. The basic chemical reaction involves the oxygen which combines with sugar to release water, carbon dioxide, and energy:

$CH_2O + O_2 = CO_2 + H_2O + \text{energy}$

The carbon dioxide released in the reaction is emitted in the atmosphere. The fast carbon cycle is strongly associated to plant life. Plant growing seasons influence the concentration in carbon dioxide in the atmosphere. During winter season in the Northern Hemisphere, when few land plants are growing, atmospheric carbon dioxide concentrations increase. During the spring-summer seasons, plants begin growing and the increased photosynthesis activity absorb large amount of carbon dioxide reducing its concentrations in the atmosphere.

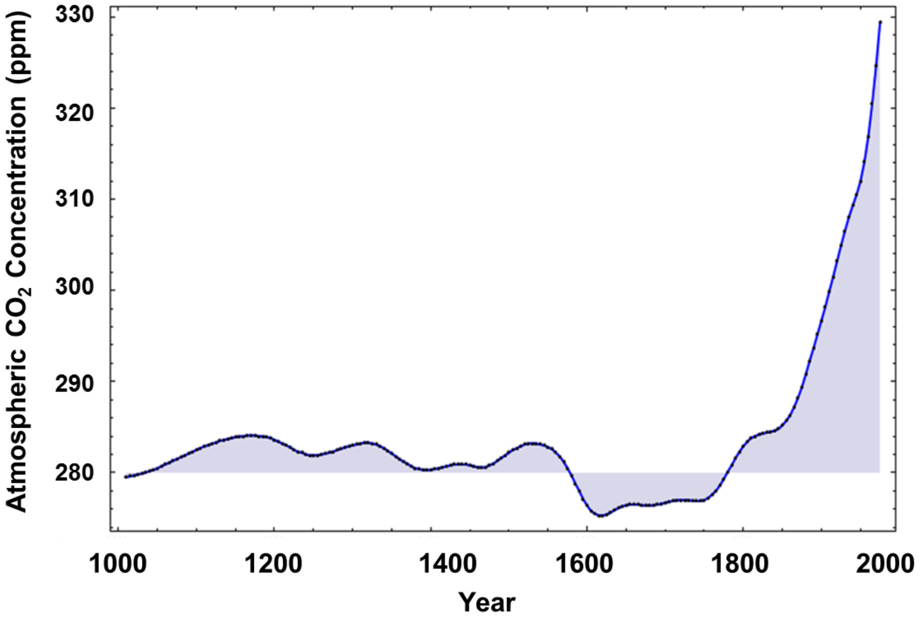


***Figure 2**. Atmospheric CO_2 concentration*

The usage of fossil fuels in large scale started with the Industrial Revolution in the 18th century, and the trend of consumption has been constantly rising since then (figure 2). The combustion of fossil fuels strongly increases the flux of carbon dioxide into the atmosphere. Likewise, removal of natural carbon sinks through land clearing, deforestation, and urbanization also contributes to increased atmospheric carbon (Animal frontiers, 2011). Forests are a dense growth of plants that had stored carbon in wood, stems and leaves. By removing large extension of forest land, plants that would absorb carbon from the atmosphere as they grow are eliminate.

Not only the usages of fossil fuel and deforestation have altered the atmospheric composition, even, agricultural and livestock activities and urbanization played a significant role altering the carbon cycle.

Without human interference, the carbon in fossil fuels would emit slowly into the atmosphere through volcanic activity over millions of years in the slow carbon cycle. By burning coal, oil and natural gas, a large amount of carbon dioxide is released (carbon that took millions of years to accumulate) into the atmosphere every year which means that, carbon from the slow cycle is moved to the fast cycle. In 2009, humans released about 8.4 billion tons of carbon into the atmosphere (NASA, 2011).

Since the beginning of the Industrial Revolution, when people first started burning fossil fuels, carbon dioxide concentrations in the atmosphere have risen from about 280 parts per million to 387 parts per million, a 39% increase.

Carbon dioxide is a GreenHouse Gas (GHG), like methane and nitrous oxide, which absorb a wide range of energy (including infrared energy) emitted from the earth. Some of the re-emitted energy returns to the earth surface heating it up (greenhouse effect). In the atmosphere, carbon dioxide is the most important gas for controlling earth's temperature. Without greenhouse gases the earth's temperature would be -18 degrees Celsius, while with too many GHG the temperature would be around 400 degrees Celsius. Each GHG absorb specific wavelengths, since the concentration of those gases are accurately calculated on the atmosphere, the related contribution to global warming is known. The definition of climate change in Intergovernmental Panel on Climate Change (IPCC) usage refers to a "*change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer*" (IPCC 2007). The previous definition refers to any change in climate over time, whether due to natural variability or as a result of human activity. The terminology used from the United Nations Framework Convention on Climate Change (UNFCCC), differs on climate change definition: "*result of change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods*" (IPCC 2007).

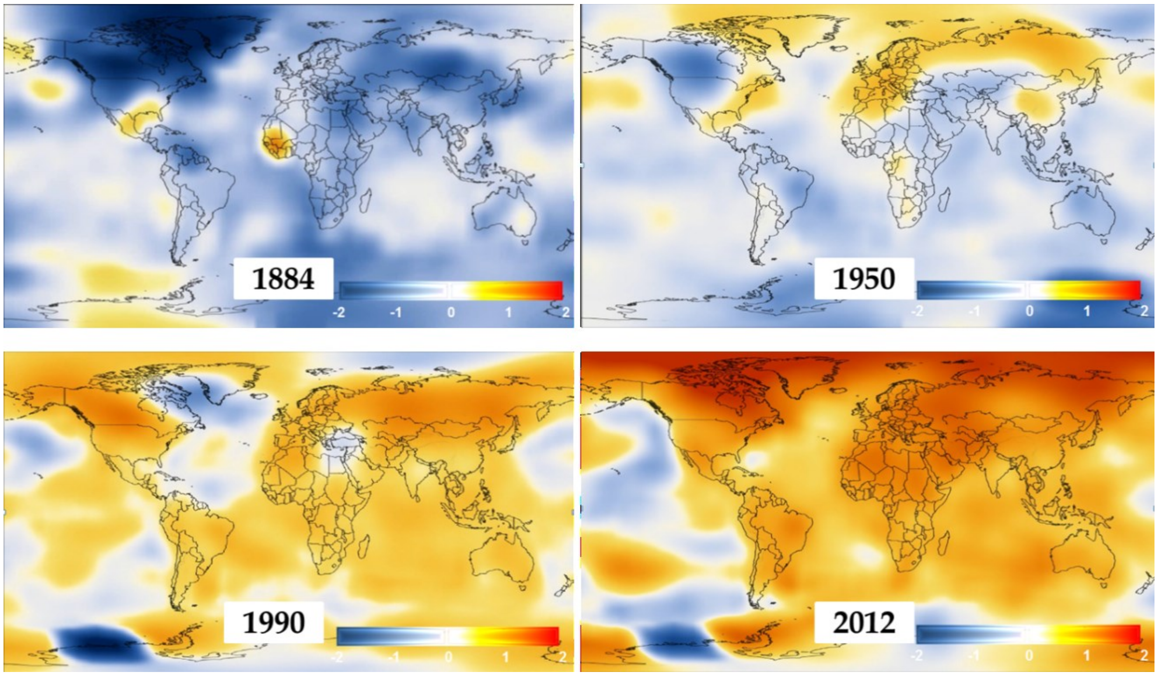


Figure 3. *Global surface temperature (adapted from NASA 2012).*

CO_2 cause about 20% of Earth' GHG effect, all GHG have risen the global temperature of 0.8 degrees Celsius since 1880 (figure 3).

According to the National Aeronautics and Space Administration (NASA), 2012 was the ninth warmest of any year since 1880. Global greenhouse gas emissions are projected to increase between 25% and 90% by 2030 related to the emissions from 2000 (figure 4). Fossil fuel usage is expected to increase by 2030, therefore, CO_2 emissions from energy use will tend to grow faster than total GHGs, increasing by 1.2–2.5% over that period (IPCC 2007).

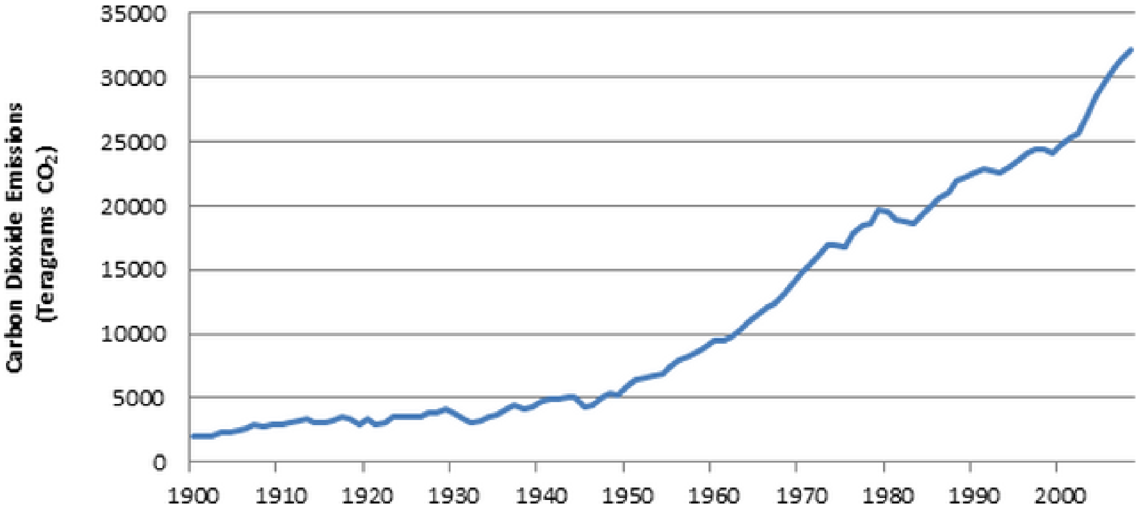


Figure 4. *Global Carbon Dioxide (CO_2) emissions from fossil-fuels 1900-2008 (Boden et al., 2010)*

1.2 Greenhouse Gas Emission in European Countries

The European Environment Agency (EEA) in 2013 published a report concerning the annual European Union greenhouse gas inventory. As shown in figure 5 the European emission (EU 27) decreased by 18.4 % between 1990 and 2011, passing from 5,574 to 4,550 million tonnes of CO_2-eq, which correspond to -1,024 million tonnes of CO_2-equivalents. GHG emissions decreased by 3.3% (155 million tonnes CO_2-equivalents) between 2010 and 2011.

GHG emission data for the EU-27 do not include emissions and removals from LULUCF (Land Use, Land Use Change and Forestry); nor do they include emissions from international aviation and international maritime transport

Figure 5. *EU-27 GHG emissions 1990–2011, excluding LULUCF (EEA, 2013)*

In accordance to the Kyoto protocol, EU 15 had to reduce GHG emissions by 341 million tonnes, on average between 2008-2012, in order to meet the reduction target of 8% compared to emissions in the 'base year'. As shown in figure 6, trend of GHG emission in EU 15 achieved the Kyoto protocol target. The decrements in emissions have been even lower than 8%, achieving a GHG reduction about 15%. The EU-27 does not have a common target under the Kyoto Protocol in the same way as the EU-15.

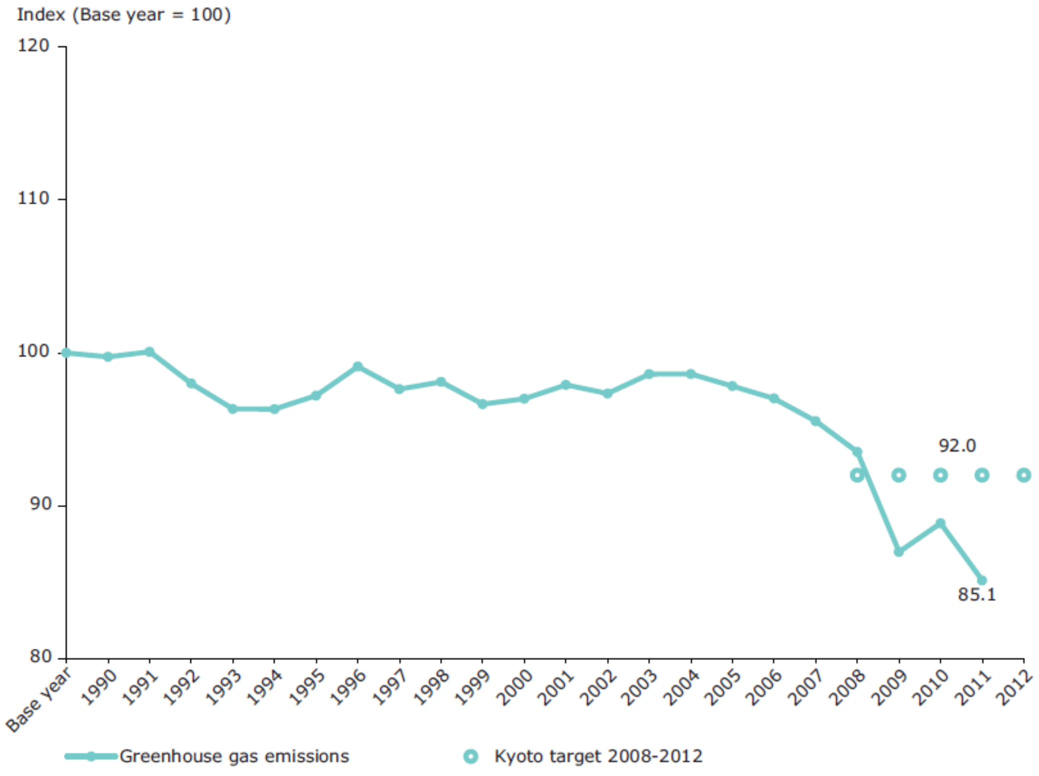
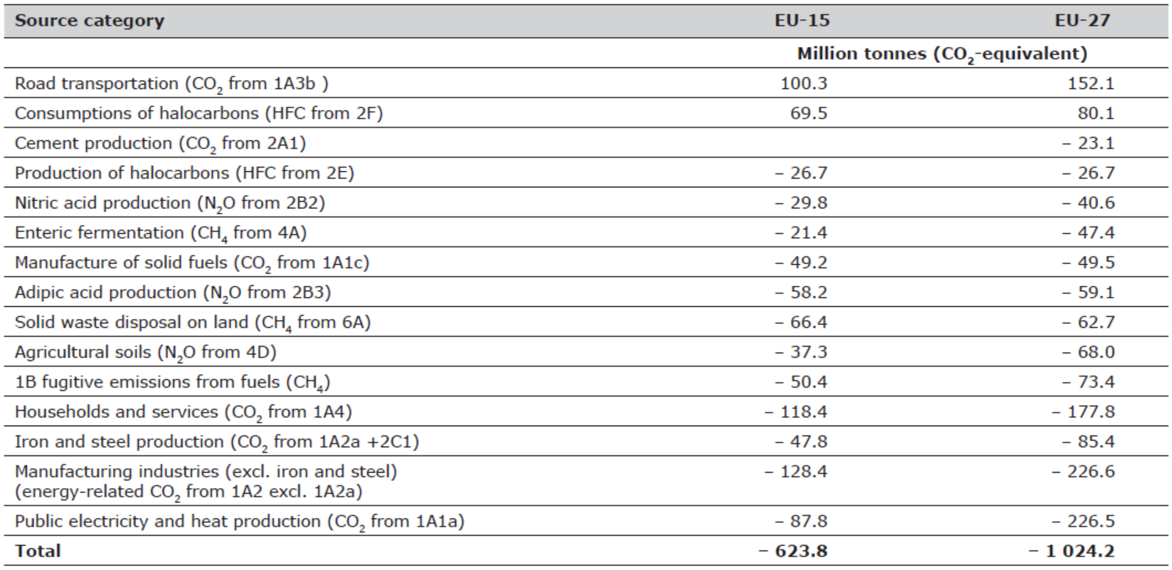


Figure 6*. EU-15 GHG emissions 1990–2011 compared with the target for 2008–2012, excluding LULUCF (EEA, 2013)*

Figure 7 shows the sources categories with the largest contribution in total GHG emissions in the EU-15 and EU-27 between 1990-2011. The main GHG reduction occurred in the Manufactory industries – 128.4 and -226.6 million tonnes of carbon dioxide equivalent for EU-15 and EU-27, respectively. Observing the EU-27 column the other source categories that affect significantly the reduction of GHG, expressed in million tonnes CO_2-eq, were public electricity and heat production (-226.5), household and services (-177.8) and even agriculture soil and enteric fermentation recorder a significant decrement of emission (-68 and -47.4, respectively).

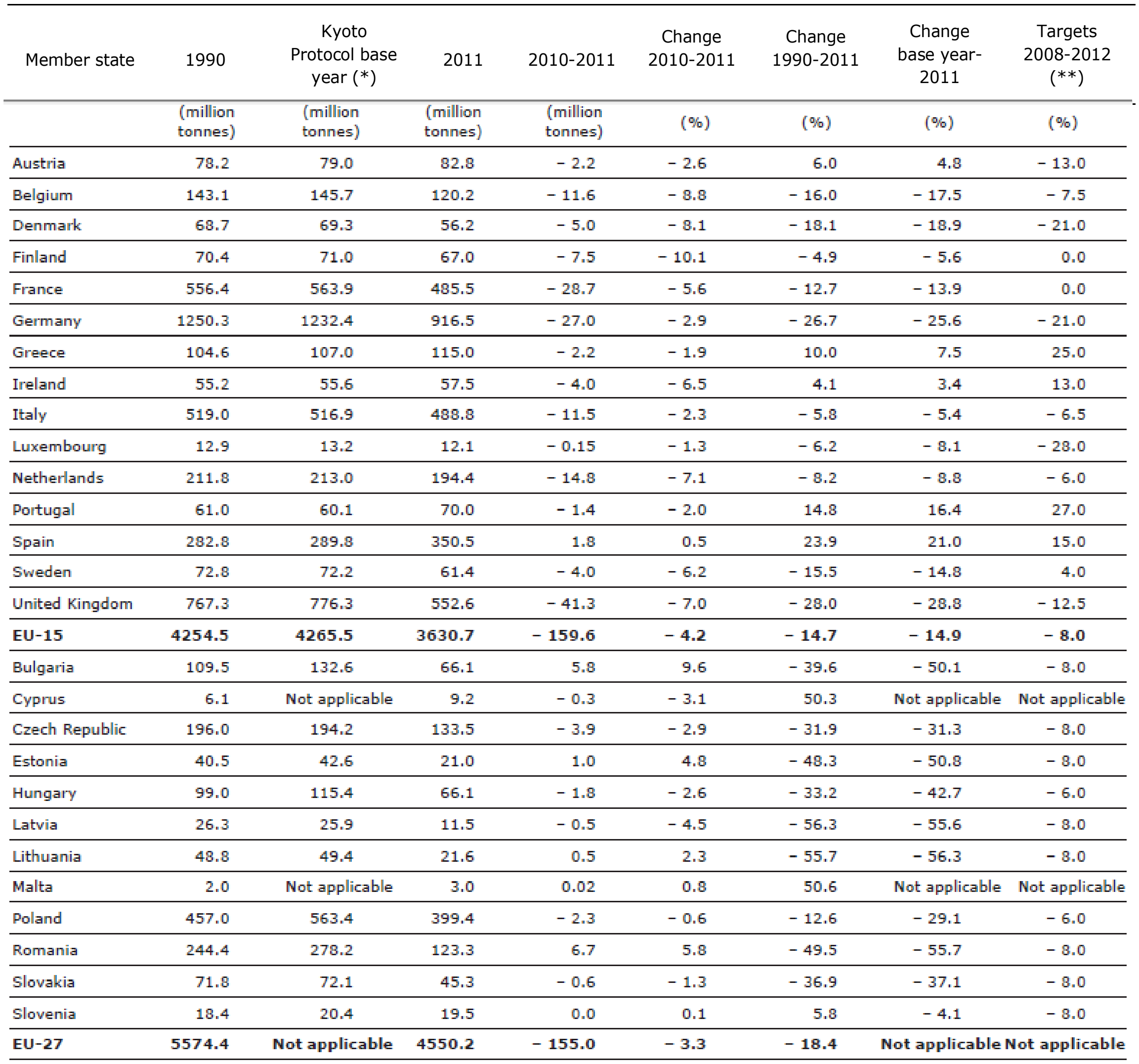


Source category	**EU-15**	**EU-27**
	Million tonnes (CO_2-equivalent)	
Road transportation (CO_2 from 1A3b)	100.3	152.1
Consumptions of halocarbons (HFC from 2F)	69.5	80.1
Cement production (CO_2 from 2A1)		– 23.1
Production of halocarbons (HFC from 2E)	– 26.7	– 26.7
Nitric acid production (N_2O from 2B2)	– 29.8	– 40.6
Enteric fermentation (CH_4 from 4A)	– 21.4	– 47.4
Manufacture of solid fuels (CO_2 from 1A1c)	– 49.2	– 49.5
Adipic acid production (N_2O from 2B3)	– 58.2	– 59.1
Solid waste disposal on land (CH_4 from 6A)	– 66.4	– 62.7
Agricultural soils (N_2O from 4D)	– 37.3	– 68.0
1B fugitive emissions from fuels (CH_4)	– 50.4	– 73.4
Households and services (CO_2 from 1A4)	– 118.4	– 177.8
Iron and steel production (CO_2 from 1A2a +2C1)	– 47.8	– 85.4
Manufacturing industries (excl. iron and steel) (energy-related CO_2 from 1A2 excl. 1A2a)	– 128.4	– 226.6
Public electricity and heat production (CO_2 from 1A1a)	– 87.8	– 226.5
Total	**– 623.8**	**– 1 024.2**

Figure 7. *Overview of EU-27 and EU-15 source categories whose emissions increased or decreased by more than 20 million tonnes CO_2-equivalents in the period 1990–2011 (EEA, 2013)*

However, road transportation and consumption of halocarbons showed a GHG increment of 152.1 and 80.1 M tonnes of CO_2-eq, respectively. Observing GHG emission from EU-15 member state, the source category that held a positive balance were road transportation and the consumption of halocarbons, while strong reduction of million tonnes of carbon dioxide emission were recorded in household and services (-118.4), public electricity and heat production (-87.8), agricultural soil and enteric fermentation (-37.3 and -21.4, respectively).

EU-27 from 1990 to 2011 were able to reduce the GHG emissions about 1,024 million tonnes of CO_2-eq. Several member states recorded a GHG reduction from 1990 to 2011 (Figure 8).



Member state	1990	Kyoto Protocol base year (*)	2011	2010-2011	Change 2010-2011	Change 1990-2011	Change base year-2011	Targets 2008-2012 (**)
	(million tonnes)	(million tonnes)	(million tonnes)	(million tonnes)	(%)	(%)	(%)	(%)
Austria	78.2	79.0	82.8	– 2.2	– 2.6	6.0	4.8	– 13.0
Belgium	143.1	145.7	120.2	– 11.6	– 8.8	– 16.0	– 17.5	– 7.5
Denmark	68.7	69.3	56.2	– 5.0	– 8.1	– 18.1	– 18.9	– 21.0
Finland	70.4	71.0	67.0	– 7.5	– 10.1	– 4.9	– 5.6	0.0
France	556.4	563.9	485.5	– 28.7	– 5.6	– 12.7	– 13.9	0.0
Germany	1250.3	1232.4	916.5	– 27.0	– 2.9	– 26.7	– 25.6	– 21.0
Greece	104.6	107.0	115.0	– 2.2	– 1.9	10.0	7.5	25.0
Ireland	55.2	55.6	57.5	– 4.0	– 6.5	4.1	3.4	13.0
Italy	519.0	516.9	488.8	– 11.5	– 2.3	– 5.8	– 5.4	– 6.5
Luxembourg	12.9	13.2	12.1	– 0.15	– 1.3	– 6.2	– 8.1	– 28.0
Netherlands	211.8	213.0	194.4	– 14.8	– 7.1	– 8.2	– 8.8	– 6.0
Portugal	61.0	60.1	70.0	– 1.4	– 2.0	14.8	16.4	27.0
Spain	282.8	289.8	350.5	1.8	0.5	23.9	21.0	15.0
Sweden	72.8	72.2	61.4	– 4.0	– 6.2	– 15.5	– 14.8	4.0
United Kingdom	767.3	776.3	552.6	– 41.3	– 7.0	– 28.0	– 28.8	– 12.5
EU-15	**4254.5**	**4265.5**	**3630.7**	**– 159.6**	**– 4.2**	**– 14.7**	**– 14.9**	**– 8.0**
Bulgaria	109.5	132.6	66.1	5.8	9.6	– 39.6	– 50.1	– 8.0
Cyprus	6.1	Not applicable	9.2	– 0.3	– 3.1	50.3	Not applicable	Not applicable
Czech Republic	196.0	194.2	133.5	– 3.9	– 2.9	– 31.9	– 31.3	– 8.0
Estonia	40.5	42.6	21.0	1.0	4.8	– 48.3	– 50.8	– 8.0
Hungary	99.0	115.4	66.1	– 1.8	– 2.6	– 33.2	– 42.7	– 6.0
Latvia	26.3	25.9	11.5	– 0.5	– 4.5	– 56.3	– 55.6	– 8.0
Lithuania	48.8	49.4	21.6	0.5	2.3	– 55.7	– 56.3	– 8.0
Malta	2.0	Not applicable	3.0	0.02	0.8	50.6	Not applicable	Not applicable
Poland	457.0	563.4	399.4	– 2.3	– 0.6	– 12.6	– 29.1	– 6.0
Romania	244.4	278.2	123.3	6.7	5.8	– 49.5	– 55.7	– 8.0
Slovakia	71.8	72.1	45.3	– 0.6	– 1.3	– 36.9	– 37.1	– 8.0
Slovenia	18.4	20.4	19.5	0.0	0.1	5.8	– 4.1	– 8.0
EU-27	**5574.4**	**Not applicable**	**4550.2**	**– 155.0**	**– 3.3**	**– 18.4**	**Not applicable**	**Not applicable**

(**) targets 2008-2012 under Kyoto Protocol and "UE burden sharing"

Figure 8. *Greenhouse gas emissions in CO_2-equivalents (excluding LULUCF) and Kyoto Protocol targets for 2008–2012 (EEA, 2013)*

Observing changes in EU-15 Unite Kingdom (-28%) and Germany (-26.7) recorded the largest decrement in million tonnes of CO_2-eq emissions, followed by Denmark, Belgium, Sweden and France, while Italy was able to reduce about -5.8% of GHG emissions. Not all member states in EU-15 were able to reduce carbon dioxide emission; Spain and Portugal increased their emissions from 1990 to 2011 around 23.9% and 14.8%, respectively. Observing EU-27 member states; Latvia, Lithuania, Romania and Estonia were the major states which recorded the highest reduction of carbon dioxide emission from 1990 to 2011 with percentage from 56.3% to 48.3%. However, Cyprus, Malta and the EU-27 do not have targets under the Kyoto Protocol base year. Different strategies were adopted from the EU-27 member states for reducing carbon dioxide emissions in the last 20 years. Decreasing emission in electricity and heat production occurred in the UK and France, thanks to a lower demand of electricity supply , accompanied by a greater use of nuclear power (UK) and lower use of coal (France) for electricity generation (EEA, 2013 b). The decrements on cement production led to reduce emission especially in Greece, Portugal, Spain and Italy. Also greater use of natural gas rather than oil, helped to reduce carbon dioxide emission in UK.

The contribution of renewable energy on CO_2-eq reduction was significant, the production of renewable energy passed from about 180 TWh in 2000 to 800 TWh in 2010 for EU-27 member states. The increment of biomass combustion, hydroelectricity, wind and solar energy production strongly increased in the last 10 years (Eurostat, 2012).

1.3 Carbon Dioxide Emission for Agriculture Sector

According to Ecofys 2010, global GHG emissions for agricultural sector accounted for 7% of the total emissions. Observing figure 9 appears evident the important contribution of fossil fuel to GHG emissions, while direct emissions accounted about 34.6%

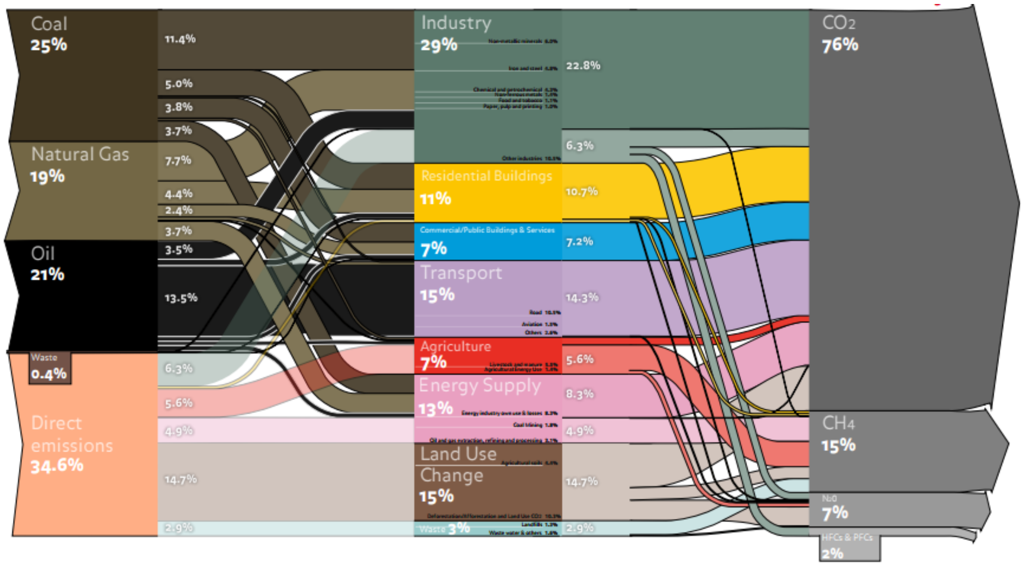


***Figure 9**. World GHG Emissions Flow Chart (Ecofys, 2010)*

The European Environment Agency in 2013 showed the repartition of GHG emission by sector for EU-27 member states. The predominant activity that emitted the 32% of total GHG emission was related with the energy industries, followed by transport (20%), residential and commercial sector (14%) and manufactory and construction (12%), while the agriculture sector accounted for 10% of total GHG emission (figure 10; EEA 2013).

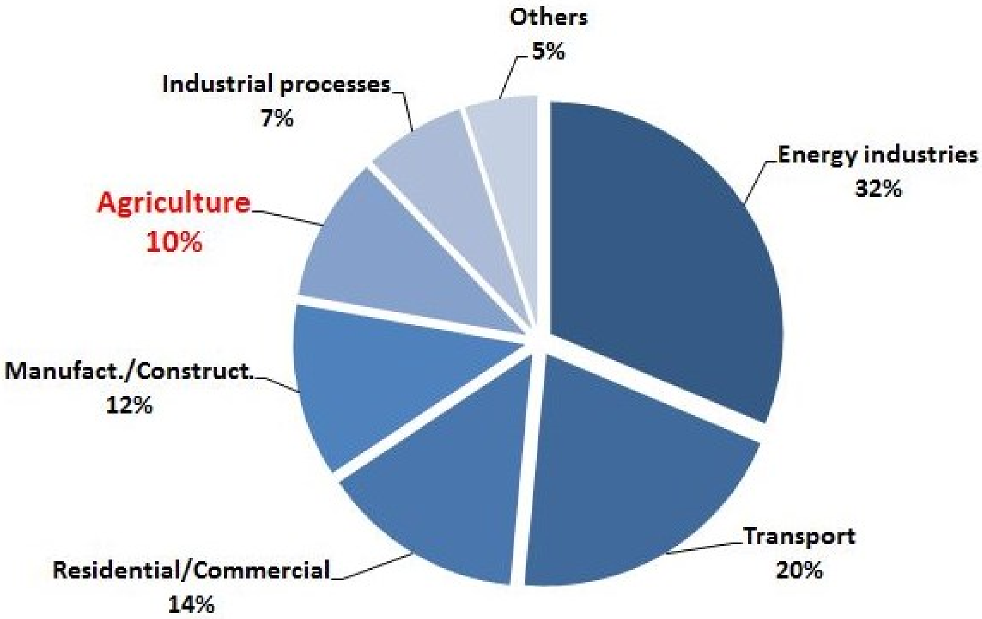


Figure 10. *European GHG Emissions by sector per 2010 (adapted from EEA, 2013)*

Inside the agricultural sector, the activities that affect significantly the GHG emission came from: agricultural soil (50.5%), enteric fermentation (32%) and manure management (16.6%; Eurostat, 2012 c).

Observing the figure 11, agricultural sector in EU-27 showed a GHG reduction of 22% in the last 20 years, which represent a decrement of 132 million tonnes of carbon dioxide equivalent (EEA, 2012).

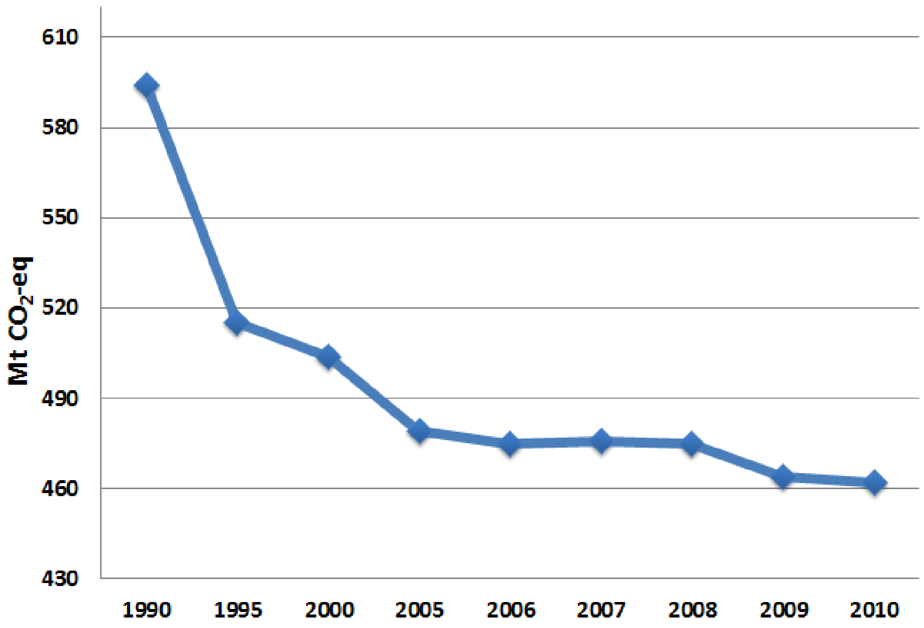


Figure 11. *Agriculture CO_2-eq trend emissions 1990-2010 (adapted from EEA, 2013)*

The reason of carbon dioxide reduction in the agriculture sector has been mainly due to a 23% reduction in nitrous oxide emission from agriculture soil, due to a decrement in nitrogenous fertilizers. Also, 22% of GHG reduction was due to a decrement in methane from enteric fermentation, mostly due to a reduction of livestock numbers (Eurostat, 2012 b).

1.4 Fossil Fuel and CO_2 Emission

Use of fossil fuel represents one of the most important sources for the energy system. The combustion of fossil products generates carbon dioxide (CO_2) and water (H_2O), which are emitted into the environment, releasing the energy of the fuel as heat. This heat may generally being used directly or to generate mechanical energy, such as transportation or even produce electricity. The energy sector is the most pollutant sector in terms of emission of greenhouse gases, and typically contributes over 90% of the CO_2 emissions and 75% of GHG emissions in developed countries (IPCC 2006).

The Intergovernmental Panel on Climate Change (IPCC) with the "*Guideline for National Greenhouse Gas Inventory, 2006*" identifies the guideline to estimate emissions from fossil fuel combustion and in particular several methods (TIERS) of details with increasing accuracy:

Tier 1, emissions are calculated from the amount of fuel combusted derived from a national statistic and then multiply for the related emission factor. The values of each emission factor depend on the content of carbon in the fossil fuels.

Tier 2: the emission from the combustion of fossil fuels are estimated as explained in Tier 1, however country-specific emission factors are consider instead of Tier 1 methods. Country-specific emission factors take into account detailed data on fuel carbon content and combustion technology applied in the country.

Tier 3, is a method for energy and emission assessment based on measurement at individual plant level. Tier 3 represents the most detailed measurement in order to provide better values of emission.

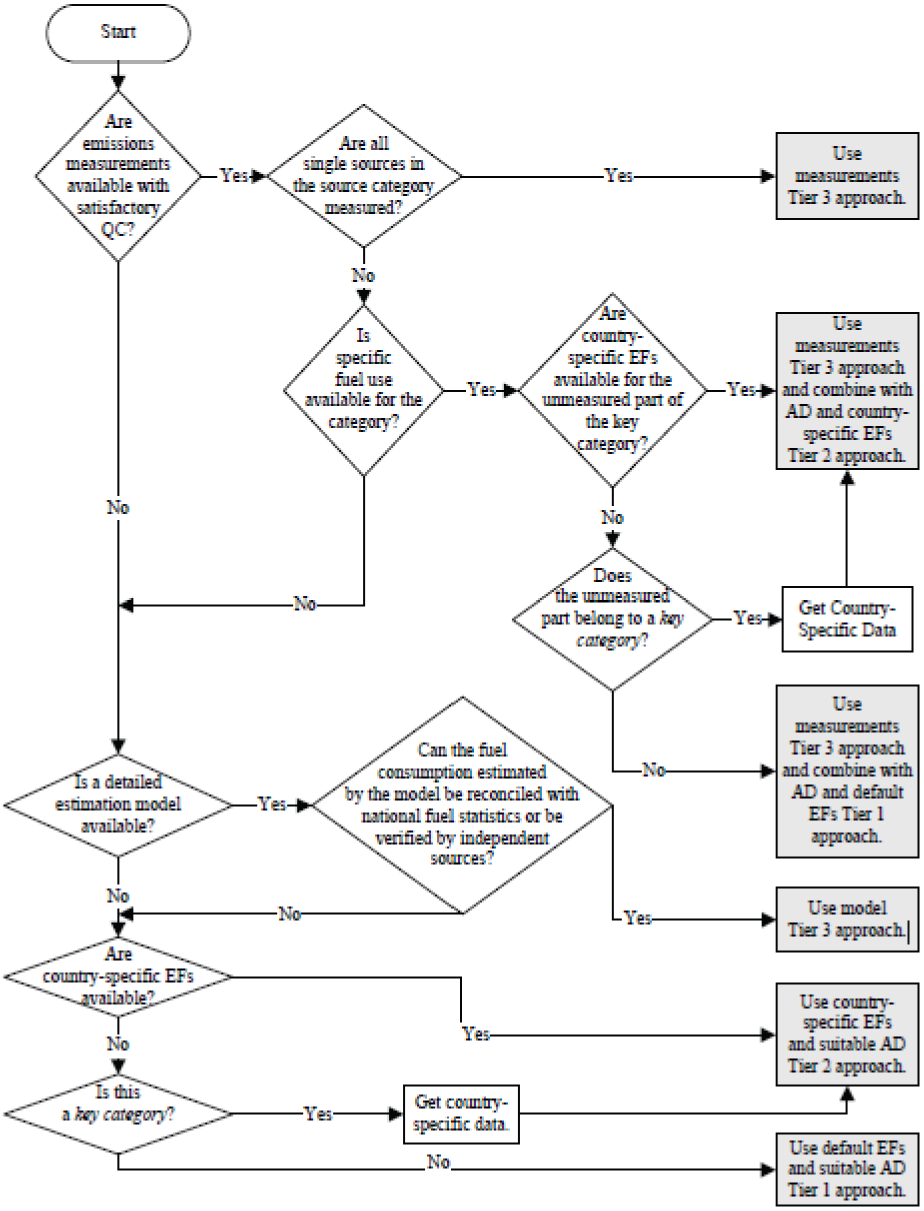
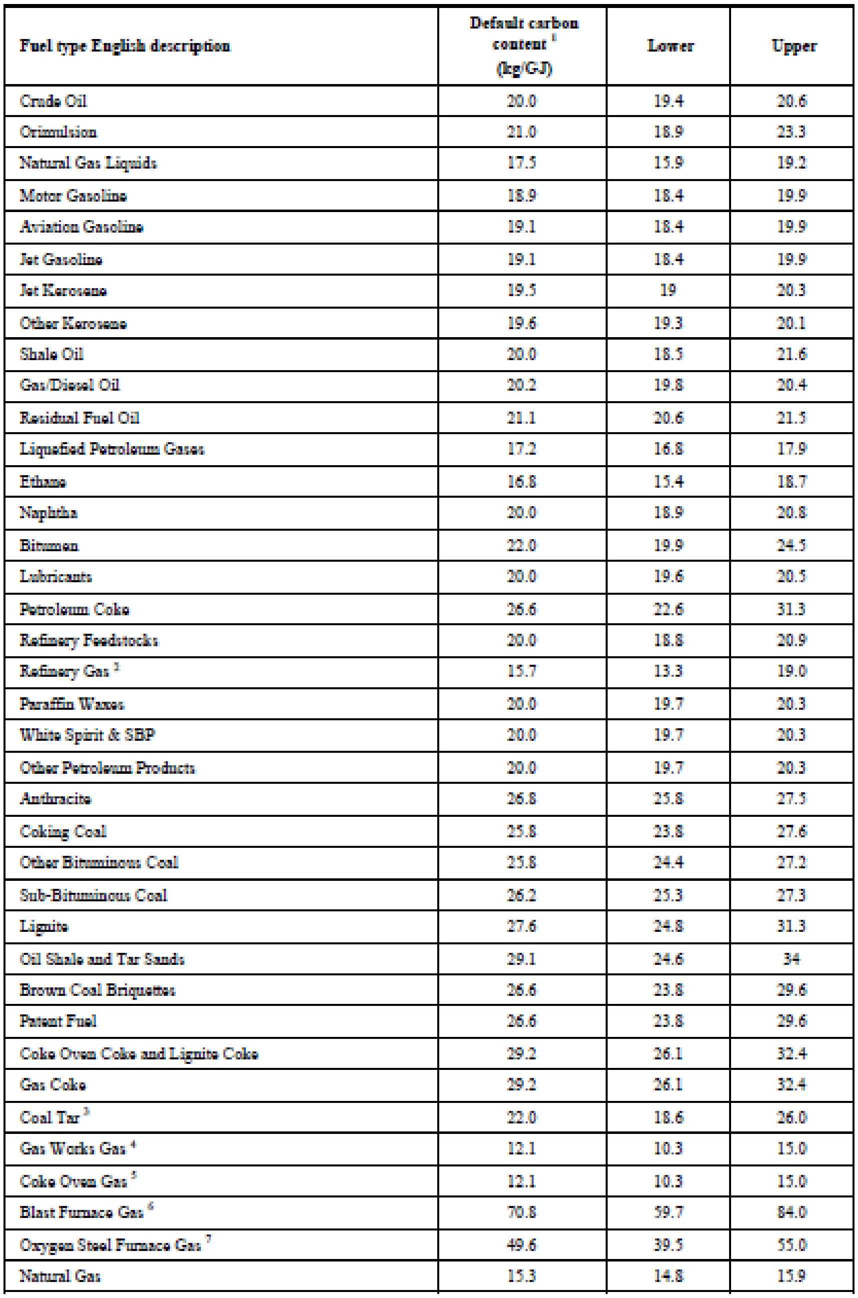


Figure 12. *Decision tree for selecting Tiers for fuel combustion (IPCC, 2006)*

During an inventory analysis for each source category and greenhouse gas, the methodology applied, in terms of tiers, may be different, depending on the importance of the source category, time available, work force and budget. The IPCC developed a decision tree to select the suitable tier for each fuel and for each gas (figure 12).

Combustion processes are optimized to obtain the maximum amount of energy per unit of fossil fuel combusted. Optimizing the combustion process the amount of CO_2 increases per unit of fuel, for this reason the quantity of carbon dioxide emitted is related to the combustion process and to the carbon content of fuels (table 1). Emission factor represents the average amount of pollutant emitted from the combustion of a specific source. It is expressed, for instance, in grams of CO_2 per unit of fossil fuel combusted.

***Table 1**. Default values of carbon content for different fuels (IPCC, 2006)*



Fuel type English description	Default carbon content [1] (kg/GJ)	Lower	Upper
Crude Oil	20.0	19.4	20.6
Orimulsion	21.0	18.9	23.3
Natural Gas Liquids	17.5	15.9	19.2
Motor Gasoline	18.9	18.4	19.9
Aviation Gasoline	19.1	18.4	19.9
Jet Gasoline	19.1	18.4	19.9
Jet Kerosene	19.5	19	20.3
Other Kerosene	19.6	19.3	20.1
Shale Oil	20.0	18.5	21.6
Gas/Diesel Oil	20.2	19.8	20.4
Residual Fuel Oil	21.1	20.6	21.5
Liquefied Petroleum Gases	17.2	16.8	17.9
Ethane	16.8	15.4	18.7
Naphtha	20.0	18.9	20.8
Bitumen	22.0	19.9	24.5
Lubricants	20.0	19.6	20.5
Petroleum Coke	26.6	22.6	31.3
Refinery Feedstocks	20.0	18.8	20.9
Refinery Gas [2]	15.7	13.3	19.0
Paraffin Waxes	20.0	19.7	20.3
White Spirit & SBP	20.0	19.7	20.3
Other Petroleum Products	20.0	19.7	20.3
Anthracite	26.8	25.8	27.5
Coking Coal	25.8	23.8	27.6
Other Bituminous Coal	25.8	24.4	27.2
Sub-Bituminous Coal	26.2	25.3	27.3
Lignite	27.6	24.8	31.3
Oil Shale and Tar Sands	29.1	24.6	34
Brown Coal Briquettes	26.6	23.8	29.6
Patent Fuel	26.6	23.8	29.6
Coke Oven Coke and Lignite Coke	29.2	26.1	32.4
Gas Coke	29.2	26.1	32.4
Coal Tar [3]	22.0	18.6	26.0
Gas Works Gas [4]	12.1	10.3	15.0
Coke Oven Gas [5]	12.1	10.3	15.0
Blast Furnace Gas [6]	70.8	59.7	84.0
Oxygen Steel Furnace Gas [7]	49.6	39.5	55.0
Natural Gas	15.3	14.8	15.9

1.5 Life Cycle Assessment (LCA) Methodology

The challenge to turn the society in a more sustainable direction, represent one of the most discussed topic of the last years. Life Cycle Assessment (LCA), also called life cycle analysis, represents an important tool to evaluate the environmental impacts associated to the production process, of goods or services from "cradle", where raw material are extracted from the natural system, through the transportation, processing, distribution, use and disposal, which represent the "grave" (Baumann-Tillman, 2004).

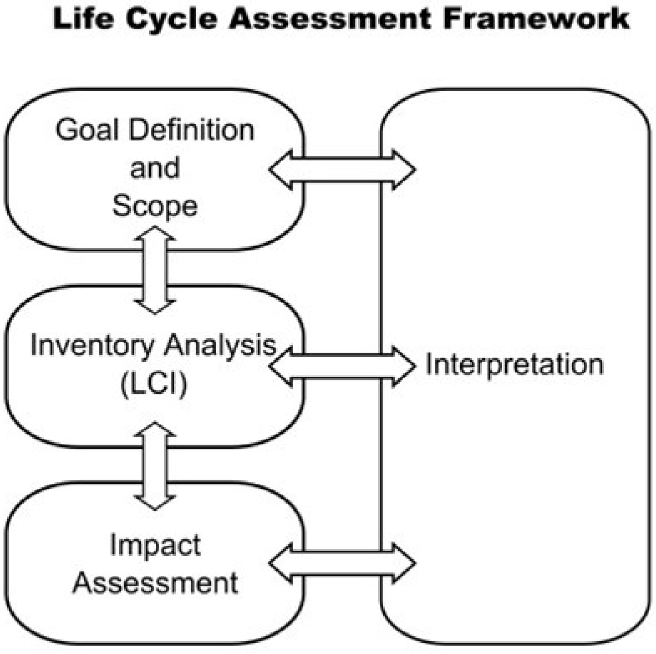


***Figure 13**. Life Cycle Assessment Framework (Anctil and Fthenakis, 2012)*

The International Organization for Standardization (ISO) provides guidelines to conduct a life cycle analysis within the series UNI EN ISO 14040-14044: 2006.

LCA is divided in four main phases: Goal and Scope definition; Inventory analysis; Impact Assessment; Interpretation (Figure 13).

1.5.1 Goal and Scope

In the goal and scope phase, the purpose of the study and the product must be clearly defined. Before carrying out an LCA analysis the application, the reason of the study and how the results are intended to be communicated, must be specified in this section.

In this phase the context of the study and the functional units are also defined. Going deeply inside the goal and scope definition phase will found that the goal of an LCA is closely related to the context in which the study is done. The initial goal could be generally formulated, but it is necessary to transform the general goal in a more specific one in order to choice the more suitable methodology for the study, also the product or service intended study must be clearly defined.

The scope section includes the choices of methodology approach to undertake. A first general flowchart of the system could be the early stage of the study; such a flowchart can be more or less detailed and it should contain the boundaries of the system. The boundary of the study represents the limit of the system analyzed, The LCA methodology it is a quite flexible tools where extensive customization can be made in order to achieve a large number of study with this approach.

When the goal, the product and the system have been decided, the functional unit will be identified. The functional unit represent the product or service to which all other modeled flows of the system are related. The functional unit is quantitative and should allow comparing different results in different situation. The production of a good or service may have a co-product. The environmental impact occurring thorough the life cycle of a product must be divided between the product, objective of the study, and the co-products. Several methodologies are available to carrying out an allocation problem: no allocation, the entire contribution of GHG emission is attributed to the main functional output; economic allocation, the environmental load is divided between product and co-product on an economic basis; mass allocation, where the emission of GHG are allocated based on the mass of product and co-product (Casey-Holden, 2005).

The categories of environmental impact to consider are defined during the scope phase, and the categories of impact concern: resource use, ecological consequence and human health.

1.5.2 Inventory Analysis

In the Life Cycle Inventory analysis (LCI) phase the system model is built in accordance to the goal and scope definition and describe all the input and output related to the system flows. The inventory analysis includes the following steps:

- Develop a flowchart that shows the overall activities included in the system boundary and the flows among each activity;

- Data collection for the overall activities must include input and output (i.e. raw material, products, energy use, waste management etc.);
- Assess the amount of resource used and pollutant emitted through the "life" of the functional unit.

1.5.3 Impact Assessment

Life Cycle Impact Assessment (LCIA) leads to define or indicate the impacts of the environmental loads collected and quantified in the inventory analysis. The objective of this phase is to express the inventory results into environmental information criteria.

During the impact assessment, the information obtained from the LCI, are aggregated into fewer indicators, following the next steps: "*classification*", which consists in sorting the inventory parameters in accordance to the environmental impact category related with; "*characterization*", which represents the contribution of emission and resource consumption for each type of environmental impact category.

Impact categories are described in ISO 14040, (2006) and are generally divided on: resource depletion, human health and ecological consequences.

Impact categories are listed in the characterization methods which transform the environmental load into impacts. The following impact categories will be described (Baumann-Tillman, 2004):

Resource: this category represents the use and depletion of natural resources, which can be divided into renewable and non-renewable resources. Non-renewable are resources that are not regenerated within human lifetime, e.g. minerals, fossil fuels and clay. Renewable resources are regenerated within human lifetime, e.g. groundwater, solar and wind energy;

Land Use: this category concerns the actual use of land as well as the change in land use, and land transformation which leads to changes in biodiversity. The calculation of land use in terms of "transformation" perspective is related to the fact that change in land use leads to a shift in the competition between different uses of land and to a change in land quality;

Global Warming: greenhouse gases have the property to absorb infrared radiation and consecutively heat the atmosphere causing climate change. The potential contribution of each gas to climate change is expressed as global warming potential (GWP). The GWP is defined as the ratio between the increased infrared absorption and the increased infrared absorption caused by 1 kg of CO_2. Since GHG have different life spans in the atmosphere, GWP have been calculated for different time horizons. The IPCC developed several GWPs which have been used in LCA studies (table 2).

Toxicity: this category is divided into human toxicity and eco-toxicity; eco-toxicity can also be divided into aquatic toxicity and terrestrial toxicity.

Photo-oxidant formation: photo-oxidants are secondary pollutants formed in the lower atmosphere from NO_x and hydrocarbons in the presence of sunlight. These substances are characteristic of photochemical smog, which cause health problems and damage to vegetation.

Table 2. *GWPs for several Greenhouse gas (adapted from IPCC 2007)*

Common Name	**Chemical Formula**	**Lifetime (years)**	**Global Warming Potential**		
			20-yr	**100-yr**	**500-yr**
Carbon dioxide	CO_2	*See a*	*1*	*1*	*1*
Methane	CH_4	*12*	*72*	*25*	*7.6*
Nitrous oxide	N_2O	*114*	*289*	*298*	*153*

a)The CO_2 response function used in this report is based on the revised version of the Bern Carbon cycle model(Bern2.5CC; Joos et al. 2001) using a background CO_2 concentration value of 378 ppm. The decay of a pulse of CO_2 with time t is given by

$$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$$

Where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years.

Acidification: SO_2, NOx, HCI and NH_3^- are the major acidifying pollutants which cause the formation of acidifying H^+ ions. The Acidification Potential (AP) is defined as the number of H^+ ions produced per kg of substance relative to SO_2.

Eutrophication: high level of nutrients that lead to shift in species composition and increase biological productivity (i.e. algal blooms) is called eutrophication. The most implicated substances in eutrophication are Nitrogen (N) and Phosphorus (P) especially in aquatic and terrestrial ecosystems. Nitrogen and phosphorus found in natural ecosystem came from different sources (i.e. agricultural fertilizers and sewage management).

1.5.4 Interpretation

Results deriving from LCA study may appear not easy to be managed, since the results may be hundreds of values. The interpretation phase in LCA methodology represents the process of assessing results in order to define conclusion, recommendations and present the results to the audience. In the interpretation step graphs, tables and charts may help to better present and compare different results (Baumann-Tillman, 2004).

1.6 LCA and Carbon Footprint of a Product

Carbon Footprint (CFP) is represented by the sum of greenhouse gas emission and removal in a product system, expressed as CO_2-eq and based on a Life Cycle Assessment (LCA) methodology, using the single impact category of climate change (ISO/TS 14067, 2013). Results quantification of CFP are expressed per functional unit. The CFP may be assessed for one or more selected process of a product system within its life cycle; in this case, a partial CFP study is defined by the ISO standards 14067:2013.

1.7 Objectives and Organization of the Research

Since preindustrial revolution the consumption of fossil fuel increased significantly and thus the related emission of carbon dioxide into the environment. The IPCC classified carbon dioxide as a greenhouse gas for its effects in climate change. The emission of greenhouse gases into the environment is topic which is increasing more and more in the last years. The agriculture sector and the livestock production are also responsible to emit remarkable quantities of GHG into the environment.

For this reason, the section one of this work focused on the energy intensity and related emission of carbon dioxide from a sample of 285 dairy farms, located in the southern regions of Italy. The study also analyzed the distribution of energy demand among on-farm operations; additionally an economic evaluation associated to the energy usage was carried out. The second section of this project utilized the results obtained from the study explained in section one, to develop two linear model to predict diesel and electricity consumption in dairy farms. A function in R studio was developed to test the applicability of both models. The outputs of the function are able to show the amount of energy consumption, the related emission of carbon dioxide and the associated cost for energy purchased.

The third section was focused on environmental analysis of 8 dairy farms, 4 conventional and 4 organic, located in the central and northern valley of the State of California, USA. The study focused in a comparison between conventional and organic farming related to the use of energy, emission of carbon dioxide and costs due to the consumption of energy.

CHAPTER II

ENERGY INTENSITY AND RELATED CARBON FOOTPRINT OF DAIRY FARMING IN SOUTHERN ITALY

2.1 Introduction

Dairy farming is evolving to more energy demanding forms of management which result in higher economic and environmental loads. Intensive mechanization has reduced the incidence of labour requirement for livestock operations and increased the utilization of appliance which required the combustion of fossil fuel. The milk quota system in the European Union will be removed by 2015. The effect of this action will increase milk production per farm and reduce the milk price by 22.7% for the Italian dairy sector (Bouamra-Mechemache et al., 2008; Lips-Rieder, 2005). These previsions lead to focus not only the cost control but even the environmental load for dairy farms. The efficient use of energy is one way to improve the environmental burden and the cost competitiveness of the milk production sector. Taking into account the entire livestock commodity chain – from land use and feed production, to livestock farming and waste management, to product processing and transportation, the Food and Agriculture Organization (FAO, 2006) attributed about 18% of global GHG emissions to the livestock sector. However, recent studies attribute to the livestock sector the 2-4% (Gill et al., 2010) to 3-8% (Capper et al., 2009) of the total GHG emissions in developed countries. The environmental load is strictly associated to the animal product (kg of milk, eggs, meat, etc.) and the system considered (Flachowsky-Hachenberg, 2009). The contribution of GHG emission from the Italian livestock sector represents 3% of the total national emissions, where the northern regions are responsible for the 65%, 9% for the central regions and 26% for the southern. The Italian dairy sector is responsible of 56% of the total livestock emissions (Pulina et al., 2012).

The reduction of GHG emissions from the dairy sector is a critical issue for a more sustainable milk production. To achieve this goal, policy makers, producers and consumers require clear and objective information about the impact of the milk product.

A review of recent literature and databases reveals that more information about GHG emission and dairy farms has become available in recent years, but it is still largely fragmented (FAO 2010). In relation to the energy consumption in dairy farms, around 25% of the non-renewable primary energy use is on-farm electricity for milking, milk refrigeration, manure handling, ventilation, lighting, etc. Diesel usage for on-farm activities (15%) represents the majority part of uses (IDF, 2009).

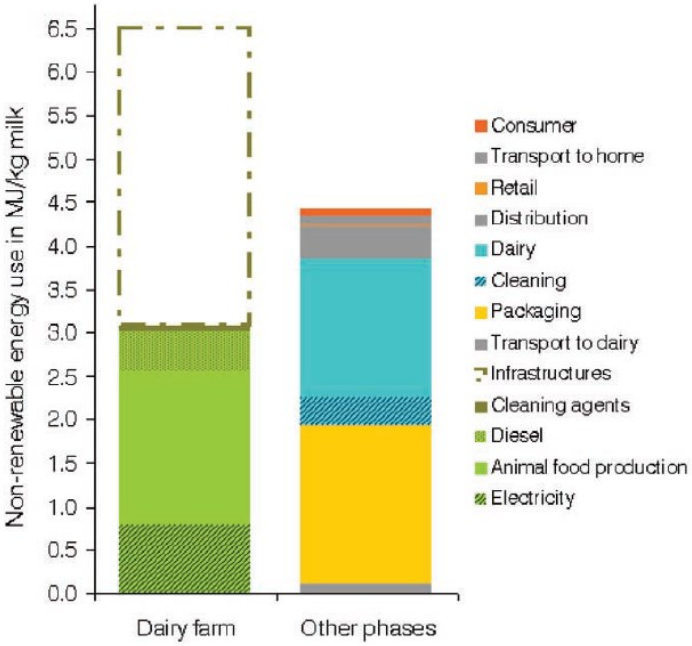


Figure 1. *Energy usage in dairy farms phases (IDF 2009)*

As shown in figure 1, the main contributor to energy use is the dairy farm phase, which represents about 40% of the total energy use in the life cycle of milk. The values shown in figure 1 do not take into account the energy embodied in machinery and buildings (indirect energy), which can represents (Rossier-Gillard, 2001) 1/3 of the total resources consumption of the life cycle of 1 kg of milk. However, buildings and machinery production are often not taken into account due to the complexity of the analysis and for the lack of knowledge in this topic. As reported in IDF 2009, further studies are needed to better characterize this issue.

Energy consumptions are strictly associated to the efficiency of the production system considered, large difference are also related to the level of technologies adopted, the type of management (intensive, extensive, conventional, organic, etc.) and herd dimensions.

In accordance to Ludington and Johnson, (2003), a study conducted in 32 US dairy farms used between 800 and 1,200 $\mathrm{kWh \cdot cow^{-1}}$ per year, while Murgia et al., (2008) reported an electricity consumption of 466 $\mathrm{kWh \cdot cow\text{-}yr^{-1}}$for 14 Sardinian dairy farms. The use of energy in the common dairy LCA study is generally expressed as total energy needed from the farms-activities, without a detailed subdivision among different fossil fuel sources.

2.2 Materials and Methods

2.2.1 Data Sources

A population of 285 conventional dairy farms distributed in four dairy plant co-operatives (named A, B, C, D) located in the south of Italy (Sardegna, Sicilia, Basilicata, Calabria e Puglia) were involved in this study. The data collection regards harvest year 2010-2011.

A partial Life Cycle Assessment methodology was used to evaluate the inputs - outputs and the potential environmental impacts of the milk production system. The phases of an LCA include: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA) and interpretation of results.

2.2.2. Goal and Scope definition

In the goal and scope phase the purpose of the study and the product involved must be clearly described, followed by the definition of the system boundary and the functional unit.

Therefore, the objectives of this study were to define the energy (electricity, diesel, gas and renewable energy) intensity of milk production at farm level, to identify the distribution of energy usages among the different on-farm activities and to estimate the emission of GHG related to the use of fossil energy. Additionally, the economic aspects related to energy consumption and to the energy savings measures have been evaluated.

2.2.3 System Boundaries

The next step of the project was to identify the energy flows (figure 2), for each fossil and renewable source used in dairy farm process.

The system boundaries were set at farm level, from cradle to farm gate and include all the facilities utilized for:

- on farm feed production;
- feed preparation and distribution;
- manure management;
- milk extraction (milking operations and refrigeration);
- water supply;

Systems for the production of renewable energy eventually present were also included in the analysis.

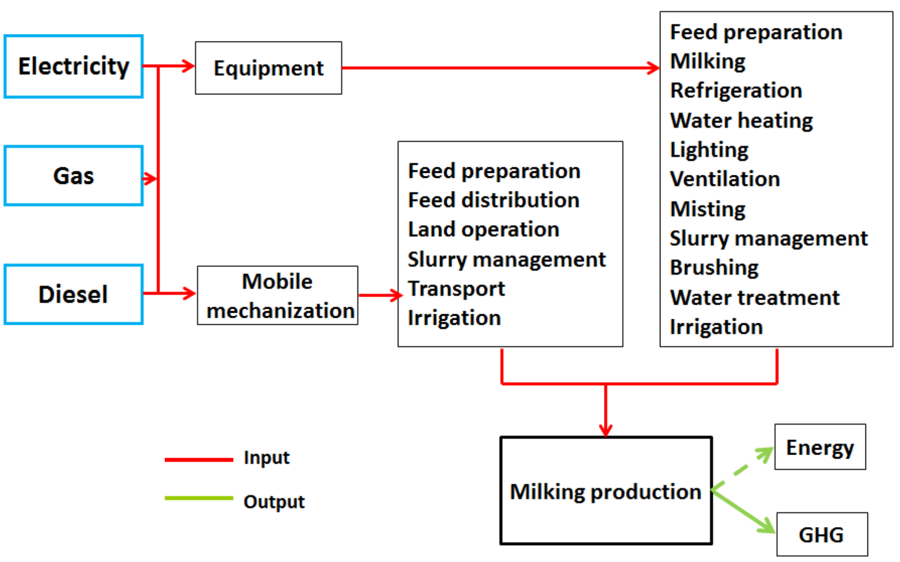


Figure 2. *Energy flows in dairy milk production*

2.2.4 Functional Unit

In dairy systems the main product is milk, which can be expressed in different units (mass, volume). In this study we refer to a quality corrected functional unit (FU) which consider both the composition of the milk and its mass. Therefore the functional unit selected was 1 kg of Fat and Protein Corrected Milk (FPCM) which allow comparing results with other studies.

In particular, the equation used to assess the FPCM was derived from IDF 2010 and takes into account the yearly production of milk expressed in kg, the percentage of protein and the percentage of fat content.

$$\text{Kg FPCM} = (\text{Milk kg} * ((0.1226 * \text{Fat }\%) + (0.0776 * \text{Protein }\%) + 0.2534)$$

2.2.5 Inventory Analysis (LCI)

Data collection were performed through a questionnaire which involved general information such as herd size, animal categories, land used, milk quality and production, and a detailed description of cultivated crops, farm structures, equipment and machinery.

The questionnaire was structured in order to fit the overall information found at farm level, in view of the high variability among farms of different size, typology, level of mechanization and management. The inquiry form was divided into 10 sections concerning:

Section 1- ***General information*****,** which encompasses the overall data of the farms such as herd size, hectares of cultivated land, position (city, province and region), milk quality and quantity, number of employs and type of herd management.

Section 2- ***Feed preparation and distribution***, where the overall operation regarding the feeding operations were collected, including power of the machinery used and related usage times.

Section 3- ***Farm structures*****,** in this part of the questionnaire the information concerning building and facilities found at farm level were included and in particular the dimension of the building, destination, composition materials and electrical installations.

Section 4- ***Slurry storage facility*****,** which considers the dimensions, typologies and equipment found in the slurry storage amenities.

Section 5- ***Fleet equipment***, represent an inventory of the overall machinery (tractors and tools) used for the dairy farm operations.

Section 6- ***Energy consumptions*****,** include the consumption receipt of the expenditure for electricity supply, fuel and LPG.

Section 7- ***Milking and milk cooling*****,** which include the information related to the type of milking parlour, number of groups, power of the equipment, milk tank dimensions, availability of energy saving devices, such as Variable Drive Speed (VDS), Milk Pre-cooler (MP) and Heat Recovering System (HRS).

Section 8- *Water usage*, referred to the use of irrigation pumps and pumps used for water supply at farm level. The two sections were kept separated during the final calculation in order to identify the consumption of energy of each operation.

Section 9- *Agronomic data*, including the information about cultivations as type of crops, type of harvesting, yields and hectares cultivated.

Section 10- *Field operations*, related to the mechanization power of the machinery, times of use, type of operation carried out and tools used were included in this section.

Detailed statistics of the monthly energy flows, such as consumption receipt of fuels, LPG, electricity and the self-produced energy from renewable sources, such as photovoltaic (PV) generators, anaerobic digestion (AD), wind power (WP) and solar panel (SP) were recorded.

Data were collected by a team of technicians which complete the questionnaire by direct measure and made a manager interview to collect all the information needed.

2.2.5.1 Electricity Audit

A detailed electricity auditing was performed to allocate the energy consumptions among the different on-farm activities. All the electrical appliances operating at farm level have been inventoried, reporting the power of each equipment and its usage time (hours per day, days per year) to obtain the annual electricity consumption. Additionally, comparison between the audit data and the electricity bills were performed to evaluate the conformity of the results.

The following on-farm electricity appliances have been detailed:

Lighting: type and power of lamps, as well the illumination time, were collected from barns and farm's facilities

Ventilation and **misting**: used to lower the air temperature in cowsheds and reduce cow's heat stress during the warm season. These equipment run only when the air temperature is above 20-25°C. Usage times were obtained from the farms manager interview.

Brushing: represent a mechanized brush to increase cow's comfort. The system is equipped with an electric motor that allows brush rotation as soon as the cow touches it. Operating time of cow brushing was set at 6 minutes/day per milking cow (DeVries, 2007).

Milking: the inputs due to the use of vacuum pump, milk pump and air compressor have been summed together to outline the total consumption of the milking operation. Additionally, the presence of a Variable Drive Speed system was taken into account when assessing the electrical consumption of the vacuum pump. The VDS device allows reducing the speed of the vacuum pump based on the vacuum level requirement during milking, thus diminishing of 40-50% the electrical consumption. Electrical consumptions of milk pump and air compressor were set as a 4% of the vacuum pump consumption.

Milk Cooling: electrical consumption for milk refrigeration shows high variations due to the presence or not of the pre-cooling system. The following procedure was used to assess the annual energy consumption (RE_{el}) of the milk tank:

$$RE_{el} = \frac{m \times c_p \times (t_1 - t_2)}{COP \times \eta \times 3.6} \qquad \left[\mathrm{kWh} \cdot \mathrm{y}^{-1}\right]$$

Where m (kg · year^{-1}) is the mass of milk, c_p (MJ kg^{-1} °C^{-1}) the milk specific heat value, t_1 and t_2 (°C) the initial and final milk temperatures, COP and η are respectively the coefficient of performance and the efficiency of the refrigeration system, 3.6 the conversion factor from MJ to kWh. The electricity required from milk cooling is reduced by the use of pre-coolers which lower the temperature of the milk entering the tank. The magnitude of this reduction depends on the temperature of the cooling media; a decrease of 16°C was set in t_1 value when the pre-cooler was available.

Water heating: both the milking system and the cooling tank need high volumes of water in order to clean and disinfect all the equipment used during the milking operation. Hot wash water (50÷65°C) and different water heating systems were found during the survey: 85% of the investigated farms were equipped with an electrical water heater and 90% with heat recovery systems which recuperate the heat given off by the condenser of the refrigeration circuit. The quantities of hot water produced vary based on the quantity of milk refrigerated.

The following equation was used to assess the energy (HW_{el}) related with hot water consumptions:

$$HW_{el} = \frac{m \times c_w \times (t_1 - t_2)}{\eta \times 3.6} \qquad \left[\mathrm{kWh} \cdot \mathrm{y}^{-1}\right]$$

where m (kg· year^{-1}) is the mass of wash water set at 12 kg per milking unit per milking (SCE, 2004) plus 150-200 L per day for the bulk tank, cp (MJ kg^{-1} °C^{-1}) the water specific heat value, t_1 and t_2 (°C) the initial and final water temperatures, η the efficiency of the electric boiler, 3.6 the conversion factor from MJ to kWh. Different Δt values were applied according to the presence/absence of HRS and the final water temperature required.

Water supply: energy consumptions have been split among **water pumping,** related only to cowshed and parlour water requirements, and **irrigation**, associated with the water distribution systems for crops.

Slurry management: energy consumptions are related to the equipment used for manure removal, storage and treatment.

Other: this section includes the operations with lower impact on dairy farm energy demands such as water treatment, electrical equipment for feed preparation and high pressure cleaning.

2.2.5.2 Diesel Audit

Regarding the estimation of on-farm fuel diesel consumptions, all processes have been grouped into four main areas:

Field operations, related to forage and animal feed production. The overall tasks carried out for crop cultivation were divided into four sections: slurry distribution; soil tillage; sowing; fertilization and treatment; harvesting and storage of the products.

Slurry management, included operations such as sewage management and treatment.

Feeding operations, related to feed preparation and distribution by means of mixer trailers.

Irrigation, included the overall operations carried out for irrigation and water pumping.

To calculate the tractor diesel consumptions due to each operation, the usage time of the machinery, the power of the tractor and the fuel consumption at partial load have been considered. Q was derived from the following equation (Grisso et al., 2004):

$$Q = (0.22\,X + 0.096)\cdot P_{pto} \quad (\mathrm{L\cdot h^{-1}})$$

which considers the rated power of the machinery (P_{pto}, *kW*) and the estimated ratio (*X, decimal*) of the rated power being used during field operations (Table 1).

A value of 0.30 was set for light operations till to a value of 0.65 for the heaviest ones.

A conversion factor of 0.835 $\mathrm{kg\cdot L^{-1}}$ was then used to transform the equation results in kg of diesel.

***Table 1**. estimated ratio of the machinery rated power*

Operations	**Rated Power**
Tillage	0.65
Harrowing	0.60
Rolling	0.30
Fertilization	0.35
Sawing	0.35
Treatments	0.30
Mowing	0.45
Raking	0.40
Baling	0.50
Picking	0.40
Transport	0.50
Harvesting	0.60
Slurry spreading	0.50
Feed preparation	0.40
Feed distribution	0.50
Slurry treatment	0.45

2.2.6 Impact Assessment

The Global Warming Potential (GWP) was used to evaluate the contribution of the carbon dioxide to the Greenhouse effect. As defined by IPCC 2006, the contribution of carbon dioxide to the climate change is equal to 1 for all time horizon available.

The carbon dioxide emission derived from energy uses was calculated multiplying the total consumptions to the following specific emission factors: 0.4103 kg CO_2-eq kWh^{-1} (ISPRA 2011), based on the energy mix used to produce electricity in Italy, 3.15 kg CO_2-eq kg^{-1}(ENEA 2010) to assess the emission from diesel combustion and 2.87 kg CO_2-eq kg^{-1} to calculate the emission from Liquefied Petroleum Gas (LPG).

On farm renewable energy production was monitored to assess the total production of each system ($kWh \cdot year^{-1}$), to determine the efficiency (kWh per kW_p^{-1}), to assess the reduction of carbon dioxide release into the environment and to evaluate the economic benefit through the renewable energy production

2.2.7 Renewable Energy

To assess the environmental benefit of renewable systems, a net emission factor of -0.3813 kg CO_2-eq$\cdot kWh^{-1}$ produced was considered, derived from the difference between the index of the Italian energy mix (0.4103 kg CO_2-eq$\cdot kWh^{-1}$) and the CO_2 emitted during the renewable system production (0.029 kg CO_2-eq$\cdot kWh^{-1}$, Raugei et al., 2009). Total production of renewable energy (and related benefit in terms of carbon dioxide avoided) has been distributed to the whole number of farms for each group. However, benefits derived from renewable systems have been also analysed separately among farms which adopted that technology.

2.2.8 Allocation

No allocation between milk and meat production were considered in this study, since the farms were specialized exclusively for milk production, therefore meat production were strictly related to the sold of surplus calves and culled cows.

2.2.9 Energy Efficiency, Sustainability and Economic Indicators

The overall data were structured in a data base created on Microsoft Excel. Preliminary analyses were performed in order to identify errors and complete the missing information. Further calculations were done to determine energy efficiency and sustainability indicators.

One method of comparing energy usage is through the use of Energy Utilization Indices (EUIs), which can provide a common basis to compare the amount of energy used to produce by a piece of equipment (Edens et al., 2003; Ludington-Johnson, 2003).

The EUIs considered to express electricity usage were: kWh·head^{-1}(referred to the herd dimension), kWh·Lactating Cow^{-1} (LC), kWh·hectare^{-1} (related to the cultivated land extent) and kWh·kg FPCM^{-1}. In regards to the usage of diesel the EUIs considered were: kg·head^{-1}, kg·LC^{-1}, kg·hectare^{-1} and kg per kg FPCM. The use of LPG where decomposed into EUIs in the same way: kg·head^{-1}, kg·LC^{-1}, kg·hectare^{-1}, kg per kg

FPCM. The production of renewable energy was also express with the EUIs methodology: kWh·head^{-1}, kWh·LC^{-1}, kWh·hectare^{-1} and kWh per kg FPCM.

The sustainability indicators also provide a method to compare GHG emission from different scenarios. As Sustainability Indicator (SI) the emission of carbon dioxide equivalent was expressed as: kg CO_2-eq·head^{-1}, kg CO_2-eq·LC^{-1}, kg CO_2-eq·hectare^{-1}, kg CO_2-eq per kg FPCM^{-1}.

An economic evaluation were also included in this study, the Economic Indicators (ECI) utilized to allow comparison between different scenarios were: euro·head^{-1}, euro·LC^{-1}, euro·hectare^{-1} and euro per kg FPCM. The costs per unit of each energy source used for the economic evaluation where derived from the energy receipt analysis. The average values calculated over 2011 prices were: 0.183 euro per kWh of electricity, 0.994 euro per kg of diesel fuel, 0.635 euro per kg of LPG, as well as electricity from renewable system was set as 0.183 euro per kWh.

2.3 Results & Discussion

The characteristics of the studied farms are summarized in table 2. The average herd dimension was 127 heads (range 6-1,320) where the group A had the highest average on herd size (177 heads), while the group C had the lowest average number of total dairy cows (82 heads). The yearly average of milk yield, expressed in tonnes of FPCM per lactating cow, accounted for 7.69 in a range of 1.16 and 15.0 tonnes. 44 hectares of land were the average of utilized area, where the highest cropped land belonged to the group A and the lowest land extension for group D.

Table 2 also define the sample examined with a family farm management where the average of total workers accounted for 3 units per farm and the family labour (2.2 units) represent 73% of the total workforces. The average distance from the dairy farms to the dairy plant co-operative was 31 km.

Table 2. *Data summary of the examined farms, average per farm on a yearly basis*

General Information	**A**	**B**	**C**	**D**	**A+B+C+D**	**SD**	**Min**	**Max**
Number of farms	83	88	70	44	285	-	-	-
Total heads (n)	177	124	82	112	127	142	6	1320
LC (n)	79	55	41	53	58	62	2	600
Milk yield (t FPCM/LC)	9.61	8.57	6.97	7.32	7.69	2.58	1.16	15.0
Total land (ha)	52	40	42	39	44	43	2	338
Total workers (n)	3.3	2.8	2.3	3.8	3.0	2.1	1.0	20
Family workers (n)	2.9	2.1	1.8	1.8	2.2	1.3	0.0	10
Distance from dairy fact. (km)	34.7	34.8	22.8	-	31	38	1	160

Great differences were observed in relation to the type of herd management. Group A and D showed 87% and 64% of the total farms with a barn confinement, while barn plus pasture management accounted for 59% and 69%, respectively in group B and C. Only the group A showed 5% of the farms with an extensive management (table 3).

The ratio between number of heads and land extent in hectares confirm that the group A held the most intensive management among the four groups. Likewise the group A showed the highest ratio between number of heads per worker, while the highest ratio between land extent and worker belonged to the group C.

***Table 3**. Data summary for type of management, breed and terrain position*

Farm Information	**A**	**B**	**C**	**D**
Barn %	87	41	31	64
Barn+Pasture %	8	59	69	36
Pasture %	5	0	0	0
Head/hectares	3.40	3.09	1.97	2.87
Head/worker	54	45	36	29
Hectares/worker	16	15	18	10
Holstein %	87	40	56	48
Brown %	7	15	4	0
Local %	0	1	0	2
Mix %	6	44	40	50
Valley %	83	16	24	23
Hill %	17	78	43	70
Mountain %	0	6	33	7
Leased land (% of total)	27	58	63	69
Irrigated land (% of total)	49	6	5	59

As shown in table 3, 87% and 56% of the farms in group A and C respectively, held cows of Holstein breed, while group B and D showed 44% and 50% of mixed breed. Terrain position showed that group A had 83% of the farms located in valley while group B and D were 78% and 70% of the farms located in hills. These results agree with the fact that farms with intensive management were located in valley and raise cows of Holstein breed (group A), while farms more extensive were mostly located in hills or mountain and the preferred breed raise were Brown and mix of breeds (group B, C and D).

The analysis carried out (table 4) for the machinery used for on-farm activities showed group A with the highest number of tractors and self-propelled machinery per farm (3.82 units). However, observing the ratio among the power expressed in kW, the number of total heads and hectares, the results showed that group B held the highest value (1.80 $kW \cdot head^{-1}$) while group C had the highest value for $kW \cdot hectare^{-1}$ (2.02).

Table 4. *Data for fleet equipment; averages per groups and ratios*

Fleet equipment	**A**	**B**	**C**	**D**
Tractors + Self-Propelled (n)	3.82	3.23	2.6	2.82
Total Power (kW)	269	223	166	168
kW/head	1.52	1.80	2.02	1.50
kW/hectare	5.18	5.56	3.99	4.31
Hectares/machinery	13.6	12.4	16.0	13.8

Table 5 shows results for the machinery utilized for feed preparation and distribution. These operations involve different type and categories of equipment, as tractors, mixer wagons, wheel loaders, etc. The results showed group A and B with the highest number of equipment used and total power (kW), while to the group C and D belonged the lower values. The results for the ratio between total power and total number of heads underlined that group C held the highest value (0.84 $kW \cdot head^{-1}$) even though it had a low number of machinery used and power installed. Table 5 analyze the fleet equipment of mixer wagons showing that 93% of the farms in group A utilized mixer wagon for feed preparation and distribution, while in groups B and D the values decrease to 38% and 43% respectively, due to the wide use of pasture. Several indices were listed in order to identify ratios among mixer wagon's power (kW), volume (m^3) and total number of heads. Results show range from 0.49 to 0.81 $kW \cdot head^{-1}$ for group B and C respectively, and 0.090 to 0.155 $m^3 \cdot head^{-1}$ per group A and C respectively.

Table 5. *Data for feed preparation and distribution machinery; averages per groups and ratios*

Groups	**A**	**B**	**C**	**D**
Tractors+Self-Prop. Machinery (n)	1.6	1.7	0.61	0.48
Total power (kW)	123	79	39	33
kW/head	0.85	0.92	0.84	0.34
Farms with Mixer Wagon %	93	38	54	43
Total power Mixer Wagon (kW)	89	82	66	72
kW/head	0.56	0.49	0.81	0.74
Mixer Wagon capacity (m^3)	14.9	15.3	11.86	13.11
m^3/head	0.090	0.094	0.140	0.155

The information of milking system and refrigeration are listed in table 6. The average number of milking units per installations was 10.7 for the group A and 5.9 for the group C. The ratio between lactating cow and milking units was 7.6 per group A and B, while 6.9 and 8.4 lactating cows per milking unit for the group C and D respectively. Several type of milking system were observed during the survey: the most common system was the herringbone type for A, B and C groups, while the group D held the higher percentage of milking cart and batch system. No rotary milking parlour was found, while group A, B and C held an Automatic Milking System (AMS).

The average power installed for vacuum pumps showed that group A held the highest value (4.56 kW) and group D the lower value (2.64 kW). The related ratio between Watt installed per lactating cow and milking times per lactating cow agree with the fact that farms with higher values of $\text{Watt}{\cdot}\text{LC}^{-1}$ spent higher time in milking operations.

The total power installed for the refrigeration tank ranged from 5.2 to 3.6 kW, while the related ratio between power on the refrigeration tank and milk produced showed that group A had the higher value in terms of power installed (5.2 kW) and at the same time the lower ratio between power and milk stored (6.89 $\text{Watt}{\cdot}\text{t FPCM}^{-1}$). Farms in group D showed the lowest values in terms of average power installed (3.6 kW), but higher values when the power were divided for the milk stored (9.32 $\text{Watt}{\cdot}\text{t FPCM}^{-1}$). These results underline the fact that farms more intensive held higher values of power installed at milking parlor level, but when divided per herd dimension or milk production, intensive farms held lower value per unit.

Table 6. *Milking parlour information. Data for type of milking system and refrigeration*

Milking Parlor	**A**	**B**	**C**	**D**
Milking units (n)	10.7	7.2	5.9	6.3
LC/milking unit	7.6	7.6	6.9	8.4
Cart %	8.4	23	31	45
Herringbone %	76	59	56	32
Tandem %	1.2	1.1	5.7	0.0
Batch %	13	1.1	4.3	25
Stanchion barn %	0.0	14	1.4	0.0
Rotary %	0.0	0.0	0.0	0.0
AMS %	1.2	1.1	1.4	0.0
Total power vacuum pump (kW)	4.56	3.77	2.67	2.64
Watt/LC	69	90	87	93
Milking time (minutes/LC)	2.61	3.46	3.09	5.25
Daily milk production (liters)	2,008	1,248	763	1,028
Refrigeration capacity (liters)	2,376	2,927	1,821	1,490
Total power ref. tank (kW)	5.2	4.6	3.9	3.6
Watt/t FPCM	6.89	9.80	13.7	9.32

Information in Table 7 showed the average presence of other equipment among the different groups. Fan and misting system were related to assure the temperature comfort of cows insides the cowshed. In group A, about 38.6% and 20.5% of the farms used fan and misting systems respectively. Lower percentages of presence for fan and misting systems were found in group B, C and D. As shown in table 7, the ratio between power installed and number of cows for group C had the highest values for both fan and misting system: 39 and 6.9 Watt per head respectively.

The presence of electrical brush in cowshed was listed as well. Low values of presence of 7.95%, 8.57% and 11.4% were observed respectively in groups B, C and D, while group A showed the highest diffusion (32.5%). However the ratio between Watt installed for mechanical brush and lactating cows showed the lowest value of 3.3 Watt·LC^{-1} in farms of group A.

Installations for water treatment were present in 51.8% and 21.4% of farms in group A and C respectively, while no equipment where found in farms of group D.

Table 7. *Other equipment information. Data for fan and misting system, brushing and water treatment.*

Other Equipment	**A**	**B**	**C**	**D**
Fan system %	38.6	22.7	12.9	11.4
Total power Watt	3,935	2,776	6,087	11,360
Watt/head	17	13	39	21
Misting system %	20.5	2.27	4.29	4.55
Total power Watt	992	1,600	878	3,000
Watt/head	5.0	4.0	6.9	3.1
Brushing %	32.5	7.95	8.57	11.4
Total power Watt	317	743	1,119	2,703
Watt/LC	3.3	4.8	16	15
Water Treatment %	51.8	4.55	21.4	0.0
Total power Watt	408	443	293	0.0
Watt/head	2.4	8.2	3.3	0.0

The operations related to the removal and treatment of slurry are listed in table 8. Results show that the removal of slurry occurred for 88%, 86% and 63% only through the use of scrapers moved by tractors in group B, C and D respectively, while group A had 66% of slurry removal by means of the combination between tractors and hydraulic scrapers. Flushing system technology was found only in farms belonging to group A (4.8%).

Table 8. *Slurry removal and treatment*

Slurry Removal and Treatment	**A**	**B**	**C**	**D**
Only Tractors %	29	63	88	86
Tractors + Scrapers %	66	38	12	14
Flushing %	4.8	0.0	0.0	0.0

The geographical position of the sample analyzed lead to adopt an irrigation system to supply water during the dry season. Table 9 shows that in group A and D the presence of irrigation systems was 82% and 75% respectively. Water pumping and distribution occurred in different ways among farms; in particular, in group A 80.9% of water was supply from the net system, where no energy consumption was needed. Groups B and C privileged the use of diesel pumps, with percentages of 69.2 and 53.8 respectively, while 46.7% of the farms in group D used electrical pumps to supply irrigation water for crop production.

Table 9. *Irrigation systems*

Irrigation	**A**	**B**	**C**	**D**
Presence %	82	15	19	75
Hectares irrigated	16.6	14.5	7.23	21.7
Net system %	80.9	15.4	7.69	36.7
Diesel pumping %	10.3	69.2	53.8	16.7
Electricity pumping %	8.82	15.4	38.5	46.7

Energy saving devices allow reducing electricity consumption in several farm operations. As shown in table 10 about 30% of farms in group A used a Variable Drive Speed (VDS), while very low percentages were found in groups B, C and D (3.41%, 1.43% and 4.55% respectively). Milk pre-coolers (21.7%) and heat recovery systems (60.2%) were mostly found in group A while groups B, C and D held lower percentage of presence of saving devices.

Table 10. *Energy saving devices information*

Saving Devices	**A**	**B**	**C**	**D**
Variable Drive Speed (VDS) %	30.1	3.41	1.43	4.55
Milk Pre-cooler %	21.7	2.27	7.14	6.82
Heat Recovering System %	60.2	19.3	4.29	6.82

The percentage of farms with energy production systems are listed in table 11. 15% and 14% of photovoltaic installation occurred in group A and B respectively, while group C held the highest value of solar panel systems for the production of hot water.

Only group B and D had available an anaerobic digestion system (1.1% and 4.5% respectively), while group B held 1.1% of farms with eolic system.

Table 11. *Renewable energy systems.*

Renewable Systems	**A**		**B**		**C**		**D**	
	%	**N**	**%**	**N**	**%**	**N**	**%**	**N**
Photovoltaic System	15	13	14	12	5.7	4	6.8	3
Solar Panels	1.2	1	4.5	4	20	14	0.0	0
Anaerobic Digestion	0	0	1.1	1	0	0	4.5	2
Eolic	0	0	1.1	1	0	0	0	0

Annual electricity bills were analyzed to compare results derived from the energy audit and the electricity supply. The information was available for more than 90% for farms of: group A, B and D, while only the 15.7% of the farms of group C had the electricity purchase records available. When electricity receipts were analyzed, a high number of other uses, not related with the production of milk, ensued or were not specified. Group B and C had the highest percentage for receipts which include other uses, 86% and 90% respectively. Group A and D showed the highest results for receipts which included only on farm activities, 53% and 32% respectively. The results listed in table 12 underline the problem of conducting an energy survey in dairy farms, accounting the requirement of energy sources only from energy receipts information. Energy purchased records can be used to have a general information about energy consumption but it must be consider very carefully, since those not include energy consumption by contractors and other uses not related with milk production.

Table 12. *Electricity receipts information*

Electricity receipts	**A**	**B**	**C**	**D**
Percentage of available receipts	98.8	89.8	15.7	95.5
Receipts which include only on-farm activities %	53	15	5.7	32
Receipts which include other uses %	17	86	90	68
Receipts which other uses are not specified %	30	0.0	4.3	0.0

2.3.1 Group A

2.3.1.1 Energy Intensity

The average annual energy consumed by farms in group A accounted for 17,424 kg of diesel fuel, 31,636 kWh of electricity and 60 kg of LPG, while the production of electricity from renewable source was 12,525 kWh. Diesel consumption accounted for 222 kg·LC^{-1}, 354 kg per cultivated hectare and 0.027 kg per kg of FPCM. For the electricity, the EUI were 434 kWh per lactating cow and 0.058 kWh per kg FPCM. The EUI related with LPG consumption accounted for 1.2 kg per lactating cow and 2.4e^{-4} per kg of FPCM per year. The production of electricity through a renewable source allowed producing the following EUI: 106 kWh per lactating cow and 0.011 kWh per kg of milk sold (table 13).

Table 13. *Energy data summary for group A, averages per farm on a yearly basis (N=83)*

	Average	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg)	17,424 (±11,577)	99 (±21)	222 (±73)	354 (±150)	0.027 (±0.013)
Electricity (kWh)	31,636 (±21,800)	193 (±78)	434 (±177)	718 (±415)	0.058 (±0.051)
LPG (kg)	60 (±122)	0.5 (±1.2)	1.2 (±2.9)	2.0 (±5.9)	2.4e^{-4} (±8.4e^{-4})
Renewable (kWh)	12,525 (±47,353)	45 (±151)	106 (±360)	209 (±759)	0.011 (±0.039)

The analysis of electricity usage showed that milking and milk refrigeration were the most demanding operations in all the dairy farms examined, requiring both 23% of the annual electricity consumption (figure 2). The other processes that affect significantly the electricity requirements were: water pumping (13%), water heating (12%) and slurry management (8%), followed by irrigation and fan-misting (6% each), lighting (5%), brushing and other (2% each). The whole operations carried out at the milking parlour were responsible of 58% of the total electricity consumption.

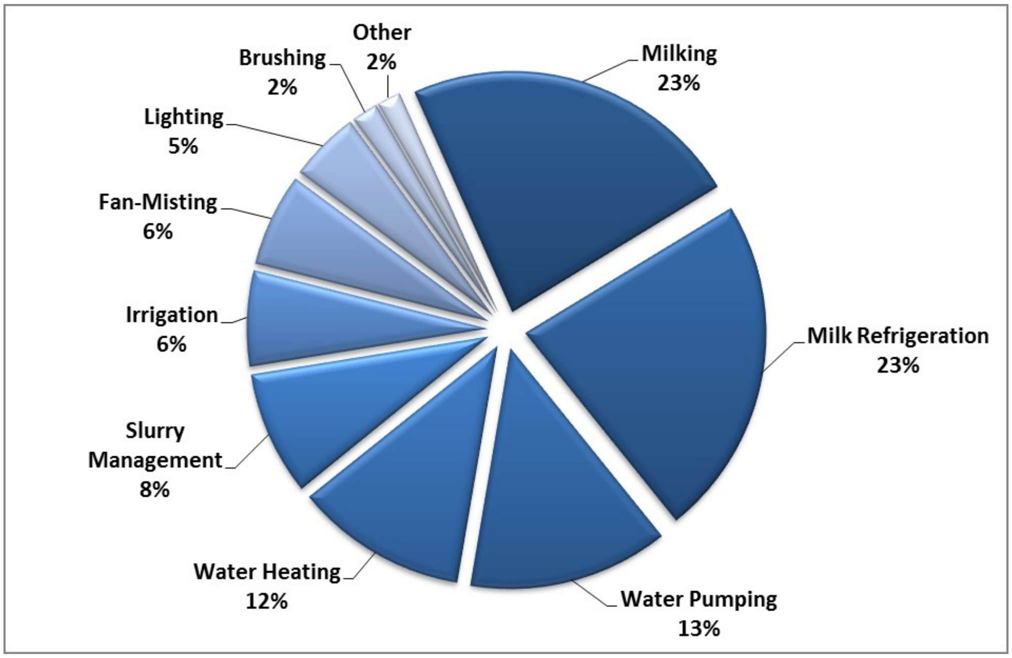


Figure 2. *Allocation of electricity usage among on-farm operations*

Analysing the diesel consumption associated both to farm and field processes (figure 3), feed preparation and distribution represent 47% of the total fuel utilization, field operations related to crop cultivation accounted for 43% and the slurry management for 9%, while irrigation represent 1% of the total diesel consumption. The total diesel consumed for land operations was allocated into 4 phases where each consumption accounted for: 15% for sewage distribution on the soil, 28% for soil preparation, 8% for sowing and fertilization, while harvesting and feed transportation into the farms were the most demanding operations, requiring 49% of total diesel used per field operations.

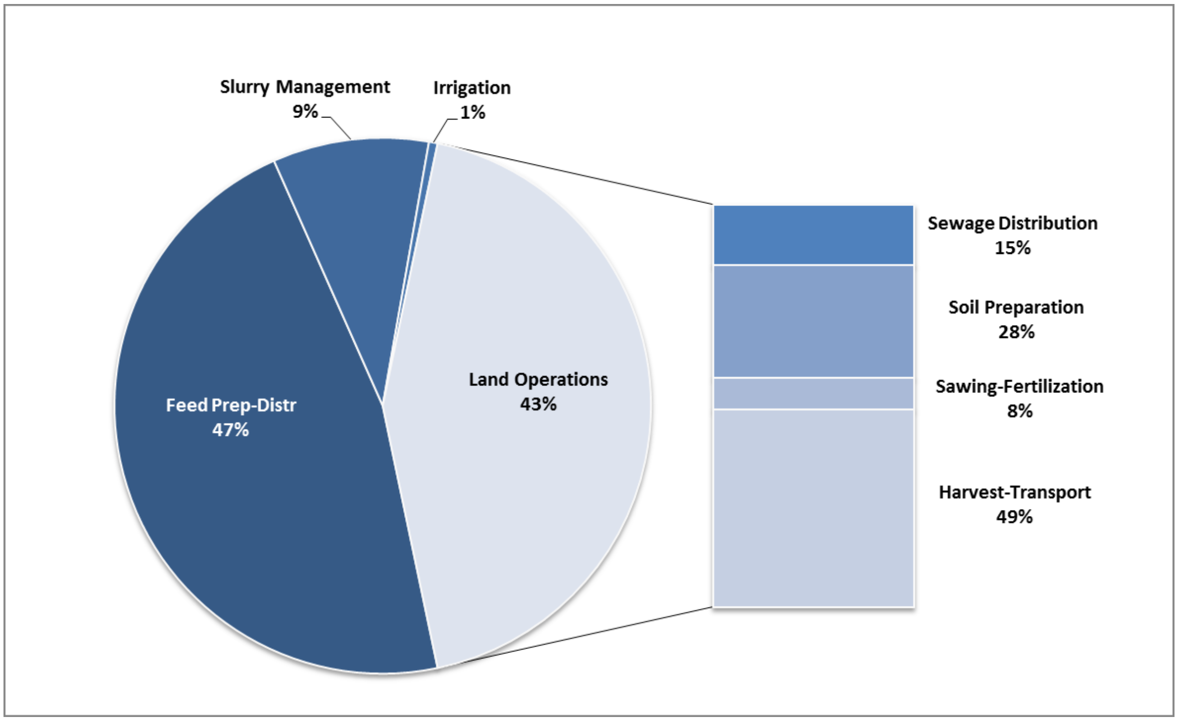


Figure 3. *Allocation of diesel usage among on-farm operations*

Crop selection (average percentage of total cultivated hectares) of the investigated farms for group A was based on:

- 36% corn silage -*Zea Mays L.*, (range 3-52 ha/farm);

- 56% grass hay and silage - *Lolium spp., Triticosecale Wittm. ex A. Camus., Avena sativa L., Hordeum Vulgare L.,* (range of 2-69 ha/farm);
- 5% alfalfa forage - *Medicago Sativa L.*, (range 2-16 ha/farm);
- 2% cereal for grains - *Avena sativa L., Hordeum Vulgare L., Triticum spp.*, (range from 2-34 ha/farm).

As showed in figure 4 corn silage and hay represent an important quote of feed production (70% of the cultivated land) at farm level, while alfalfa and cereal grains production accounted respectively 5% and 2% of the total.

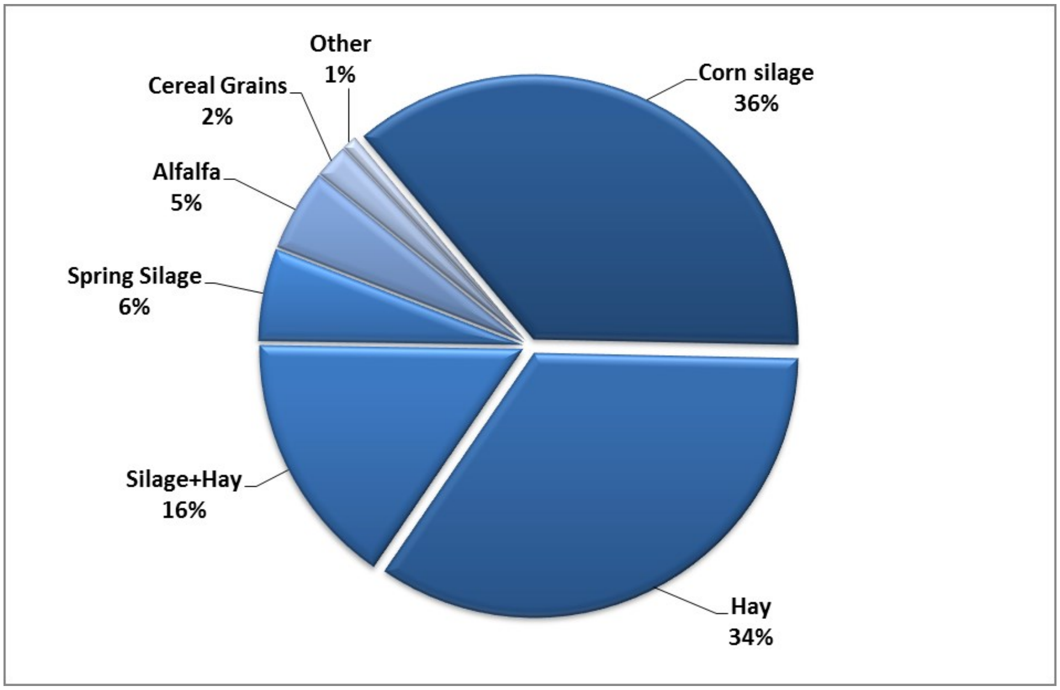


Figure 4. *Average crops selection for group A (average % of total cultivated land)*

Further analyses about diesel fuel combustion for each crop cultivated were assessed. Crops which required more mechanized operations were responsible of higher consumption of fuel: 106 (±51) kg of diesel·hectare^{-1} for spring silage; 111 (±44) kg of diesel·hectare^{-1} for grass hay; 137 (±40) kg of fuel diesel·hectare^{-1} to harvest cereal grains; 166 (±76) kg of diesel·hectare^{-1} for alfalfa products and finally, corn silage which required 170 (±44) kg of diesel·hectare^{-1}.

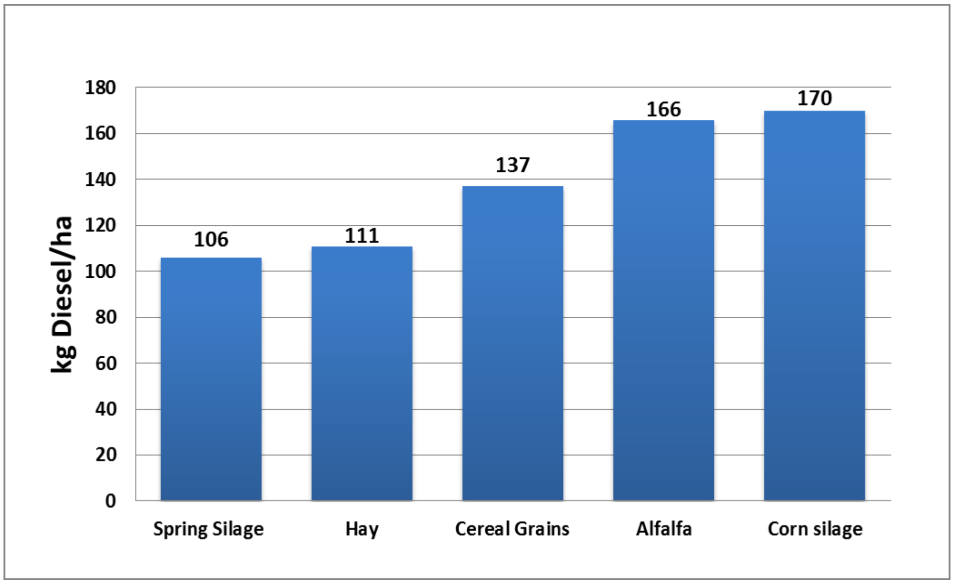


Figure 5. *Diesel fuel consumption per cultivated crop*

When diesel consumptions per hectare related to each crop were referred to the yield, expressed as tonnes of Dry Matter (DM) produced, the analysis showed reversal results. Figure 6 reports diesel fuel consumption per tonne of product harvested: while corn silage and alfalfa were the crops with the highest fuel requirement per hectare, showed the lowest quantities of diesel consumption per tonne of product harvested (11 and 17 kg diesel per tonne of DM respectively). Cereal grain production showed the highest requirement of fuel per product harvested (70 kg diesel per t of DM) since the yield of cereal grain was generally low. Hay crops and spring silage showed consumptions of 24 and 29 kg of diesel per tonne of DM produced, respectively.

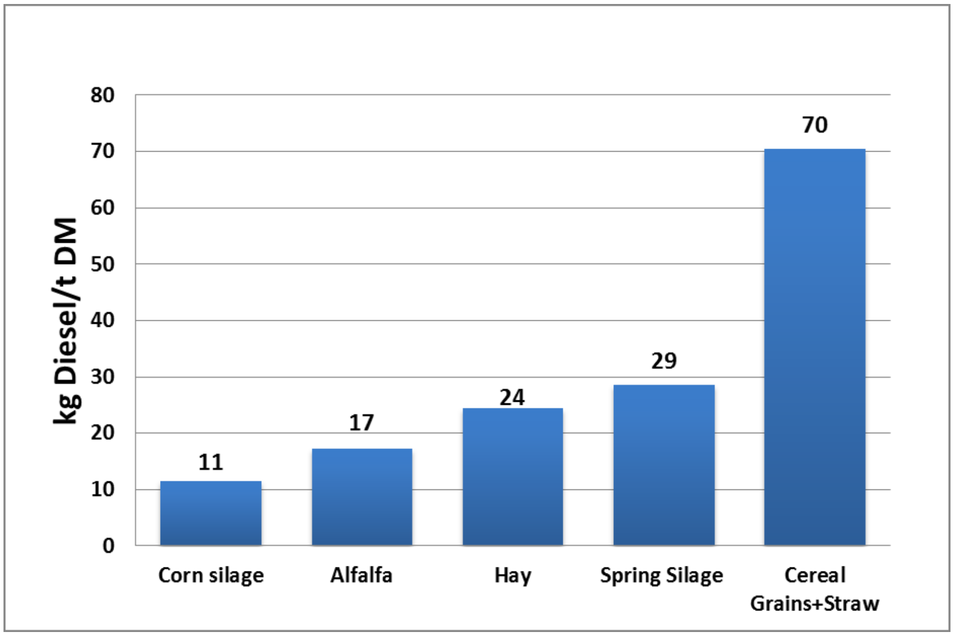


***Figure 6**. Diesel consumption per unit of crop harvested*

2.3.1.2 Carbon Dioxide Emission

The annual carbon dioxide emissions associated with the electricity inputs were 178 kg CO_2-eq·LC^{-1} and 0.024 kg CO_2-eq per kg of FPCM (table 14).

The annual emissions from diesel consumption were 700 kg CO_2-eq per lactating cow and 0.084 kg CO_2-eq per kg of FPCM per year. When referred to the cultivated land, this index was 1,115 kg CO_2-eq ·ha^{-1} per year. The emissions related to the usage of LPG were very low: 4 kg CO_2-eq per lactating cow and 0.001 kg CO_2-eq per kg of FPCM.

Table 14. *Emission data summary for group A, averages per farm on a yearly basis (N=83)*

Carbon dioxide emission	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg CO_2-eq)	54,886 (±36,467)	311 (±97)	700 (±230)	1,115 (±471)	0.084 (±0.041)
Electricity (kg CO_2-eq)	12,980 (±8,945)	79 (±32)	178 (±73)	295 (±170)	0.024 (±0.021)
LPG (kg CO_2-eq)	164 (±344)	1.5 (±3.5)	3.6 (±8.3)	5.6 (±17.2)	0.001 (±0.002)
Total emissions (kg CO_2-eq)	**68,012** (±42,876)	**392** (±105)	**882** (±245)	**1,416** (±572)	**0.111** (±0.059)
Renewable energy (kg CO_2-eq)	-4,776 (±18,056)	-18 (±58)	-42 (±137)	-82 (±289)	-0.004 (±0.015)
Total emissions (kg CO_2-eq)	**63,237** (±42,490)	**374** (±125)	**840** (±288)	**1,334** (±592)	**0.107** (±0.062)

The farm average emission of carbon dioxide equivalent, due to all energy usages, was 68 t CO_2-eq per year that corresponded to 882 kg CO_2-eq per lactating cow and 0.111 kg CO_2-eq per kg of FPCM. Considering the emission avoided through the production of renewable energy (-4,776 kg CO_2-eq), the final emissions were 63 t CO_2-eq per year, which correspond to 840 kg CO_2-eq per lactating cow and 0.107 kg CO_2-eq per kg of milk sold. The avoided emissions accounted for 7% of reduction for total farms emission and 4% of CO_2-eq emission avoided per kg of FPCM per year.

Figure 7 illustrates the total carbon dioxide emission (diesel plus electricity) attributed to each farm operations, where diesel consumptions represents the most pollutant sources of the farms. Feed management showed the 38% of the total carbon dioxide emissions, followed by land operations (35%) and slurry management (9%), while electricity usage accounted for a lower part of the total carbon dioxide emissions. Milking and milk refrigeration represent each 4% of CO_2 emissions, while water heating and water pumping accounted for 2% and 3%, respectively.

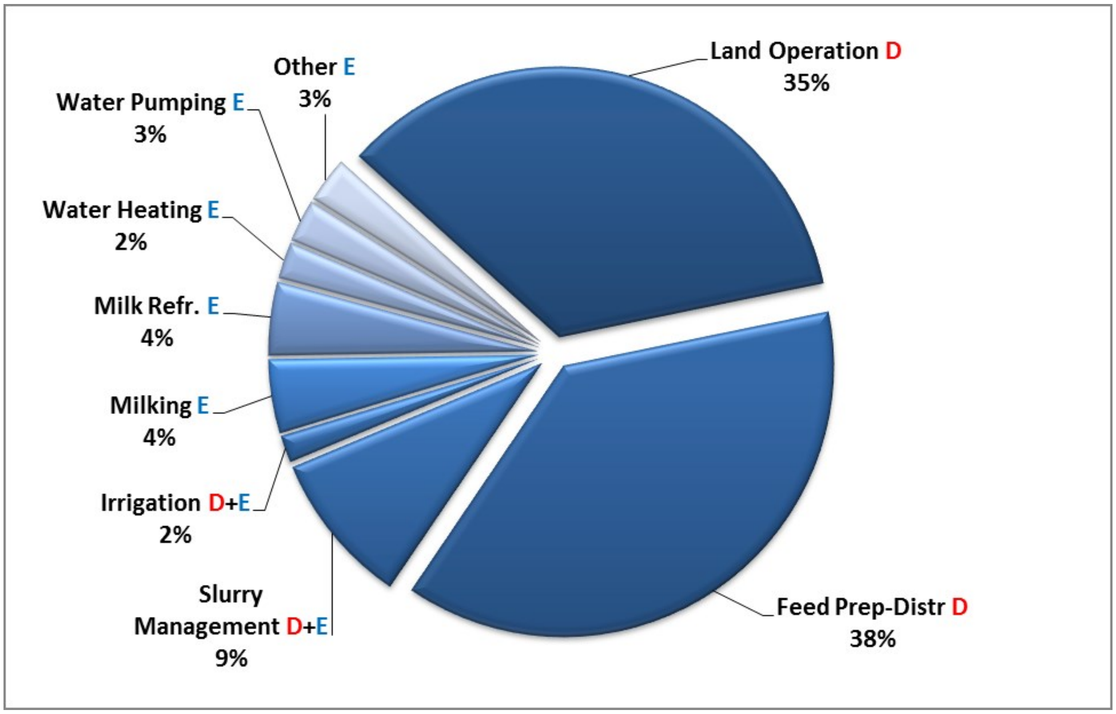


Figure 7. *Allocation of GHG emissions from electricity (E) and Diesel (D) to farm activities*

As illustrated in table 15 the emissions of CO_2-eq were classified on herd size. Four categories, from less than 50 heads to over 200 heads, were set to identify emissions trend.

Table 15. *Herd size classes for group A, averages per farm on a yearly basis (N=83)*

Herd size class	**<50**	**50-100**	**100-200**	**>200**
Farms (n)	7	11	37	28
Heads (n)	35	76	139	302
Lactating cows (n)	14	35	63	132
Milk production (t)	59.9	260	607	1,329
Milk yield (t/LC)	4.02	7.27	9.59	10.1
Land (ha)	14	36	40	81
LPG (kg)	52 (±103)	101 (±117)	41 (±106)	73 (±141)
LPG emission (kg CO_2eq)	149 (±296)	291 (±337)	116 (±304)	180 (±405)
Diesel (kg)	1,924 (±1,587)	10,253 (±2,422)	13,262 (±4,047)	29,616 (±11,015)
Diesel emission (kg CO_2eq)	6,061 (±4,998)	32,297 (±7,629)	41,776 (±12,749)	93,292 (±34,696)
Electricity (kWh)*	8,785 (±4,240)	16,653 (±7,712)	25,766 (±6,772)	50,992 (±26,337)
Electricity emission (kg CO_2eq)	3,605 (±1,740)	6,833 (±3,164)	10,572 (±2,779)	20,922 (±10.806)
Total kg CO_2eq/100 kg milk	**18.40** (±8.97)	**17.52** (±7.43)	**9.018** (±2.56)	**8.851** (±2.15)

**On-farm electricity from renewable sources was not included*

The highest number of farms, 37, was located in the “100-200” group, while 7 farms belonged to the group “less than 50”. The analysis showed that larger farms were associated with higher yield of milk (tonnes·LC^{-1} per year). Further analysis demonstrated that the CO_2 emissions were higher in farms placed into small herd size class: 18.40 kg CO_2-eq per 100 kg FPCM in farms in class with less than 50 heads; 17.52 kg CO_2-eq per 100 kg FPCM in farms with a herd dimension between 50 and 100 heads, the 9.018 kg CO_2-eq per 100 kg FPCM per farms in class with herd size between 100 and 200 heads and 8.851 kg CO_2-eq per 100 kg FPCM per farms in class with herd dimension over than 200 heads. Larger farms were able to produce milk about 52% lower carbon dioxide emission than small farms (group “>200” against group “<50”).

Table 16 shows the emissions of CO_2-eq based on milk yield class. Four categories, less than 5 tonnes of milk to over 10 tonnes of milk sold, were set to identify emissions trend.

The highest number of farms, 36, was located in the class ≥ 10 t of FPCM” group, followed by farms with milk yield 8 to 10 tonnes of milk sold (28), while 7 farms belonged to the group “less than 5 t of FPCM”. The results showed that farms with higher milk yields (milk tonnes·LC^{-1}) were associated with higher herd dimension.

Table 16. *Milk yields class for group A, averages per farm on a yearly basis (N=83)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	7	12	28	36
Heads (n)	49	115	186	215
Lactating cows (n)	23	50	85	94
Milk production (t)	68.6	334	774	1,014
Milk yield (t/LC)	3.12	6.44	8.99	10.8
Land (ha)	26	37	56	56
LPG (kg)	52 (±103)	101 (±148)	45 (±102)	53 (±127)
LPG emission (kg CO_2eq)	149 (±297)	290 (±425)	129(±294)	151 (±363)
Diesel (kg)	4,118 (±3,578)	11,091 (±7,203)	19,026 (±11,722)	20,876 (±11,226)
Diesel emission (kg CO_2eq)	12,971 (±11,270)	34,937 (±22,689)	59,933 (±36,925)	65,761 (±35,361)
Electricity (kWh)*	9,540 (±4,543)	33,222 (±42,880)	30,087 (±13,745)	36,508 (±16,250)
Electricity emission (kg CO_2eq)	3914 (±1,864)	13631 (±17,594)	12,345 (±5,640)	14979 (±6,667)
Total kg CO_2eq/100 kg milk	**24.36** (±8.80)	**15.40** (±5.37)	**9.76** (±2.62)	**8.21** (±1.90)

**On-farm electricity from renewable sources was not included*

Further analysis demonstrated that the emissions of carbon dioxide equivalent were higher in farms belonged to lower milk yield class, in particular: 24.36 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms in class with yield lower than 5 tonnes; 15.40 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms belonged in class with FPCM yield between 5 and 8 tonnes; 9.76 kg

CO_2-eq·100 kg FPCM^{-1} per farms in class with milk yield between 8 and 10 tonnes and 8.21 kg CO_2-eq·100 kg FPCM^{-1} per farms in class with milk yield over than 10 tonnes. Farms with higher level of milk production were able to produce milk emitting about 3 times less carbon dioxide than farms with lower milk yield (group ">10" vs group "<5").

2.3.1.3 Economic Aspects

The usage of energy represents an important part of the total costs for milk production.

Table 17. *Costs of energy usage for group A, averages per farm on a yearly basis (N=83)*

	Average	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (Euro)	17,314 (±11,507)	98 (±21)	221 (±73)	352 (±149)	2.66 (±1.29)
Electricity (Euro)	5,789 (±3,989)	35 (±14)	79 (±32)	131 (±76)	1.06 (±0.93)
LPG (Euro)	38 (±77)	0.3 (±0.76)	0.8 (±1.8)	1.2 (±3.7)	0.02 (±0.05)
Total Costs (Euro)	**23,142**	**134**	**301**	**484**	**3.74**
Renewable energy (Euro)	2,488 (±8,665)	8.7 (±27)	20 (±66)	39 (±139)	0.22 (±0.71)
Total Costs (Euro)	**20,653** (±14,840)	**125** (±46)	**281** (±107)	**445** (±217)	**3.52** (±2.22)

Table 17 shows the costs related to the use of different energy sources: diesel fuel accounts as the highest part of the costs related to the energy purchased, with an average of 17,314 euro per farm, which corresponded to 221 euro per lactating cow and 2.66 euro per 100 kg of milk sold. Electricity supply was responsible of 5,789 euro as average per farm, 79 euro per lactating cow and 1.06 euro per 100 kg FPCM when reported to the milk production.

The purchase of LPG represented the lowest part of the total energy cost, with 38 euro per farm, corresponding to 0.8 euro per lactating cow and 0.02 euro per 100 kg of milk produced. Expressing the energy costs in percentage, diesel fuel represents 74.8% of the total cost, followed by electricity 25% and LPG, which accounted only for 0.16%.

On-farm energy productions from renewable sources were considered into the analysis, showing an average profit, in terms of avoided costs, of 2,488 euro per farm, which correspond to 20 euro per lactating cow and 0.22 euro per 100 kg of milk sold. Thanks to the self-production of energy through a renewable system, the average total costs, of the whole group, were reduced to 20,653 euro (10.8% of reduction), which represent a decreased of 5.9% of costs per 100 kg of milk sold

Further analysis highlighted the benefits derived to the use of saving devices in terms of energy and money saved. As shown in table 18 the use of Variable Drive Speed (VDS) connected to the vacuum pump, allowed to save 7,259 kWh (average in farms having VDS) which corresponded an economy of 1,307euro per farm a year and a reduction of 0.11 euro per 100 kg of FPCM sold. The use of Milk Pre-cooler (MP) produced an average economy of 7,556 euro, which corresponds to 0.14 euro per 100 kg of milk produced, while the Heat Recovery System (HRS) saved 5,803 euro per farm and 0.11 euro per 100 kg of FPCM sold. Saving devices were able not only to save money, but at the same time, to avoid carbon dioxide emission into the environment.

Table 18. *Economic and environmental results through the use of energy saving devices (ESD) for group A, averages per farm having ESD on a yearly basis.*

	Number of Farms	Saved kWh per Farm/y	kWh/100 kg FPCM	kg CO2-eq/Farm	Euro Total/Farm	Euro/100 Kg FPCM	Power kWp
Variable Drive Speed	25	7,259	0.61	2,978	1,307	0.11	-
Milk Pre-cooler	18	7,556	0.76	3,100	1,360	0.14	-
Heat Recovery	50	5,803	0.60	2,381	1,045	0.11	-
Photovoltaic	13	92,909	0.84	38,121	16,724	1.5	111 (49-250)
Solar panel	1	4,888	0.17	2,006	880	0.31	-
Anaerobic Digestion	0	0	0	0	0	0	-
Eolic	0	0	0	0	0	0	-

Table 19 showed that 43.4% of farms were located into the group which had a milk yield higher than 10 tonnes of FPCM per year, while 33.7% belonged to the group from 8 to 10 tonnes of milk per year; only the 23% of farms were situated in group which held less than 8 tonnes of FPCM per year. The results showed also a correlation between milk yields and herd size, in fact, the number of heads increase when milk yields increase (expressed as tonnes of milk per lactating cow a year).

Table 19. *Costs of energy usage for milk yields class, averages per farm on a yearly basis (N=83)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	7	12	28	36
Heads (n)	49	115	186	215
Lactating cows (n)	23	50	85	94
Milk production (t)	68.6	334	774	1,014
Milk yield (t/LC)	3.12	6.44	8.99	10.8
Land (ha)	26	37	56	56
LPG (kg)	52	101	45	53
LPG cost (Euro)	33	64	29	33
Diesel (kg)	4,118	11,091	19,026	20,876
Diesel cost (Euro)	4,241	11,424	19,597	21,503
Electricity (kWh) *	9,540	33,222	30,087	36,508
Electricity cost (Euro)	1,717	5,980	5,416	6,572
Total costs (Euro/100 kg milk)	**8.50** (±2.96)	**5.40** (±1.75)	**3.30** (±0.84)	**2.79** (±0.62)

**On-farm electricity production from renewable sources was not included*

The trend of costs due to energy usage shows evident decrement per unit of milk sold, when the milk yield increase. In particular, costs decreased of: 40% in farms placed in group from 5 to 8 tonnes of milk yield (5.24 euro) instead farms which held milk yields lower than 5 tonnes (8.73 euro); 38% in farms located in group from 8 to 10 tonnes of milk yield (3.24 euro) instead farms which had milk yields between 5 and 8 tonnes (5.24 euro); 14.5% in farms sited in group with milk yield higher than 10 tonnes (2.24 euro) instead farms which had milk yields from 8 to 10 tonnes (3.24 euro). When the extremity values (8.73 and 2.77 euro) were compared, the analysis showed a reduction of 3 times less costs going from 5 to over 10 tonnes of milk yield.

The consumption of energy sources lead to generate environmental impacts through emission of greenhouse gas, which were proportional related to the quantity of fossil products used, and at the same time to the costs supported from farms.

Further analysis demonstrated the relationship between carbon dioxide emissions and costs; in particular for the group A, each kilogram of CO_2-eq emitted was associated to an expenditure of 0.34 euro per kg CO_2-eq (SD ±0.013).

2.3.2 Group B

2.3.2.1 Energy Intensity

The average diesel fuel consumed, on a yearly basis, by farms of group B amounted to 17,321 kg, 23,051 kWh of electricity and 109 kg of LPG, while electricity production from renewable source was 17,761 kWh. Diesel consumption amounted to 209 $kg{\cdot}LC^{-1}$, 349 kg per cultivated hectare and 0.028 kg per kg of milk (FPCM). Electricity EUI was 484 kWh per lactating cow and 0.067 $kWh{\cdot}kg\ FPCM^{-1}$. The LPG consumptions were 2.2 kg per lactating cow and $2.4e^{-4}$ per kg of FPCM. The renewable electricity production allowed producing the following energy utilization indices: 147 kWh per lactating cow and 0.022 kWh per kg of milk sold (table 20).

Table 20*. Energy data summary for group B, averages per farm on a yearly basis (N=88)*

	Average	Head	LC	Hectare	kg FPCM
Diesel (kg)	12,321 (±17,529)	93 (±48)	209 (±117)	349 (±217)	0.028 (±0.018)
Electricity (kWh)	23,051 (±24,967)	214 (±84)	484 (±199)	899 (±632)	0.067 (±0.035)
LPG (kg)	109 (±315)	1.0 (±2.5)	2.2 (±5.8)	3.4 (±9.5)	$2.4e^{-4}$ ($\pm 7.9e^{-4}$)
Renewable elect. (kWh)	17,761 (±116,136)	66 (±214)	147 (±496)	263 (±975)	0.022 (±0.088)

The electricity uses showed that milking and milk refrigeration were the most requiring operations, demanding respectively 29% and 23% of the total electricity consumed per year (figure 8). The other activities that affect considerably the electricity requirements were: water heating (18%) and water pumping (11%), followed by slurry management and lighting (5% each), fan-misting (3%), brushing (2%) and irrigation (1%). The allocation analysis showed that the operations carried out at the milking parlour were responsible of 70% of the total electricity consumption.

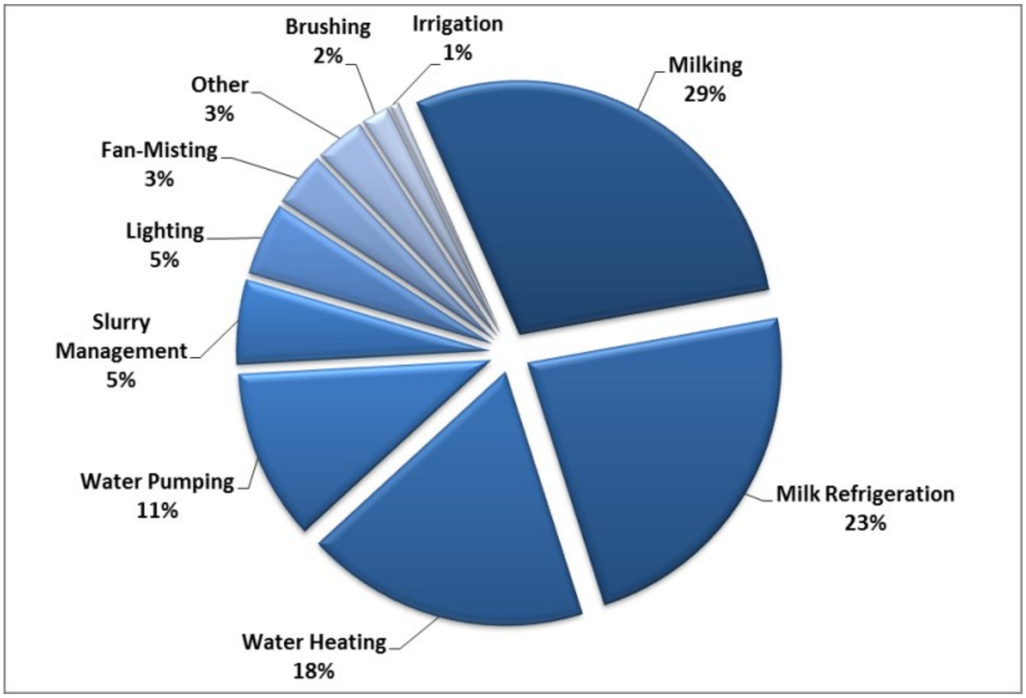


***Figure 8**. Allocation of electricity usage among on-farm operations*

The consumption analysis of diesel fuel related to farm and field activities showed that (figure 9): field operations associated to crop cultivation amounted for 40%, feeding preparation and distribution represent 35% of the total fuel utilization, and the sewage management 17%, while irrigation accounted for 7% of the total diesel combustion. The overall diesel consumed by land activities was allocated into 4 phases, where: 12% of fuel was used for sewage distribution on the soil, 41% for soil preparation, 9% for sowing and fertilization, while harvesting and products transport to the farms required 39% of total diesel used per field operations.

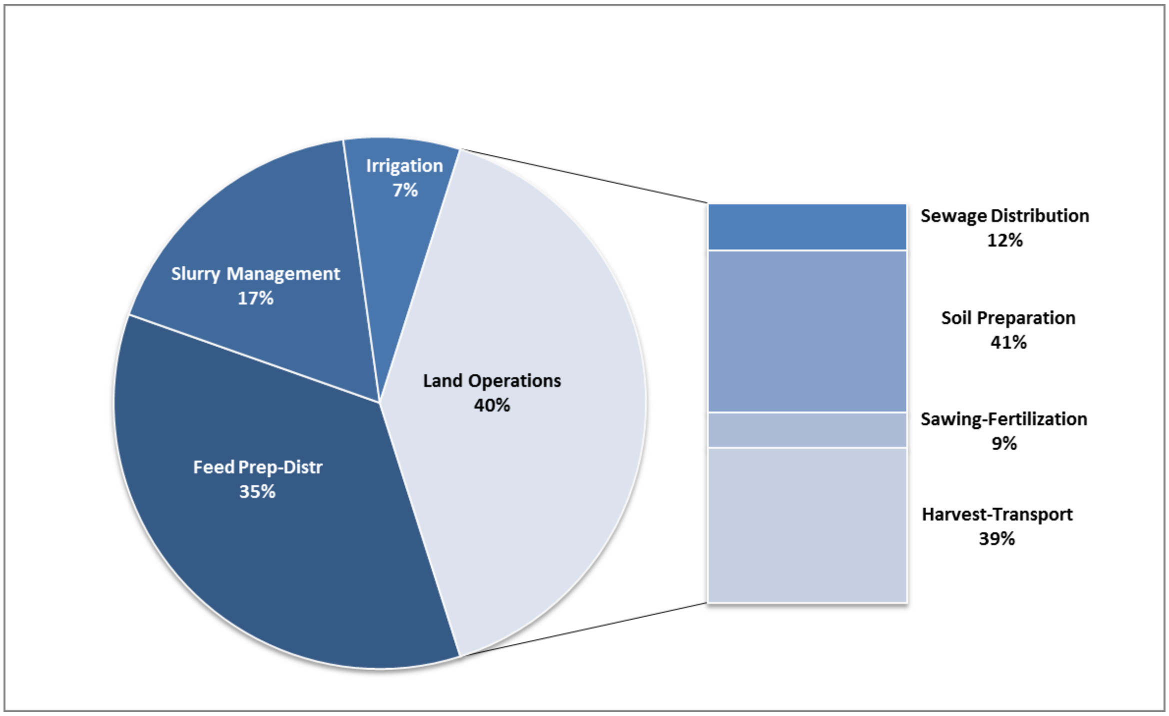


Figure 9. *Allocation of diesel usage among on-farm operations*

Crop choice of the examined farms for group B (expressed as average percentage of total cultivated hectares) was based on:

- 62% by hay forage and silage (*Lolium spp., Triticosecale Wittm. ex A. Camus., Avena sativa L., Hordeum Vulgare L., (*range of 1-88 ha/farm);
- 17% for cereal for grains (*Avena sativa L., Hordeum Vulgare L., Triticum spp.*, (range 2-34 ha/farm);
- 3% by Alfalfa forage (*Medicago Sativa L.*, (range 3-36 ha/farm);
- 2% by corn silage (*Zea Mays L*., (range 3-36 ha/farm).

Figure 10 shows that grass forage for hay and hay silage represent the most abundant on-farm quote of feed production, while corn silage production accounted only for 2% of the total.

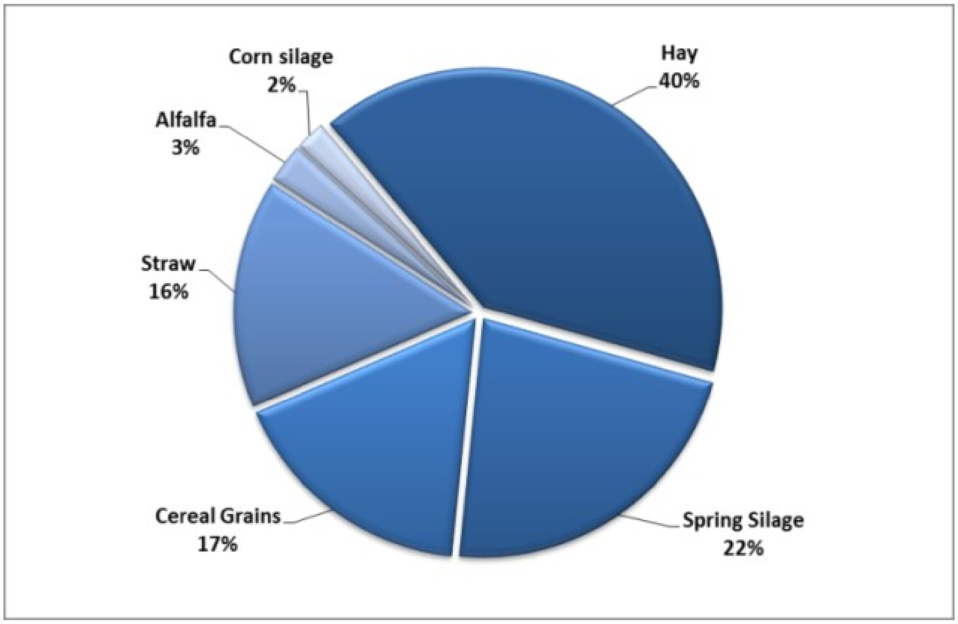


Figure 10. *Average crops selection for group B*

Figure 11 shows diesel fuel consumed for each crop cultivated. Crops that need more mechanized operations were responsible of higher fuel consumption: 118 (±35) kg of diesel·ha^{-1} for grass hay; 127 (±29) kg of fuel diesel·ha^{-1}to harvest cereal grains and straw; 154 (±84) kg of diesel·ha^{-1}for spring silage; 162 (±56) kg of diesel·ha^{-1}for corn silage and 188 (±68) kg of diesel·ha^{-1}for alfalfa products.

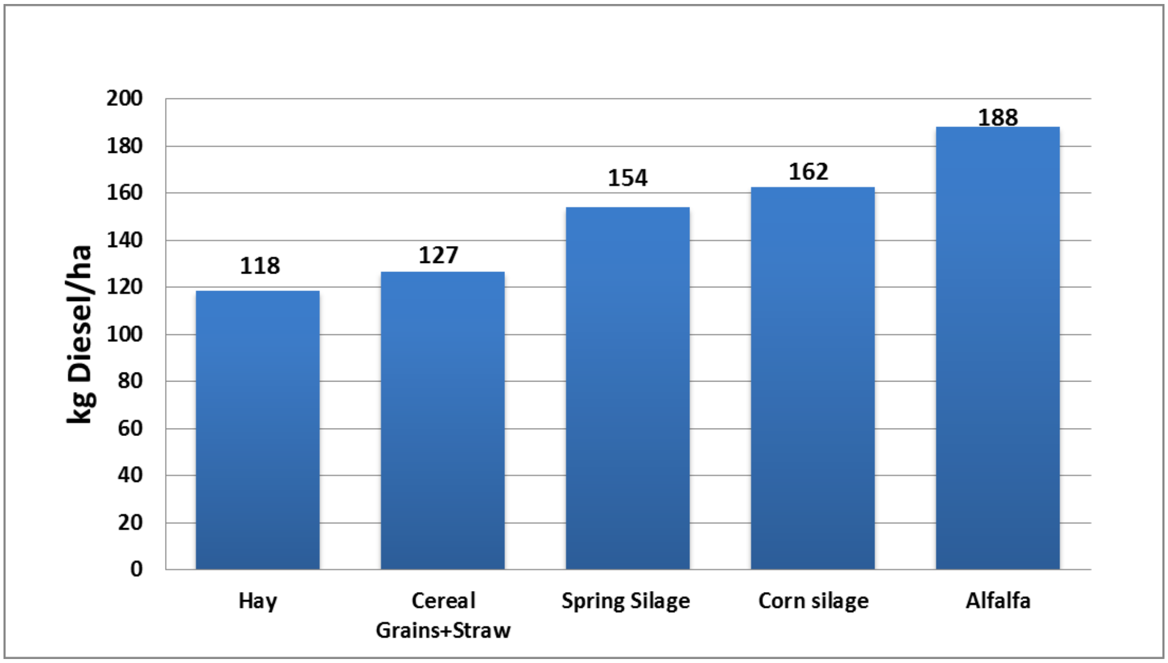


Figure 11. *Diesel consumption per cultivated area*

Figure 12 reports diesel fuel combustion per tonne of product harvested: while alfalfa and corn silage were the crops with the highest demanding fuel per hectare, those required the lowest amount of fuel per tonne of product harvested (10 and 22 kg diesel per tonne of DM, respectively), while hay products accounted for 21 kg of diesel per tonne of DM produced. Cereal grains and straw production revealed the highest requirement of fuel per product harvested (59 kg diesel per tonne of DM) since those held low yield level. Spring silage showed consumptions of 25 kg of diesel per tonne of DM produced.

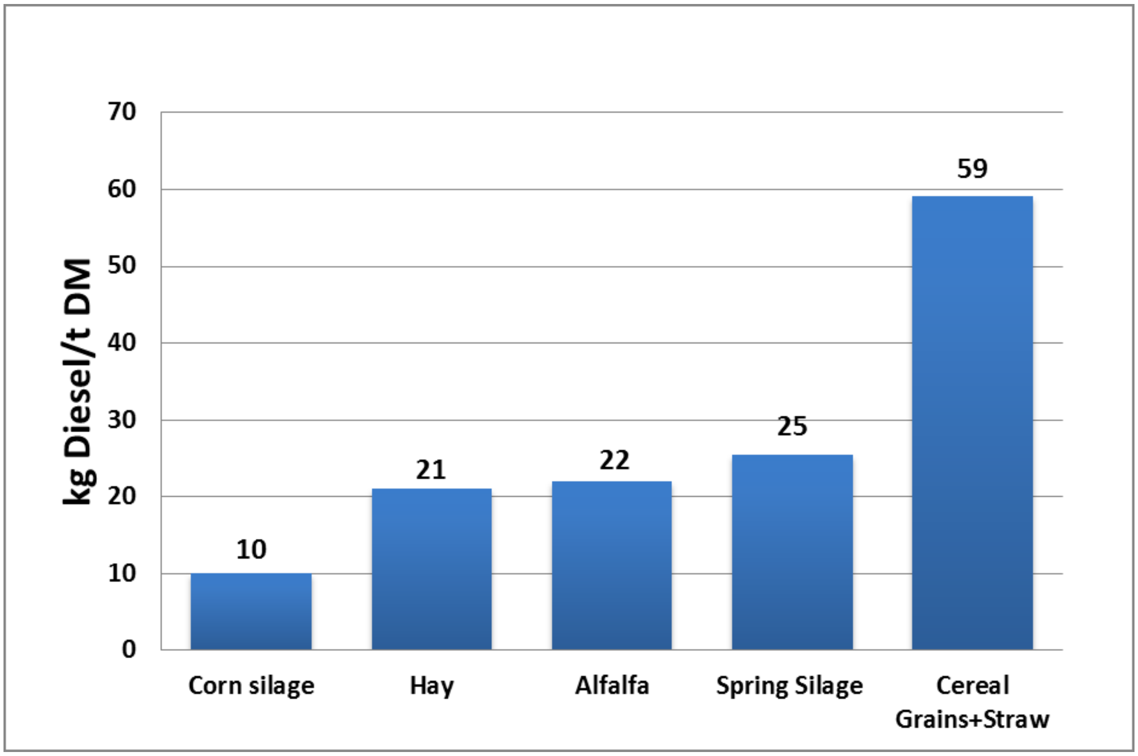


***Figure 12**. Diesel consumption per unit of crop harvested*

2.3.2.2 Carbon Dioxide Emission

The CO_2 emissions related with diesel fuel inputs were 658 kg CO_2-eq·LC^{-1} per year and 0.089 kg CO_2-eq·kg FPCM $^{-1}$ per year (table 21). When referred to the cropped land, this index accounted for 1,100 kg CO_2-eq ·ha^{-1} per year.

The annual emissions from electricity consumption were 199 kg CO_2-eq·LC^{-1} and 0.028 kg CO_2-eq·kg^{-1} of FPCM per year. The emissions associated to the LPG usage were lower than the electricity and diesel consumption: 6 kg CO_2-eq·LC^{-1} and 0.001 kg CO_2-eq per kg of FPCM.

Table 21*. Emission data summary for group B, averages per farm on a yearly basis (N=88)*

CO_2 emissions	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg CO_2-eq)	38,812 (±55,184)	292 (±152)	658 (±369)	1,100 (±682)	0.089 (±0.055)
Electricity (kg CO_2-eq)	9,458 (±10,244)	88 (±35)	199 (±82)	369 (±259)	0.028 (±0.014)
LPG (kg CO_2-eq)	294 (±879)	3 (±7)	6 (±17)	10 (±27)	0.001 (±0.002)
Total emissions (kg CO_2-eq)	**48,564** (±64,550)	**383** (±157)	**863** (±382)	**1,479** (±841)	**0.118** (±0.06)
Renewable energy (kg CO_2-eq)	-6,695 (±44,033)	-25 (±82)	-56 (±189)	-100 (±372)	-0.009 (±0.034)
Total emissions (kg CO_2-eq)	**41,869** (±55,780)	**358** (±180)	**807** (±437)	**1,379** (±941)	**0.109** (±0.07)

The overall energy usage, as average per farm, caused emissions of carbon dioxide equivalent accountable for 48.6 t CO_2-eq per year that corresponded to 863 kg CO_2-eq·LC^{-1} and 0.118 kg CO_2-eq per kg of FPCM. Subtracting the emission avoided through the production of renewable energy (6,695 kg CO_2-eq), the final emissions were 41.9 t CO_2-eq per year, which correspond to 807 kg CO_2-eq·$LC^{-1}$and 0.109 kg CO_2-eq per FPCM. The avoided emissions accounted for 13.8% of reduction for whole group emission and 7.6% of CO_2-eq emission avoided express per kg of FPCM per year. Figure 13 shows the total CO_2 emission (diesel plus electricity) allocated to each farm activities, where diesel combustion represents the most emitting sources of the farms.

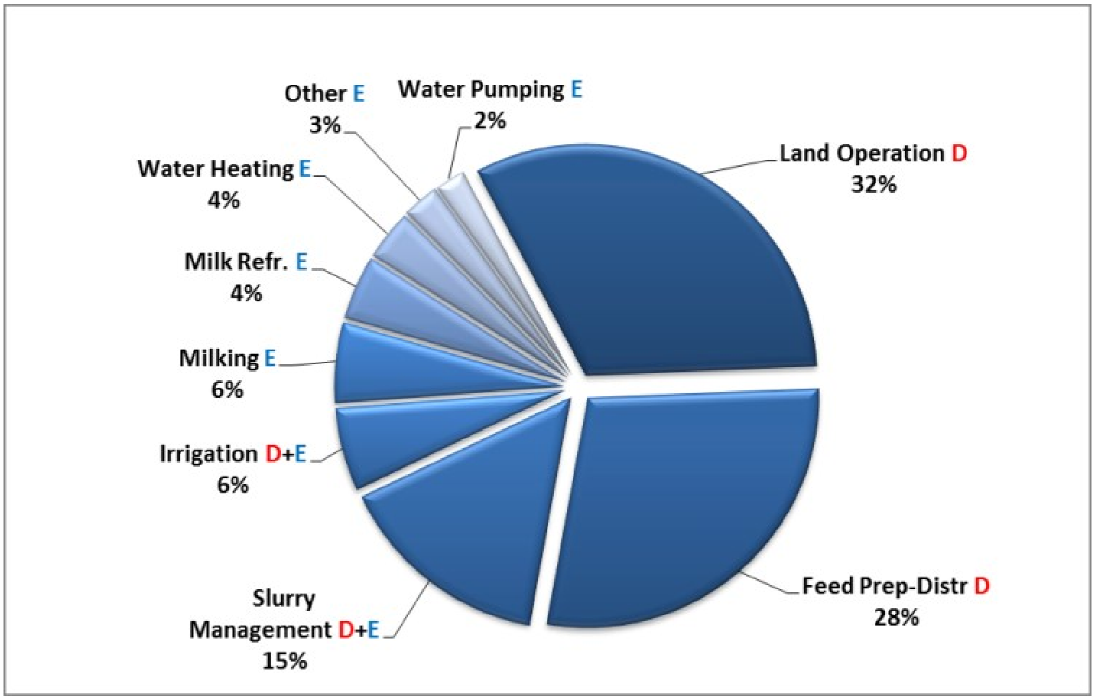


Figure 13. *Allocation of GHG emissions from electricity (E) and Diesel (D) from on-farm process.*

Land operations represent 32% of the total carbon dioxide emissions, followed by feed preparation and distribution (28%) and slurry management (15%). The electricity usage accounted for a minor part of the carbon dioxide emissions. Irrigation and milking represent each 6% of CO_2 emissions, while milk refrigeration and water heating amounted for 4% each.

Table 22 shows CO_2 emissions trend of four herd size categories, from less than 50 heads to over 200 heads. The highest number of farms, 41, was placed in the "50-100" group, followed by farms with herd size between 100 and 200 heads (21).

Results showed that larger farms were related with higher level of milk yield. Additional calculation demonstrated the CO_2 emissions were higher in farms located in small herd size class: 14.51 kg CO_2-eq per 100 kg FPCM in farms in class with less than 50 heads; the 11. kg CO_2-eq per 100 kg FPCM per farms with a herd dimension between 50 and 100 heads; 11.26 kg CO_2-eq per 100 kg FPCM per farms in class with a herd size between 100 and 200 heads and 8.907 kg CO_2-eq per 100 kg FPCM per farms in class with herd dimension over than 200 heads. Larger farms were able to produce milk emitting 1.6 times less carbon dioxide than small farms (group ">200" vs "<50").

Table 22. *Herd size class for group B, averages per farm on a yearly basis (N=88)*

Herd size class	**<50**	**50-100**	**100-200**	**>200**
Farms (n)	18	41	21	8
Heads (n)	37	71	154	519
Lactating cows (n)	17	32	68	221
Milk production (t)	118	234	625	2,057
Milk yield (t/LC)	6.72	7.19	9.09	9.23
Land (ha)	15	23	47	130
LPG (kg)	10 (±42)	65 (±167)	294 (±545)	-
LPG emission (kg CO_2eq)	29 (±122)	185 (±480)	845 (±1,565)	-
Diesel (kg)	3,339 (±2,097)	5,873 (±2,723)	18,114 (±13,813)	50,371 (±31,779)
Diesel emission (kg CO_2eq)	10,518 (±6,606)	18,501 (±8,576)	57,060 (±43,511)	158,670 (±100,103)
Electricity (kWh)*	9,618 (±3,201)	15,235 (±7,044)	28,444 (9,343±)	79,177 (±51,773)
Electricity emission (kg CO_2eq)	3,946 (±1,313)	6,251 (±2,890)	11,670 (±3,834)	32,486 (±21,242)
Total kg CO_2eq/100 kg milk	**14.51** (±8.16)	**11.34** (±4.48)	**11.26** (±6.96)	**8.907** (±2.07)

**On-farm electricity from renewable sources was not included*

As shown in table 23 the highest number of farms, 42, was located in the "5-8 t of FPCM" group, while farms with milk yield from 8 to 10 tonnes were 29.

Table 23. *Milk yield class for group B, averages per farm on a yearly basis (N=88)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	7	42	29	10
Heads (n)	56	87	159	231
Lactating cows (n)	25	39	66	109
Milk production (t)	104	268	591	1,219
Milk yield (t/LC)	4.24	6.71	8.93	11.0
Land (ha)	14	29	44	64
LPG (kg)	11 (±28)	99 (±303)	102 (±219)	180 (±570)
LPG emission (kg CO_2eq)	31 (±81)	285 (±870)	293 (±629)	518 (±1,637)
Diesel (kg)	4,304 (±2,631)	8,381 (±12,197)	15,368 (±19,692)	25,648 (±26,988)
Diesel emission (kg CO_2eq)	13,558 (±8,287)	26,399 (±38,421)	48,410 (±62,029)	80,791 (±85,011)
Electricity (kWh)*	10,985 (±2,569)	16,354 (±11,446)	29,114 (±31,848)	43,680 (±36,228)
Electricity emission* (kg CO_2eq)	4,507 (±1,054)	6,710 (±4,696)	11,946 (±13,067)	17,922 (±14,864)
Total kg CO_2eq/100 kg milk	**19.61** (±10.2)	**13.05** (±6.08)	**9.47** (±2.84)	**7.94** (±1.65)

**On-farm electricity from renewable sources was not included*

Results demonstrated that emissions of carbon dioxide equivalent were higher in farms with lower milk yield level: 19.61 kg CO_2-eq per 100 kg FPCM per farms in class with yield lower than 5 tonnes; 13.05 kg CO_2-eq per 100 kg FPCM per farms belonged in class with FPCM yield between 5 and 8 tonnes; 9.47 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield between 8 and 10 tonnes; 7.94 kg CO_2-eq per 100 kg FPCM per farms with milk yield level over 10 tonnes. Farms with higher milk yield were responsible to produce milk emitting 2.5 times less CO_2 emission than farms with lower yield.

2.3.2.3 Economic Aspects

Table 24 shows costs associated to the use of energy sources: diesel fuel represents the highest part of the costs related to the energy purchased, with an average of 12,243 euro, which corresponds to 208 euro per lactating cow and 2.78 euro per 100 kg of FPCM.

Electricity accounts for 4,218 euro as average per farm, 89 euro per lactating cow and 1.23 euro per 100 kg FPCM when reported to the milk production. The LPG purchase represents the lowest part of the total energy cost, with 69 euro per farm, corresponding to 2.2 euro per lactating cow and 0.02 euro per 100 kg of milk produced. Moreover, diesel fuel represents 69% of the total cost, followed by electricity 31% and LPG, corresponding only for 0.5%.

On-farm electricity production from renewable sources was considered available and distributed for the whole group of farms. The price was set to 0.183 euro per kWh, which represents the price of electricity purchase. However, renewable energy production benefits to other sources of incentives that were not take into account in this analysis and may produce higher economic revenue.

Table 24. *Costs of energy usage for group B, averages per farm on a yearly basis (N=88)*

	Average	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (Euro)	12,243 (±17,408)	92 (±48)	208 (±116)	347 (±216)	2.78 (±1.79)
Electricity (Euro)	4,218 (±4,569)	39 (±15.4)	89 (±36)	165 (±116)	1.23 (±0.64)
LPG (Euro)	69 (±200)	0.6 (±1.59)	1.4 (±3.7)	2.2 (±6)	0.02 (±0.05)
Total Costs (Euro)	**16,531**	**132**	**298**	**513**	**4.02**
Renewable energy (Euro)	3,250 (±21,252)	12.1 (±39)	27 (±91)	48 (±178)	0.40 (±1.6)
Total Costs (Euro)	**13,280** (±20,662)	**120** (±64)	**271** (±156)	**465** (±347)	**3.62** (±2.52)

The average profit accounted for 3,250 euro per farm, which corresponded to 27 euro per lactating cow and 0.40 euro per 100 kg of milk sold. Thanks to the self-production of energy through a renewable system, the average total costs were reduced to a 13,280 euro (19.6% of reduction), which represents a decreased of 9.9% of costs per 100 kg of milk sold

Additional analysis highlighted the benefits derived to the use of saving devices in terms of energy and money saved. As shown in table 25, the use of Variable Drive Speed (VDS) connected to the vacuum pump, allowed to save 13,675 kWh (average in farms having VDS) which corresponds an economy of 2,424 euro and 0.13 euro per

100 kg of FPCM sold. The use of Milk Pre-cooler (MP) produced an average saving of 9,714 euro, which corresponds to 0.19 euro per 100 kg of milk produced, while the Heat Recovery System (HRS) saved 7,066 euro per farm and 0.18 euro per 100 kg of FPCM.

Table 25. *Economic and environmental results through the use of Energy Saving Devices (ESD), Averages per farm having ESD on a yearly basis.*

	Number of Farms	Saved kWh per Farm/y	kWh/100 kg FPCM	Kg CO2-eq/Farm	Euro Total/Farm	Euro/100 Kg FPCM	Power kWp
Variable Drive Speed	3	13,675	0.73	5,611	2,462	0.13	-
Milk Pre-cooler	2	9,714	1.08	3,986	1,749	0.19	-
Heat Recovery	17	7,066	0.98	2,899	1,272	0.18	-
Photovoltaic	12	36,264	5.5	14,879	6,527	1.0	39 (9-150)
Solar panel	4	3,841	2.0	1,576	691	0.4	-
Anaerobic Digestion	1	1,080,000	26	443,124	194,400	4.8	150
Eolic	1	30,000	1.0	12,309	5,400	0.2	30

Table 26 shows that 47.7% of farms were placed into the group with milk yield between 5 and 8 tonnes of FPCM per year, while 32.9% belonged to the group from 8 to 10 tonnes of milk per year.

Table 26. *Costs of energy usage for milk yields class, averages per farm on a yearly basis (N=88)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	7	42	29	10
Heads (n)	56	87	159	231
Lactating cows (n)	25	39	66	109
Milk production (t)	104	268	591	1,219
Milk yield (t/LC)	4.24	6.71	8.93	11.0
Land (ha)	14	29	44	64
LPG (kg)	11	99	102	180
LPG cost (Euro)	7	63	65	115
Diesel (kg)	4,304	8,381	15,368	25,648
Diesel cost (Euro)	4,277	8,328	15,271	25,486
Electricity (kWh) *	10,985	16,354	29,114	43,680
Electricity cost (Euro)	2,010	2,993	5,328	7,993
Total costs (Euro/100 kg milk)	**6.83** (±3.32)	**4.53** (±1.95)	**3.26** (±0.91)	**2.73** (±0.53)

**On-farm electricity production from renewable sources was not included*

Results also shows a correlation between milk yields and herd size, in fact, the number of heads increase when milk yield levels increase.

The trend of costs due to energy purchased shows decrement per unit of milk sold when the milk yield increase. In fact, costs decreased of: 34% in farms located in group from 5 to 8 tonnes of milk yield (4.53 euro) instead farms which had milk yields lower than 5 tonnes (6.83 euro); 28% in farms located in group from 8 to 10 tonnes of milk yield (3.26 euro) instead farms which had milk yields between 5 and 8 tonne; 16% in farms placed in group with milk yield higher than 10 tonnes (2.73 euro) instead farms which had milk yields from 8 to 10 tonne (3.26 euro). When the extremity values (6.83 and 2.73 euro) were compared, the analysis showed that costs decreased of 2.5 times going from less than 5 to over 10 tonnes of milk yield.

Further analysis demonstrated the relationship between carbon dioxide emissions and costs; in particular for the group B, each kilogram of CO_2-eq emitted was associated to an expenditure of 0.35 euro/kg CO_2-eq (SD ±0.019).

2.3.3 Group C

2.3.3.1 Energy Intensity

The average energy consumed per farms in group C, on a yearly basis, amounted to 9,332 kg of diesel, 21,265 kWh of electricity and 39 kg of LPG, while electricity production from renewable source was 2,057 kWh. The consumption of diesel fuel accounted for 229 $kg{\cdot}LC^{-1}$, 279 kg per cultivated hectare and 0.036 kg per kg of milk. The electricity utilization indicators were 561 kWh per lactating cow and 0.088 kWh per kg FPCM per year, while LPG consumption accounted for 1.2 $kg{\cdot}LC^{-1}$and $1.7e^{-4}$ per kg of FPCM per year. On-farm renewable electricity produced: 39 kWh per lactating cow and 0.006 kWh per kg of milk sold (table 27).

***Table 27**. Energy data summary for group C, averages per farm on yearly basis (N=70)*

Energy Intensity	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg)	9,332 (±8,783)	117 (±61)	229 (±129)	279 (±215)	0.036 (±0.023)
Electricity (kWh)	21,265 (±18,490)	287 (±131)	561 (±275)	762 (±737)	0.088 (±0.040)
LPG (kg)	39 (±134)	0.6 (±2.6)	1.2 (±5)	1.2 (±4.4)	$1.7e^{-4}$ ($\pm 7e^{-4}$)
Renewable elect. (kWh)	2,057 (±8,580)	20 (±84)	39 (±163)	56 (±256)	0.006 (±0.030)

The usage of electricity showed that water heating, milking and water pumping required respectively 23%, 18% and 17% of the annual electricity consumption (figure 14). Other activities that affect the electricity requirements were: milk refrigeration (14%), irrigation (9%), slurry management and fan-misting (4% each), followed by lighting and brushing (2% each). The allocation analysis showed that the whole activities carried out at the milking parlour were responsible of 55% of the total electricity consumed.

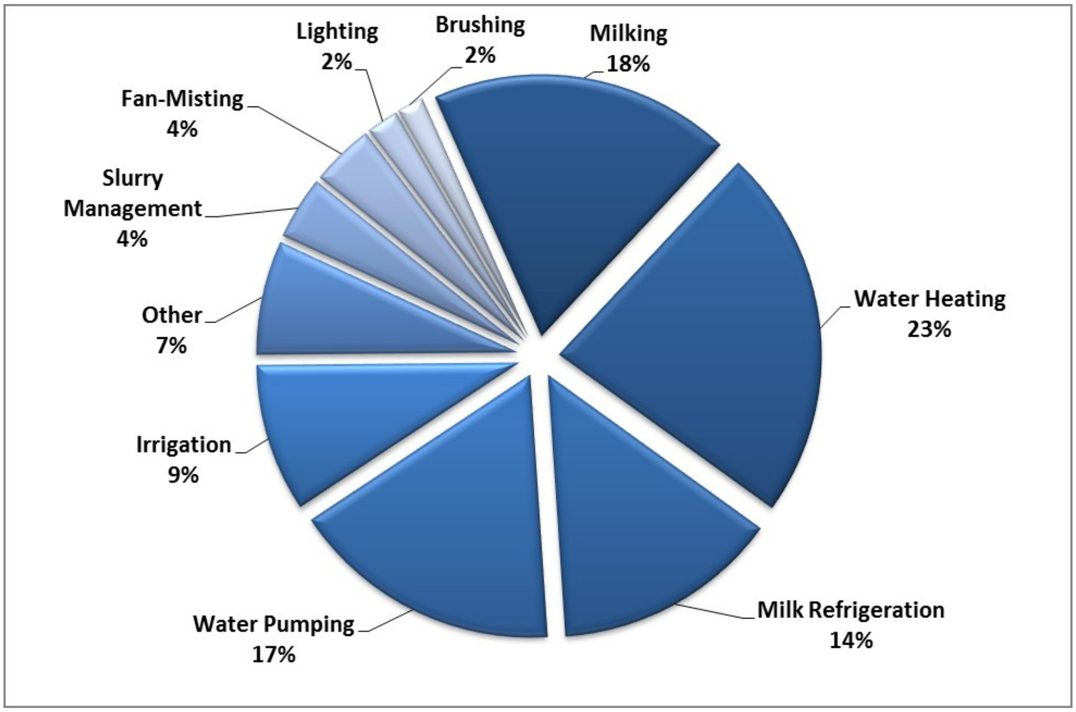


Figure14. *Allocation of electricity usage among different on-farm operations*

Diesel fuel consumption associated both to farm and field processes showed that (figure 15) field operations associated to crop production accounted for 39%, feed preparation and distribution represent 36% of the total fuel utilization, slurry management for 12%, while irrigation represents 4% of the total diesel consumed. The total diesel consumed by land operations was allocated into 3 phases, where: 33% of fuel was used for soil preparation, 16% for sowing and fertilization and 51% for harvesting and product transport to the farms.

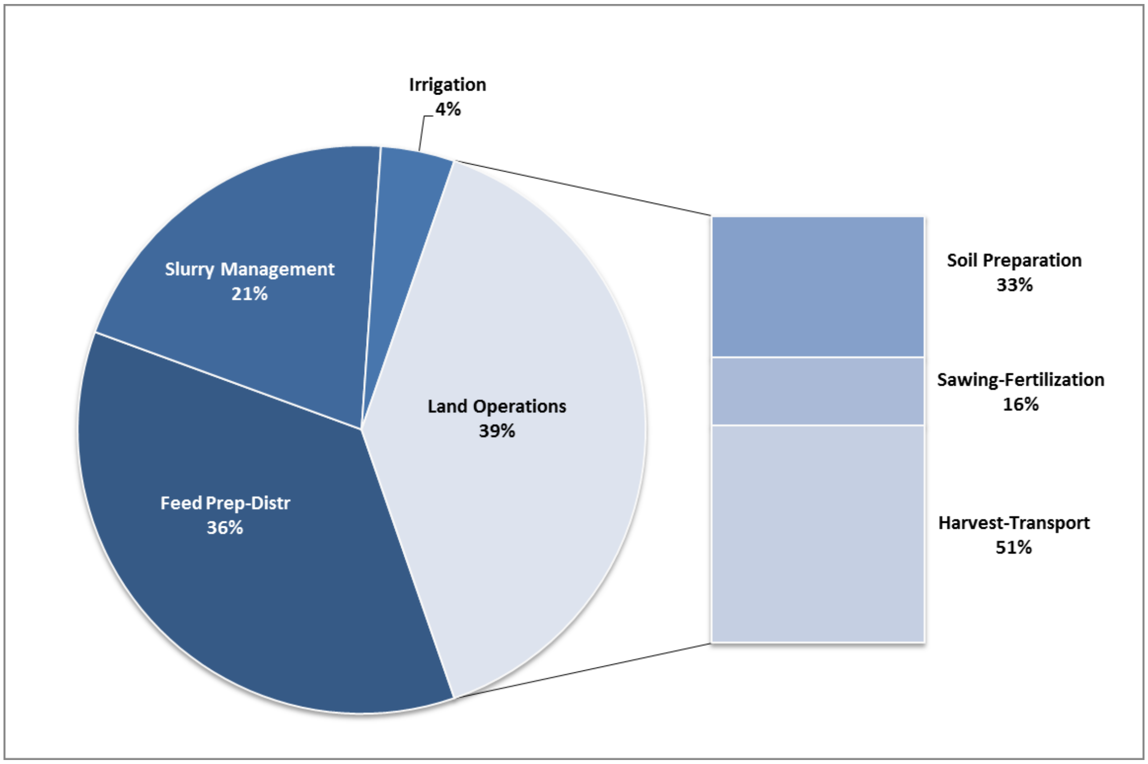


Figure 15. *Allocation of diesel usage among on-farm operations*

Crop selection for farms in group C (expressed as percentage of total hectares cultivated) was based on:

- 73% by hay and spring silage - *Lolium spp., Triticosecale Wittm. ex A. Camus., Avena sativa L., Hordeum Vulgare L.,* (range 2-80 ha/farm);
- 12% by cereal for grains and straw - *Avena sativa L., Hordeum Vulgare L., Triticum spp.*, (range from 2-50 ha/farm);
- 3% corn silage -*Zea Mays L.*, (range 1-40 ha/farm);
- 1% Alfalfa forage - *Medicago Sativa L.*, (range 6-10 ha/farm).

As showed in figure 16 the grass forage for hay and hay silage represent the most abundant part of feed production at farm level (73%), while alfalfa cultivation accounted for only 1% of the total.

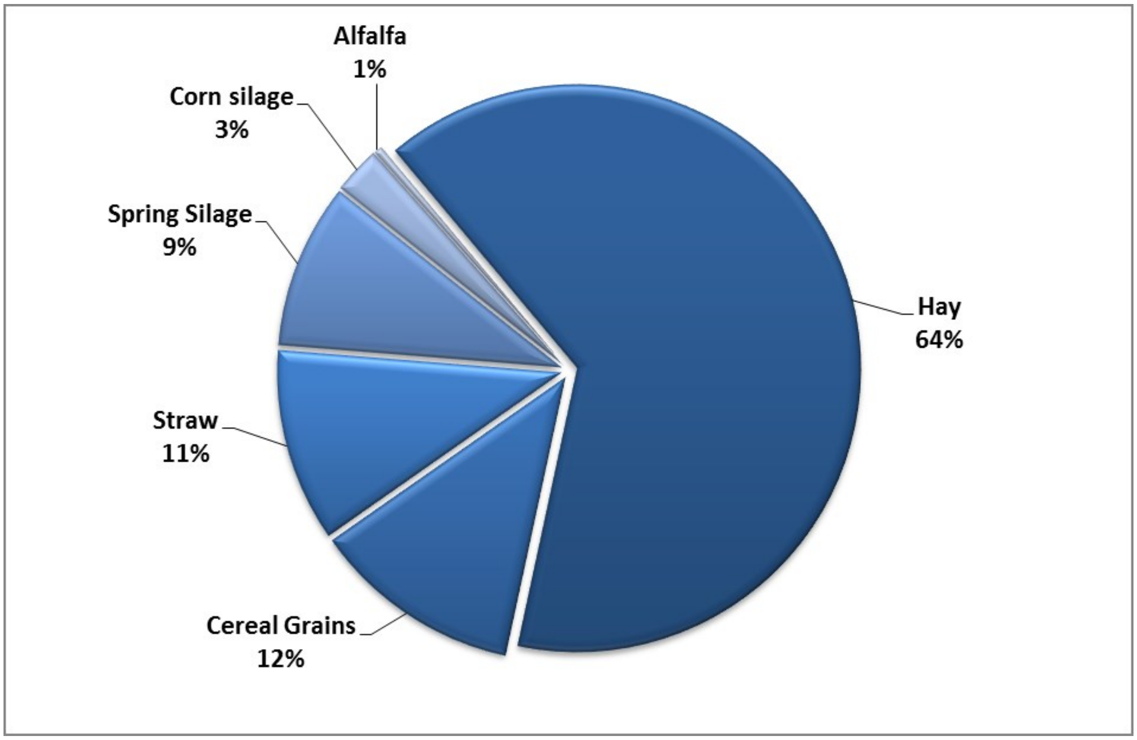


Figure 16. *Average crops selection for group C*

In figure 17 analysis related to diesel fuel consumption for each cultivated crop were: 42 (±23) kg of diesel·hectare^{-1} for alfalfa products; 100 (±44) kg of diesel·hectare^{-1} for grass hay; 141 (±41) kg of diesel·hectare^{-1} for spring silage; 144 (±38) kg of diesel·hectare^{-1} to harvest cereal grains and straw; 178 (±49) kg of diesel·hectare^{-1} for corn silage.

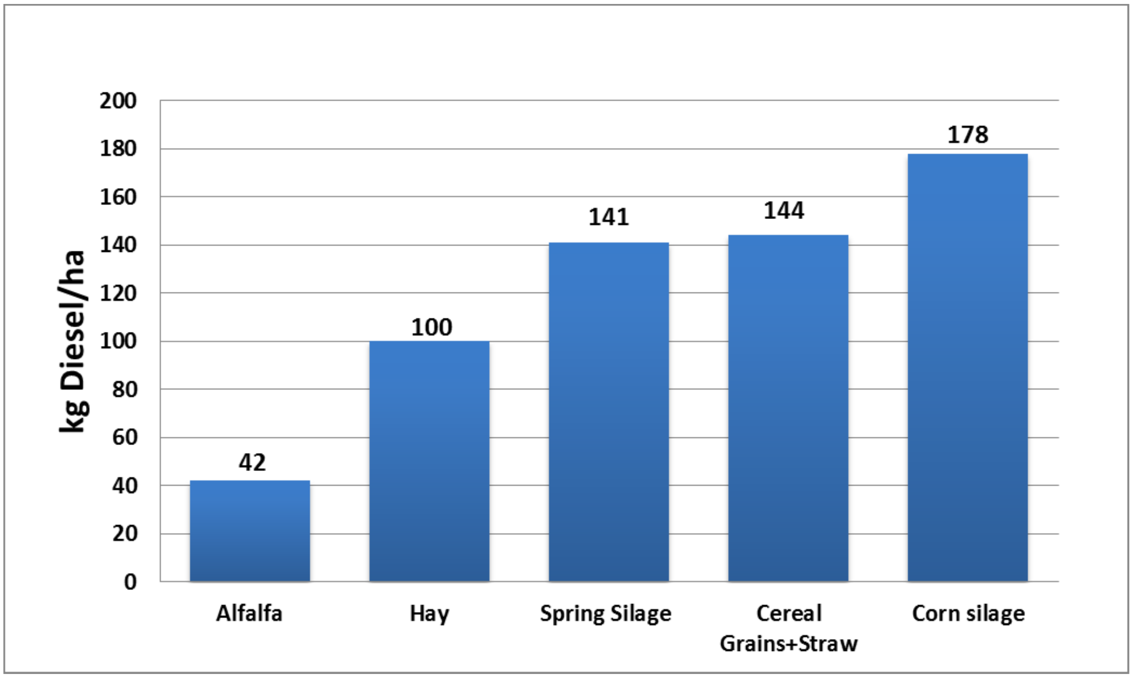


Figure 17. *Diesel consumption per cultivated crop*

When diesel consumptions per hectare were referred to the yield of each crop (tonnes of product per hectare), the analysis showed: 11 kg of diesel per tonne of DM per corn silage; alfalfa products accounted for 15 kg of fuel per tonne of DM produced. Spring silage showed consumptions of 29 kg of fuel per tonne of DM produced, while hay products accounted for 35 kg of diesel fuel per tonne of DM (figure 18). Cereal grain and straw, which held low yields level, showed the highest requirement of fuel per product harvested (79 kg diesel per tonne of DM).

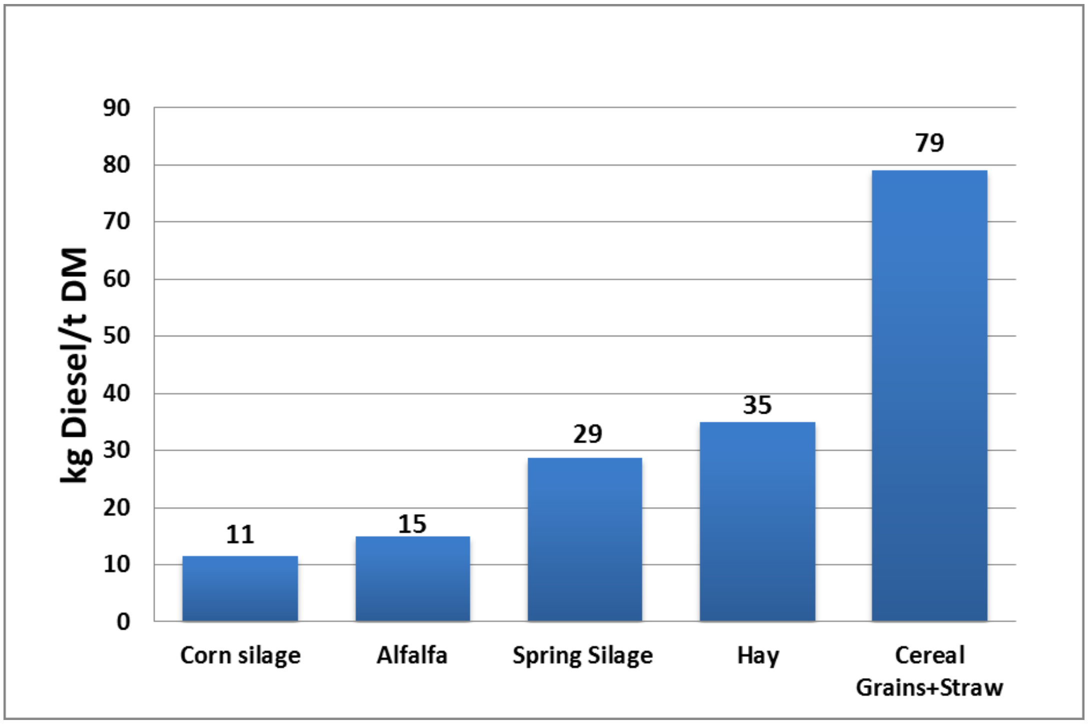


Figure 18. *Diesel consumption per unit of crop harvested*

2.3.3.2 Carbon Dioxide Emission

Carbon dioxide emissions related with diesel fuel inputs were 723 kg CO_2-eq·LC^{-1} year and 0.113 kg CO_2-eq·kg of $FPCM^{-1}$ per year (table 28). When referred to the cultivated land, this index accounted for 880 kg CO_2-eq ·ha^{-1} per year.

The annual emissions from electricity consumption were 230 kg CO_2-eq per lactating cow and 0.036 kg CO_2-eq per kg of FPCM per year. The LPG emissions were 3.57 kg CO_2-eq·$LC^{-1}$and 3.4e^{-4} kg CO_2-eq per kg of FPCM.

Table 28. *Emission data summary for group C, averages per farm on a yearly basis (N=70)*

CO_2 emissions	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg CO_2-eq)	29,395 (±27,666)	370 (±191)	723 (±405)	880 (±676)	0.113 (±0.072)
Electricity (kg CO_2-eq)	8,725 (±7,586)	118 (±54)	230 (±113)	313 (±302)	0.036 (±0.016)
LPG (kg CO_2-eq)	110 (±383)	1.81 (±7,4)	3.57 (±14.4)	3.48 (±12.7)	$3.4e^{-4}$ ($\pm 2e^{-3}$)
Total emissions (kg CO_2-eq)	**38,230** (±34,121)	**490** (±220)	**957** (±473)	**1,196** (±917)	**0.149** (±0.079)
Renewable energy (kg CO_2-eq)	784 (±3,272)	7.7 (±32)	15 (±62)	21 (±98)	0.002 (±0.011)
Total emissions (kg CO_2-eq)	**37,446** (±33,991)	**482** (±225)	**942** (±484)	**1,175** (±914)	**0.147** (±0.08)

The overall emission of carbon dioxide equivalent, express as average per farm, accounted for 38.2 t CO_2-eq per year that corresponds to 957 kg CO_2-eq per lactating cow and 0.149 kg CO_2-eq per kg of FPCM. Thanks to the production of on-farm renewable electricity (avoiding 784 kg CO_2-eq) the final emissions were 37.5 t CO_2-eq per year, which correspond to 942 kg CO_2-eq per lactating cow and 0.147 kg CO_2-eq per kg of FPCM. The avoided emissions amounted for 2.05% of reduction for total farm emission and 1.34% of CO_2-eq emission avoided per kg of FPCM per year.

Figure 19 shows the total carbon dioxide emission (diesel plus electricity) allocated to each farm activities. Field operations were responsible of 31% of total carbon dioxide emissions, followed by feed preparation and distribution (28%) and slurry management (17%). The electricity usage accounted for a minor part of the total CO_2 emissions. Irrigation and water heating represented 5% each of CO_2 emissions, while milking and water pumping accounted for only 4%, each.

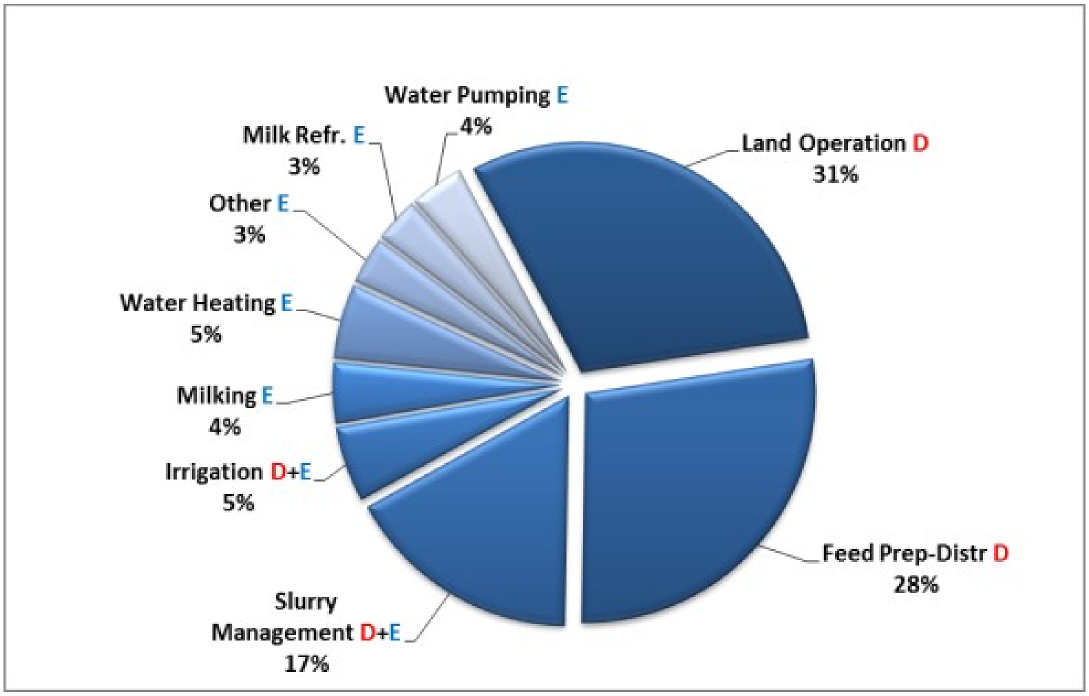


Figure 19. *Allocation of GHG emissions from electricity (E) and Diesel (D) among farm activities*

As shown in table 29 the highest number of farms, 33, were located in the "50-100" group, while only 3 farms belonged to the group "larger than 200". Results showed that larger farms were associated with higher level of milk yield, but differently from the other groups, the emissions of carbon dioxide equivalent were not negative related with the herd size of farms, in fact: 16.59 kg CO_2-eq per 100 kg FPCM per farms in class with a herd size less than 50; 13.81 kg CO_2-eq per 100 kg FPCM in farms between 50 and 100 heads; 15.42 kg CO_2-eq per 100 kg FPCM per farms in class with a herd size between 100 and 200 heads and 13.75 kg CO_2-eq per 100 kg FPCM per farms in class with herd dimension over than 200 heads.

Table 29. *Herd size class for group C, averages per farm on a yearly basis (N=70)*

Herd size class	**<50**	**50-100**	**100-200**	**>200**
Farms (n)	23	33	11	3
Heads (n)	34	75	129	350
Lactating cows (n)	19	39	65	153
Milk production (t)	111	264	492	1,186
Milk yield (t/LC)	6.17	6.90	7.60	7.92
Land (ha)	25	35	52	99
LPG (kg)	25 (±115)	56 (±163)	25 (±83)	-
LPG emission (kg CO_2eq)	69 (±329)	161 (±467)	72 (±237)	-
Diesel (kg)	3,775 (±1,993)	8,157 (±3,876)	16,202 (±7,425)	39,671 (±9,127)
Diesel emission (kg CO_2eq)	11,891 (±6,277)	25,693 (±12,208)	51,037 (±23,389)	124,965 (±28,749)
Electricity (kWh)	12,298 (±6,148)	18,015 (±7,247)	31,080 (±11,885)	89,785 (±34,072)
Electricity emission (kg CO_2eq)	5,046 (±2,522)	7,392 (±2,974)	12,752 (±4,876)	36,839 (±13,980)
Total kg CO_2eq/100 kg milk	**16.59** (±6.83)	**13.81** (±7.32)	**15.42** (±12.1)	**13.75** (±3.15)

Table 30 showed the emissions of CO_2-eq based on class of milk yield (tonnes of milk per Lactating cow a year).

Table 30. *Milk yield class for group C, averages per farm on a yearly basis (N=70)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	16	34	14	6
Heads (n)	62	89	83	92
Lactating cows (n)	32	45	42	45
Milk production (t)	112	295	380	499
Milk yield (t/LC)	3.61	6.53	8.86	11.2
Land (ha)	40	33	36	52
LPG (kg)	44 (±175)	13 (±56)	52 (±151)	131 (±241)
LPG emission (kg CO_2eq)	126 (±502)	39 (±160)	150 (±434)	375 (±693)
Diesel (kg)	6,654 (±7,362)	9,452 (±9,145)	10,684 (±6,703)	12,636 (±13,852)
Diesel emission (kg CO_2eq)	20,959 (±23,191)	29,775 (±28,806)	33,654 (±21,113)	39,803 (±43,632)
Electricity (kWh)*	14,012 (±5,909)	24,269 (±23,707)	21,876 (±10,981)	21,884 (±18,980)
Electricity emission (kg CO_2eq)	5,749 (±2,425)	9,958 (±9,727)	8,976 (±4,505)	8,979 (±7,788)
Total kg CO_2eq/100 kg milk	**25.41** (±14.7)	**13.55** (±5.36)	**12.17** (±4.34)	**10.85** (±3.61)

**On-farm electricity from renewable sources was not included*

The highest number of farms, 34, was placed in the "5-8 t of FPCM" group, followed by farms with milk yield less than 5 tonnes (16), while 14 farms belonged to the group "8-10 t of FPCM". Carbon dioxide emissions for each class were: 25.41 kg CO_2-eq per 100 kg FPCM per farms in class with yield lower than 5 tonnes; 13.55 kg CO_2-eq per 100 kg FPCM per farms belonged to class with FPCM yield between 5 and 8 tonnes; 12.17 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield between 8 and 10 tonnes and 10.85 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield over than 10 tonnes. Farms with higher milk yield were responsible to produce milk emitting 2.3 times less carbon dioxide emission than farms with lower milk yield (class ">10" vs class "<5").

2.3.3.3 Economic Aspects

As shown in table 31 cost associated to the use of energy sources accounted for: 9,273 euro for diesel fuel, which correspond to 228 euro per lactating cow and 3.58 euro per 100 kg of milk sold; electricity usage was responsible of 3,891 euro as average per farm, 103 euro per lactating cow and 1.61 euro per 100 kg FPCM when reported to the milk production; LPG represented the lower part of the total energy costs, with 25 euro per farm, corresponding to 0.8 euro per lactating cow and 0.01 euro per 100 kg of milk produced. Expressing these costs in percentage, diesel fuel represents 68.8% of the total cost, followed by electricity 30.9% and LPG, which accounted only for 0.19%.

Table 31. *Costs of energy usage for group C, averages per farm on yearly basis (N=70)*

	Average	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (Euro)	9,273 (±8,730)	116 (±61)	228 (±128)	277 (±214)	3.58 (±2.29)
Electricity (Euro)	3,891 (±3,384)	53 (±24)	103 (±50)	139 (±135)	1.61 (±0.73)
LPG (Euro)	25 (±85)	0.4 (±1.7)	0.8 (±3.1)	0.8 (±2.8)	0.01 (±0.04)
Total Costs (Euro)	**13,189**	**169**	**331**	**417**	**5.20**
Renewable elect. (Euro)	376 (±1,570)	3.66 (±15)	7.14 (±30)	10.3 (±47)	0.110 (±0.55)
Total Costs (Euro)	**12,813** (±11,623)	**166** (±77)	**324** (±166)	**407** (±324)	**5.09** (±3.42)

The on-farm electricity production from renewable sources was responsible of an economy of 376 euro per farm, which correspond to 7.14 euro per lactating cow and 0.001 euro per 100 kg of milk sold. Thanks to the self-production of electricity through a renewable system, the average total costs were reduced to 12,813 euro (2.9% of reduction).

The benefits derived to the use of energy saving devices were included in the analysis. As shown in table 32 using Variable Drive Speed (VDS) allowed saving 1,752 kWh (average in farms having VDS) which corresponds to an economy of 315 euro, as average per farm, and 0.19 euro per 100 kg of FPCM. The use of Milk Pre-cooler (MP) produced an average economy of 5,788 euro, which corresponds to 0.16 euro per 100 kg of milk produced, while the Heat Recovery System (HRS) saved 5,913 euro per farm and 0.23 euro per 100 kg of FPCM sold.

Table 32. *Economic and environmental results through Energy Saving Devices (ESD) for group C, Averages per farm having ESD on a yearly basis.*

	Number of Farms	**Saved kWh per Farm/y**	**kWh/100 kg FPCM**	**Kg CO2-eq/Farm**	**Euro Total/Farm**	**Euro/100 Kg FPCM**	**Power kWp**
Variable Drive Speed	1	1,752	0.10	719	315	0.19	-
Milk Pre-cooler	5	5,788	0.87	2,375	1,042	0.16	-
Heat Recovery	3	5,913	0.13	2,426	1,064	0.23	-
Photovoltaic	4	36,000	8.1	14,771	6,480	1.47	23 (20-30)
Solar panel	14	3,319	0.9	1,362	597	0.16	-
Anaerobic Digestion	-	-	-	-	-	-	-
Eolic	-	-	-	-	-	-	-

Table 33 illustrates that only the 8.6% of farms in group C were situated in class with milk yield higher than 10 tonnes of FPCM per year. When the milk yield increase, the trend of costs due to the energy usage decrease.

Table 33. *Costs of energy usage for milk yields class, averages per farm on a yearly basis (N=70)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	16	34	14	6
Heads (n)	62	89	83	92
Lactating cows (n)	32	45	42	45
Milk production (t)	112	295	380	492
Milk yield (t/LC)	3.61	6.53	8.86	11.2
Land (ha)	40	33	36	52
LPG (kg)	44	13	52	131
LPG cost (Euro)	28	9	33	83
Diesel (kg)	6,654	9,452	10,684	12,636
Diesel cost (Euro)	6,612	9,393	10,616	12,556
Electricity (kWh) *	14,012	24,269	21,876	21,884
Electricity cost (Euro)	2,564	4,441	4,003	4,005
Total costs (Euro/100 kg milk)	**8.85** (±5.01)	**4.72** (±1.79)	**4.18** (±1.44)	**3.71** (±1.30)

**On-farm electricity production from renewable sources was not included*

In fact: costs decreased of 47% in farms belonged to group from 5 to 8 tonnes of milk yield (4.72 euro) instead farms which had milk yields lower than 5 tonnes (8.85 euro); 11% in farms located in group from 8 to 10 tonnes of milk yield (4.18 euro) instead farms which had milk yields between 5 and 8 tonnes; 11% in farms placed in group with milk yield higher than 10 tonnes (3.71 euro) instead farms which had milk yields from 8 to 10 tonnes. When the extremity values (8.85 and 3.71 euro) were compared, the analysis showed that costs decreased of 2.4 times going from less than 5 to more than 10 tonnes of milk yield.

The relationship between each kilogram of CO_{2}-eq emitted and costs, accounted for an expenditure of 0.35 euro per kg CO_2-eq (SD ±0.015).

2.3.4 Group D

2.3.4.1 Energy Intensity

The average annual diesel consumed by farms in group D accounted for 16,219 kg, followed by electricity 30,385 kWh and 360 kg of LPG, while on-farm renewable electricity accounted for 138,088 kWh. The Energy Utilization Indices (EUI), on a yearly basis, for diesel consumption accounted for 2,482 kg·LC^{-1}, 584 kg per cultivated hectare and 0.093 kg per kg of milk produced per year. The EUI associated with electricity consumption accounted for 500 kWh per lactating cow and 0.086 kWh per kg FPCM per year, while the LPG consumed was 6.8 kg per lactating cow and 0.001 per kg of FPCM. Electricity production from renewable source produced the following EUI: 248 kWh per lactating cow and 0.028 kWh per kg of FPCM (table 34).

Table 34. *Energy data summary for group D, averages per farm on a yearly basis (N=44)*

Energy Intensity	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg)	16,219 (±20,844)	237 (±364)	482 (±488)	584 (±741)	0.093 (±0.125)
Electricity (kWh)	30,385 (±95,221)	221 (±119)	500 (±334)	922 (±2,419)	0.086 (±0.062)
LPG (kg)	360 (±1,186)	3.1 (±11)	6.8 (±23)	10.7 (±33)	0.001 (±0.003)
Renewable elect. (kWh)	138,088 (±856,502)	119 (±647)	248 (±1,415)	3,485 (±21,954)	0.028 (±0.16)

Further analysis highlighted that the operations which required the most electricity consumption were irrigation 29% and milking 16%. The other activities that affect considerably the electricity requirements were: brushing and milk refrigeration, requiring 12% and 11% respectively. Water heating and water pumping usage accounted for 10% each, while fan-misting and lighting required 6% and 3% respectively (figure 20).

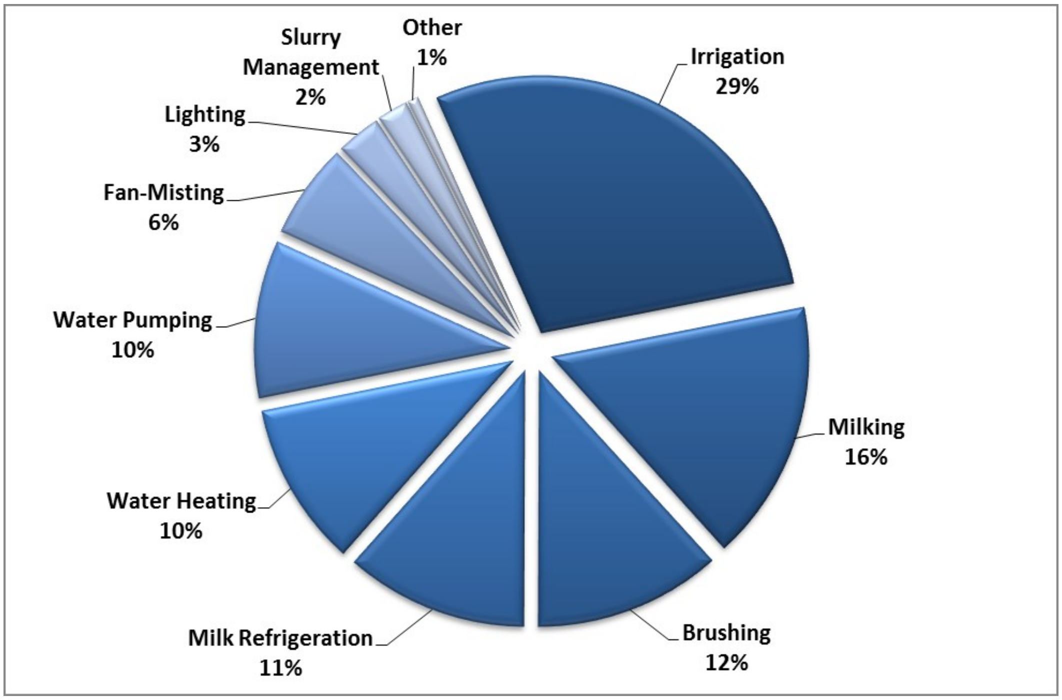


Figure 20. *Allocation of electricity usage among on-farm operations*

Analyzing the diesel consumption (figure 21) related both to farm and field processes, feed preparation and distribution accounted for 32%, land operations associated to crop cultivation represent the 25% of the total fuel utilization, irrigation for 22%, while slurry management represents 21% of the total diesel consumption.

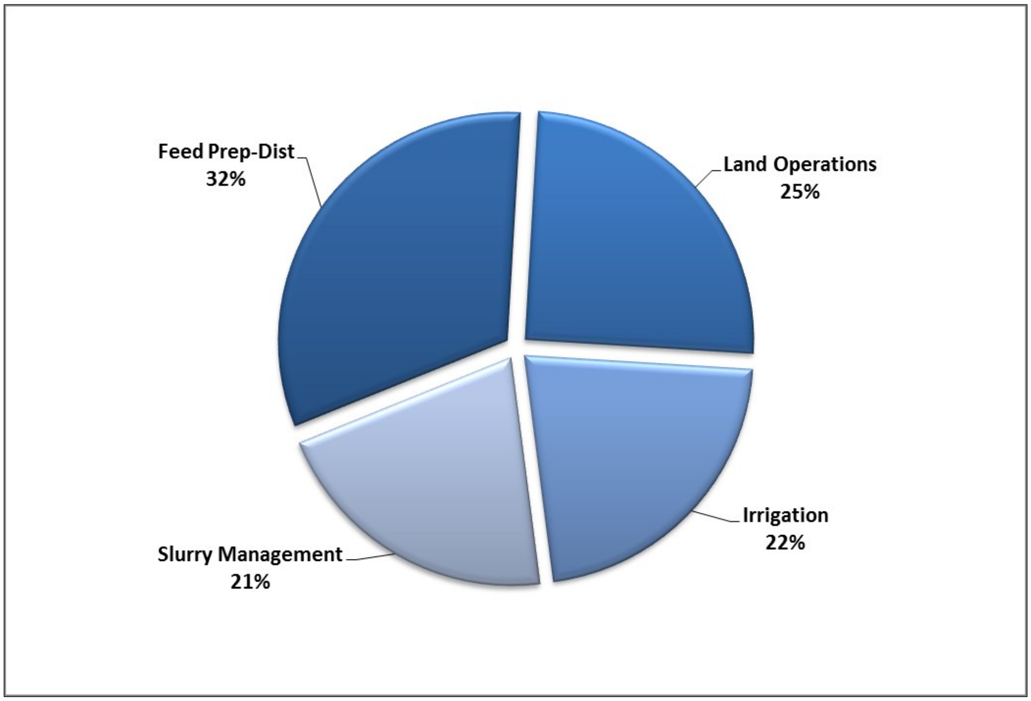


Figure 21. *Allocation of diesel usage among on-farm operations*

The main crops cultivated (expressed as percentage of total cultivated hectares) in farms of group D were based on:

- 68% hay and silage - Lolium spp., Triticosecale Wittm. ex A. Camus., Avena sativa L., Hordeum Vulgare L., (range of 4-121 ha·farm^{-1});
- 16% corn silage - Zea Mays L., (range 2-156 ha·farm^{-1});
- 8% alfalfa - Medicago Sativa L., (range 0.5-20 ha·farm^{-1});
- 7% cereal for grains - *Avena sativa L., Hordeum Vulgare L., Triticum spp.,* (range from 3-17 ha·farm^{-1}).

As shown in figure 22 the grass forage for hay and hay silage represents an important quote of feed production at farm level (68%), while cereal for grains accounted for only 7% of the total.

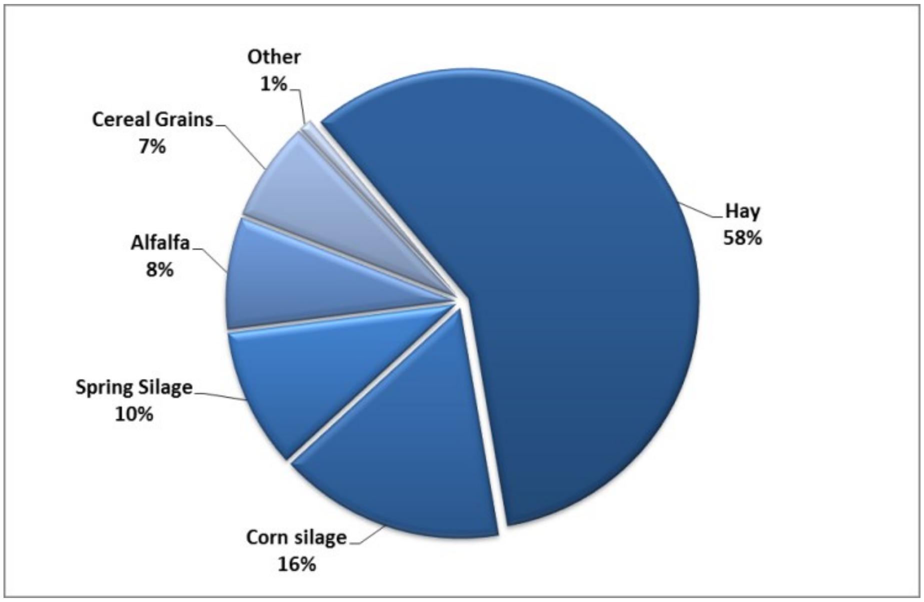


Figure 22. *Average crops selection for group D*

As illustrate in figure 23 the analysis related to fuel consumption for each crop cultivated was: 110 kg of diesel·hectare^{-1} per hay products; 132 kg of diesel·hectare^{-1} per alfalfa; 134 kg of diesel·hectare^{-1} for spring silage; 150 kg of fuel diesel·hectare^{-1} to harvest cereal grains; 170 kg of diesel·hectare^{-1} for corn silage.

Figure 24 shows diesel fuel consumption per tonne of Dry Matter (DM) product harvested: while corn silage was the crops with the most demanding fuel per hectare, it required the lowest quantities of diesel per tonne of product harvested (14 kg per tonne of DM). Alfalfa products accounted for 18 kg of diesel per tonne of DM produced.

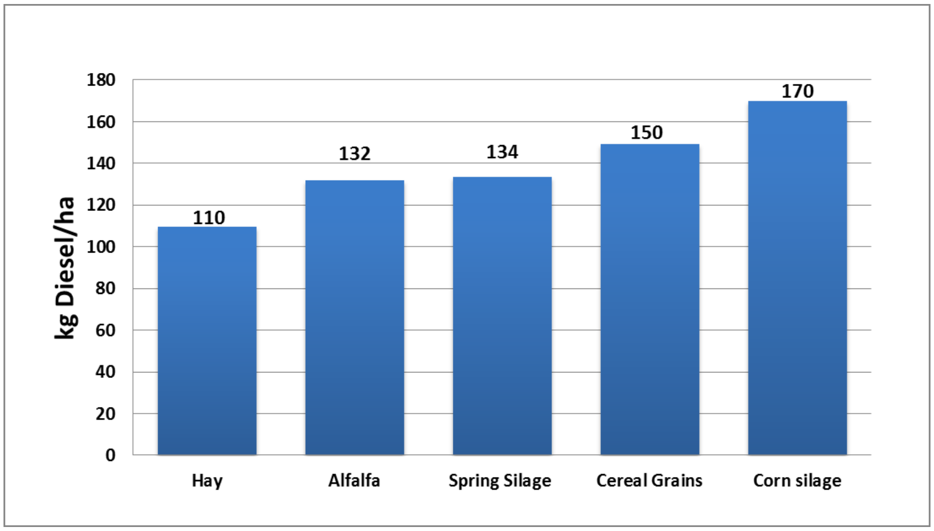


Figure 23*. Diesel consumption per cultivated area*

Spring silage and hay products showed consumptions of 21 kg of fuel per tonne of DM produced, each. Cereal grain production revealed the highest requirement of fuel per product harvested (48 kg per tonne of DM).

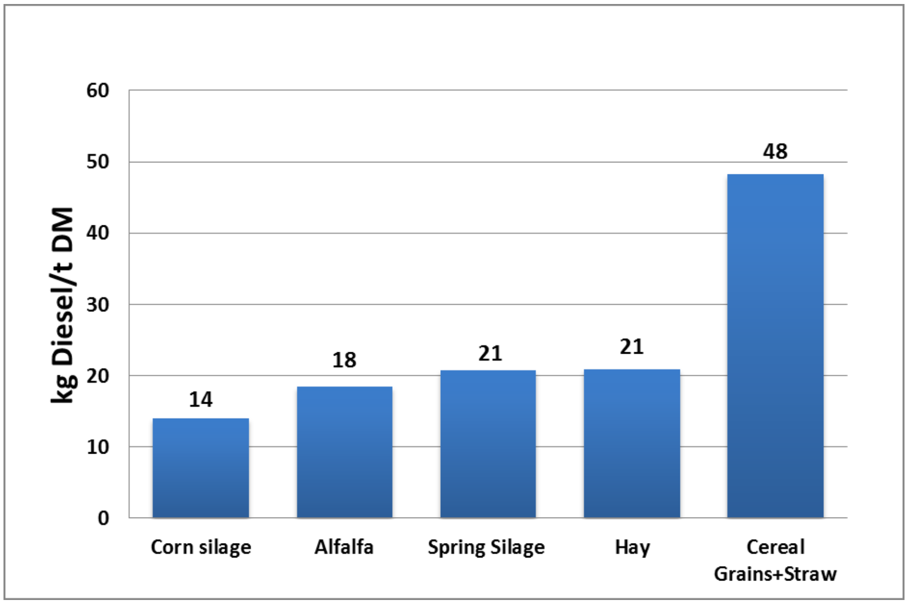


Figure 24. *Diesel consumption per unit of crop harvested*

2.3.4.2 Carbon Dioxide Emission

Table 35 reports the annual CO_2 emissions associated with diesel fuel consumption which corresponds to 1,520 kg CO_2-eq·LC^{-1} and 0.294 kg CO_2-eq per kg of FPCM. When referred to the cultivated land, this indicator accounts for 1,840 kg CO_2-eq·ha^{-1}. The annual emissions from electricity consumption were 205 kg CO_2-eq·LC^{-1} and 0.035 kg CO_2-eq per kg of FPCM, while LPG emissions were lower than the other energy consumptions accounting for 20 kg CO_2-eq·LC^{-1} and $3e^{-3}$ kg CO_2-eq per kg of FPCM.

Table 35. *Emission data summary for group D, averages per farm on a yearly basis (N=44)*

CO_2 emission	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg CO_2-eq)	51,090 (±65,660)	746 (±1,146)	1,520 (±1,539)	1,840 (±2,335)	0.294 (±0.39)
Electricity (kg CO_2-eq)	12,467 (±39,069)	91 (±49)	205 (±137)	378 (±993)	0.035 (±0.026)
LPG (kg CO_2-eq)	963 (±3,294)	9 (±30)	20 (±67)	31 (±94)	0.003 (±0.008)
Total (kg CO_2-eq)	**64,520** (±100,613)	**846** (±1,143)	**1,745** (±1,558)	**2,249** (±2,975)	**0.332** (±0.396)

The overall carbon dioxide equivalent emissions, expressed as average per farm on a yearly basis, were 64.5 tonnes of CO_2-eq per year that corresponds to 1,745 kg CO_2-eq per lactating cow and 0.332 kg CO_2-eq per kg of FPCM. Figure 25 shows the annual carbon dioxide emission (diesel plus electricity) allocated to each farm operations, where diesel consumptions for feed preparation and distribution represents the 25% of the total, followed by irrigation (23%) and field operations (20%). Slurry management accounted about 17% of the total CO_2 emissions. The electricity usage amounted for a minor part of the total carbon dioxide emissions, in fact, the operations carried out at the milking parlor was responsible only for 7% of the total emissions.

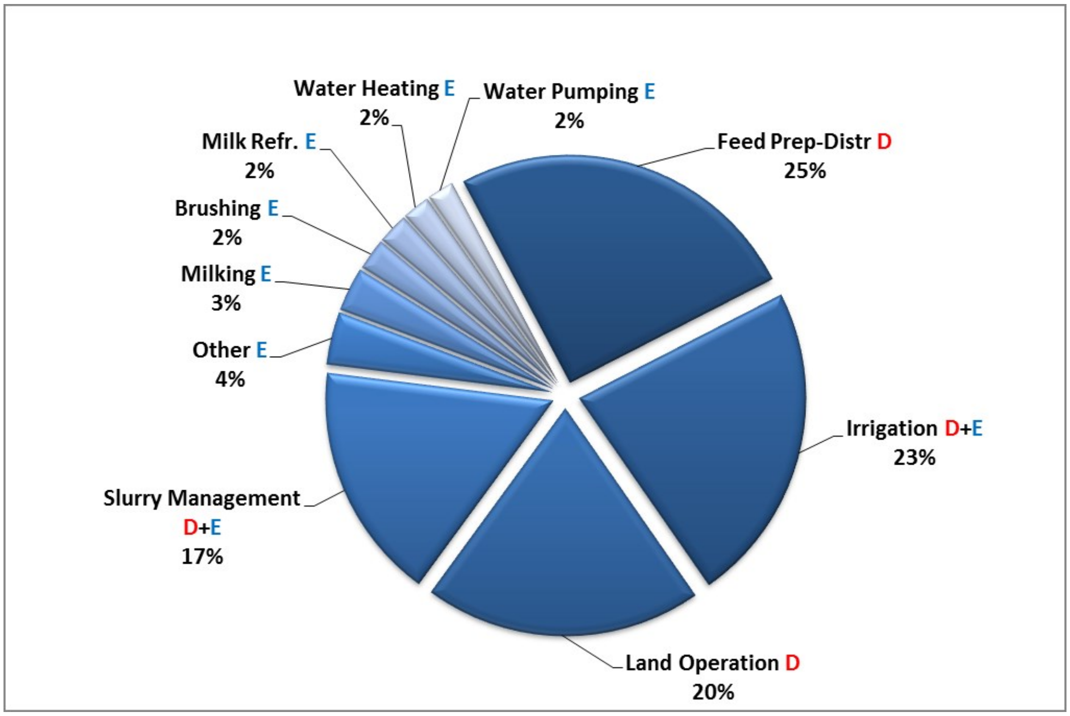


Figure 25. *Allocation of GHG emissions from electricity (E) and Diesel (D) among farm operations.*

As explained in table 36 the highest number of farms, 22, were located in the "less than 50 heads" group, while only 5 farms belonged to the group "greater than 200 heads". Results also showed emissions of carbon dioxide equivalent were negative related with the herd size of farms, in fact: 37.23 kg CO_2-eq·100 kg $FPCM^{-1}$ in farms with a herd size less than 50; 41.48 kg CO_2-eq·100 kg FPCM^{-1} per farms belonged to the class between 50 and 100 heads; 17.79 kg CO_2-eq·100 kg FPCM^{-1} per farms in class with herd size between 100 and 200 heads and 15.44 kg CO_2-eq·100 kg FPCM^{-1} per farms with a herd dimension over than 200 heads.

Table 36. *Herd size class for group D, averages per farm on a yearly basis (N=44)*

Herd size class	**<50**	**50-100**	**100-200**	**>200**
Farms (n)	22	11	6	5
Heads (n)	31	63	147	537
Lactating cows (n)	15	30	66	257
Milk production (t)	88	192	392	2,128
Milk yield (t/LC)	6.34	6.05	6.29	7.74
Land (ha)	19	31	57	72
LPG (kg)	50 (±131)	391 (±1,039)	80 (±130)	1,789 (±2,855)
LPG emission (kg CO2eq)	136 (±377)	1,123 (±2,982)	230 (±372)	5,134 (±8,193)
Diesel (kg)	6,212 (±5,302)	17,103 (±14,716)	16,844 (±11,207)	57,556 (±33,694)
Diesel emission (kg CO2eq)	19,567 (±16,703)	53,875 (±46,356)	53,060 (±35,301)	181,302 (±106,137)
Electricity (kWh)	7,776 (±5,027)	12,675 (±7,927)	19,569 (±8,650)	181,809 (±254,118)
Electricity emission (kg CO2eq)	3,190 (±2,063)	5,200 (±3,253)	8,029 (±3,549)	74,596 (±104,265)
Total kg CO2eq/100 kg milk	**37.23** (±47.9)	**41.48** (±37.7)	**17.79** (±12.2)	**15.44** (±7.79)

Table 37 shows the emissions of CO_2-eq based on 4 classes of milk yield (tonnes of milk per lactating cow a year). 19 farms were located in the “5-8 t of FPCM” group, while 13 farms held milk yield less than 5 tonnes. Further analysis demonstrated that the emissions of carbon dioxide equivalent were higher in farms belonged to lower milk yield class. Only the group “greater than 10” showed higher carbon dioxide emission due to the small number of farms placed in this class.

The emissions trend were: 64.06 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms in class with yield lower than 5 tonnes; 22.44 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms belonged to class with FPCM yield between 5 and 8 tonnes; 15.21 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms in class with milk yield between 8 and 10 tonnes and 27.82 kg CO_2-eq·100 kg $FPCM^{-1}$ per farms in class with milk yield over than 10 tonnes.

Table 37. *Milk yield class for group D, averages per farm on a yearly basis (N=44)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	13	19	10	2
Heads (n)	51	90	253	12
Lactating cows (n)	23	44	118	3
Milk production (t)	74.3	287	1,050	43.5
Milk yield (t/LC)	3.74	6.54	8.90	14.1
Land (ha)	29	39	34	7
LPG (kg)	76 (±146)	187 (±556)	1,022 (±2,226)	-
LPG emission (kg CO2eq)	219 (±419)	538 (±1,595)	2932 (±6,390)	-
Diesel (kg)	12,790 (±12,505)	13,671 (±13,310)	27,934 (±35,994)	4,142 (±4,149)
Diesel emission (kg CO2eq)	40,289 (±39,389)	43,064 (±41,928)	87,991 (±113,382)	13,047 (±13,070)
Electricity (kWh)	7,979 (±4,867)	18,009 (±16,315)	88,679 (±194,305)	1,960 (±19)
Electricity emission (kg CO2eq)	3,274 (±1,997)	7,389 (±6,694)	36,385 (±79,723)	804 (±8)
Total kg CO2eq/100 kg milk	**64.06** (±58.7)	**22.44** (±20.05)	**15.21** (±9.04)	**27.82** (±14.4)

2.3.4.3 Economic Aspects

Table 38 illustrates costs associated to the use of energy sources: diesel fuel accounts for 16,117 euro, which represents 479 euro per lactating cow and 9.24 euro per 100 kg of milk sold.

Table 38. *Costs of energy usage for group D, averages per farm on a yearly basis (N=44)*

	Average	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (Euro)	16,117 (±20,718)	236 (±3.62)	479 (±486)	580 (±737)	9.24 (±12.4)
Electricity (Euro)	5,560 (±17,425)	40 (±22)	92 (±61)	169 (±443)	1.57 (±1.13)
LPG (Euro)	229 (±753)	2.0 (±6.99)	4.3 (±14.6)	6.8 (±21)	0.06 (±0.19)
Total Costs (Euro)	**21,906**	**278**	**575**	**756**	**10.9**

The farm average euro spent per electricity were 5,560, 92 euro per lactating cow and 1.57 euro per 100 kg FPCM when referred to the milk production. The annual average cost of LPG purchased was 229 euro per farm, which corresponded to 4.3 euro per lactating cow and 0.06 euro per 100 kg of milk produced. The diesel fuel represents 73.6% of the total cost, followed by electricity 25.4% and LPG which accounted only for 1.04%.

Using Energy Saving Devices (ESD) allowed reducing energy requirement of farms. Table 39 shows that using Variable Drive Speed (VDS) permitted an economy of 0.17

euro per 100 kg of FPCM. The Milk Pre-cooler (MP) allowed to save 2,773 euro, which corresponds to 0.13 euro per 100 kg of milk produced, while the Heat Recovery System (HRS) saved 470 euro per farm and 0.03 euro per 100 kg of FPCM sold.

Table 39. *Economic and environmental results through the use of ESD, averages per farm having ESD on a yearly basis.*

	Number of Farms	**Saved kWh per Farm/y**	**kWh/100 kg FPCM**	**Kg CO2-eq/Farm**	**Euro Total/Farm**	**Euro/100 Kg FPCM**	**Power kWp**
Variable Drive Speed	2	24,660	9	10,118	4,439	0.17	-
Milk Pre-cooler	3	15,406	7	6,321	2,773	0.13	-
Heat Recovery	3	2,614	2	1,072	470	0.03	-
Photovoltaic	3	19,100	43	7,837	3,438	0.78	27 (18-36)
Solar panel	0	0	0	0	0	0	-
Anaerobic Digestion	2	2,949,786	746	1,210,297	530,961	13.4	-
Eolic	0	0	0	0	0	0	-

As shown in table 40, 43.2% of farms are located into the group with milk yield between 5 and 8 tonnes of FPCM per year, while 29.5% belonged to the group less than 5 tonnes of milk per year. The trend of costs showed a decrement of 64% in farms belonged to the group from 5 to 8 tonnes of milk yield (7.51 euro) instead farms which had milk yields lower than 5 tonnes (20.82 euro), while 33% of reduction was recorded per farms located in group from 8 to 10 tonnes of milk yield (5.04 euro) instead farms which had milk yields between 5 and 8 tonnes.

Table 40. *Costs of energy usage for milk yields class, averages per farm on a yearly basis (N=44)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	13	19	10	2
Heads (n)	51	90	253	12
Lactating cows (n)	23	44	118	3
Milk production (t)	74.4	287	1050	43.5
Milk yield (t/LC)	3.74	6.54	8.90	14.1
Land (ha)	29	39	34	7
LPG (kg)	76	187	1022	0
LPG cost (Euro)	49	119	649	0
Diesel (kg)	12,790	13,671	27,934	4,142
Diesel cost (Euro)	12,709	13,585	27,757	4,116
Electricity (kWh) *	7,979	18,009	88,679	1,960
Electricity cost (Euro)	1,460	3,296	16,228	359
Total costs (Euro/100 kg milk)	**20.82** (±18.4)	**7.51** (±6.59)	**5.04** (±2.86)	**9.06** (±4.37)

**On-farm electricity production from renewable sources was not included*

2.3.5 Overall Results

The overall results of the studied farms are summarized in table 41. The total average herd size was 127 heads (ranging from a minimum of 6 heads to a maximum of 1,320 heads). The largest dimension was observed from group A (177heads), while group C had the lowest average (82 heads). The outcomes of the analysis showed a positive correlation between herd size and milk yield, intensive farms were able to achieve higher level in milk yield (table 41). Global results about diesel consumption, related with on-farm activities, showed an average fuel combustion of 13,675 kg per year, which corresponds to 264 kg of diesel per lactating cow and 0.040 kg of diesel per kg of FPCM. Similar results were obtained in all the groups analyzed, except for the group D which showed greater values in terms of diesel used per lactating cow (482 kg) and per kg of milk sold per year (0.093kg). Considering the characteristic among different groups (discussed in the previous paragraphs) appears that greater levels of diesel usage in group D were due to the high number of irrigation systems. The annual electricity consumption showed high variability among farms, with average values from 31,636 kWh per group A to 21,265 kWh per group C, respectively. Observing the electricity EUI per lactating cow (434 kWh·LC^{-1}) and milk produced (0.058 kWh·kg FPCM^{-1}), farm of group A detained at the same time, the lowest values of consumption, while farms of group C showed the higher indices expressed per lactating cow (561 kWh·LC^{-1}) and kg of milk sold (0.088 kWh per kg FPCM). Group A showed a high efficiency of energy utilization expressed per herd size and milk production than group D.

Table 41*. Overall results for energy intensity referred to 285 dairy farms, averages on a yearly basis*

Overall Results	**A**	**B**	**C**	**D**	**A+B+C+D**	**SD**	**Min**	**Max**
Number of farms	83	88	70	44	285	-	-	-
Total heads (n)	177	124	82	112	127	142	6	1,320
Lactating cows (n)	79	55	41	53	58	62	2	600
Milk yield (t/LC)	9.61	8.57	6.97	7.32	7.69	2.58	1.16	15.0
Total land (ha)	52	40	42	39	44	43	2	338
Total Diesel (kg)	17,424	12,321	9,332	16,219	13,675	15,085	425	117,380
Diesel per Lact. Cow (kg)	222	209	229	482	264	250	23	2,679
Diesel per kg FPCM (kg)	0.027	0.028	0.036	0.093	0.040	0.056	0.004	0.715
Total Electricity (kWh)	31,636	23,051	21,265	30,385	26,283	42,463	1,633	626,828
Electricity per Lact. Cow (kWh)	434	489	561	500	494	242	135	2,134
Electricity per kg FPCM (kWh)	0.058	0.067	0.088	0.086	0.075	0.054	0.021	0.465
Total LPG (kg)	60	109	39	360	109	497	0.0	6,545
LPG per Lact. Cow (kg)	1.2	2.2	1.2	6.8	2.4	10.3	0.0	145
LPG per kg FPCM (kg)	7.9E-5	2.4E-4	1.7E-4	1.0E-3	3.5E-4	1.3E-3	0.0	0.017

The consumption of LPG was very low in all farms, showing an average demand of 109 kg per year, where group D held the highest consumption (360 kg) and group C recorded the lowest value of consumption (39 kg). These results are higher than those found in similar studies carried out on European dairy farms. In a French study conducted by L'Institut de l'Elevage (2009) which involved 60 dairy farms (milk yield 7.2 t LC^{-1} per year) the EUI was 420 $kWh \cdot LC^{-1}$ and 0.059 kWh per kg of milk per year; only group A held lower value expressed per kg of milk sold (0.058 kWh). These values are 15% lower than the present study in terms of kWh for lactating cows and 21% lower if referred to the unit of milk. Similar values were reported in an Italian study carried out on 60 dairy farms (milk yield 8 tonnes LC^{-1} per year) in the Emilia Romagna region (Rossi, 2012): 510 kWh per cow per year and 0.064 kWh per kg of milk per year. A German study (Jäkel, 2003) carried out on 41 dairy farms shows an average EUI of 0.09 kWh per kg of milk, a value that is 16.6% higher of the present result. The EUI of 0.05 kWh per kg of milk obtained in a previous study carried out in Sardinia (Murgia et al., 2008) is similar to the results of the present study per farms located in Sardinia (0.058 kWh per kg milk). The differences in farm technology and in milk yield per cow affect significantly the energy efficiency indicators.

To compare all the energy used at farm level, the values recorded have been expressed as fossil primary energy consumed (MJ). Large productions of milk allow reducing the consumption of electricity per unit of milk sold.

Table 42. *Overall results for direct energy demand expressed as primary energy (averages per farm on a yearly basis)*

Overall Results	**Group A**	**Group B**	**Group C**	**Group D**	**A+B+C+D**	**Min**	**Max**
Number of farms	83	88	70	44	285	-	-
Total heads (n)	177	124	82	112	127	6	1,320
Lactating cows (n)	79	55	41	53	58	2	600
Milk yield (t FPCM/LC)	9.61	8.57	6.97	7.32	7.69	1.16	15.0
Total land (ha)	52	40	42	39	44	2	338
Total Diesel (MJ)	801,504	566,766	429,272	746,074	629,050	19,550	5,399,480
Diesel per Lact. Cow (MJ)	10,212	9,614	10,534	22,172	12,144	1,058	123,234
Diesel per kg FPCM (MJ)	1.24	1.29	1.66	4.28	1.84	0.18	32.9
Total Electricity* (MJ)	286,939	209,073	192,874	275,592	238,387	14,811	5,685,330
Electricity* per Lact. Cow (MJ)	3,936	4,435	5,088	4,535	4,481	1224	19,355
Electricity* per kg FPCM (MJ)	0.53	0.61	0.80	0.78	0.68	0.19	4.22
Total LPG (MJ)	3,036	5,515	1,973	18,216	5,515	0	331,177
LPG per Lact. Cow (MJ)	61	111	61	344	121	0	7337
LPG per kg FPCM (MJ)	0.0040	0.0121	0.0086	0.0506	0.0177	0	0.860
Total Primary Energy (MJ)	**1,091,479**	**781,354**	**624,119**	**1,039,882**	**872,952**	**34,361**	**11,415,987**
Total per Lact. Cow (MJ)	**14,209**	**14,161**	**15,683**	**27,051**	**16,746**	**2,282**	**149,926**
Total per kg FPCM (MJ)	**1.77**	**1.91**	**2.46**	**5.11**	**2.54**	**0.37**	**37.97**

Table 42 reports an average consumption of 2.54 MJ per kg FPCM of primary energy. Diesel fuel consumption represents the main resource used, with 1.84 MJ per kg of milk which denotes the 72.4% of the total primary energy requirement, while electricity consumption represents the 26.8%.

Large differences were observed among groups, where groups A and B reported a total consumption of primary energy of 1.77 and 1.91 MJ per kg of milk respectively. Groups C showed 2.46 MJ per kg of milk of primary energy used, while group D held the highest value 5.11 MJ per kg of milk, which is about 2 times higher than the average observed for 285 farms. Groups which held high level of diesel consumption corresponds low indices of fuel usage expressed per cow or milk produced. Observing allocation results of diesel usage for each group of farms, land operations and feed preparation and distribution were found to be the most demanding activities at farm level. Also, intensive farms resulted more efficient in terms of fuel usage; in facts, small farms, in terms of land extent, held an elevated ratio of $kW{\cdot}ha^{-1}$ causing larger amount of fuel usage (figure 26) as discussed in the previous paragraph. Moreover, the same trend of power employed was observed in feed preparation and distribution activities (figure 27). The power ratio ($kWh{\cdot}head^{-1}$) found for feed management decline when herd size increase, the efficient fuel use for feed operations were lower in larger farms rather than small farms.

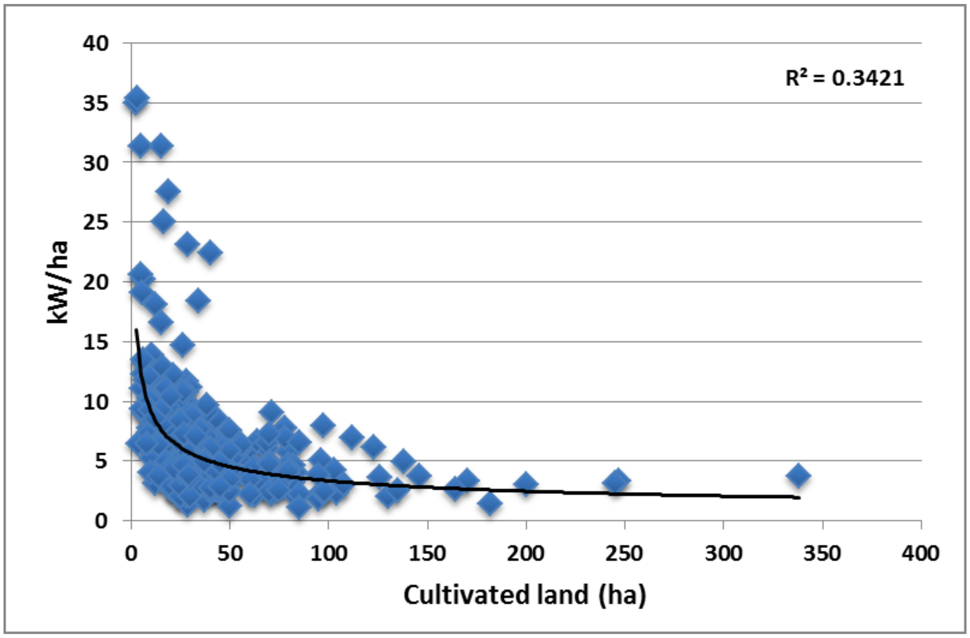


Figure 26. *Powers of tractors per hectare (kW/ha) against cultivated land (ha).*

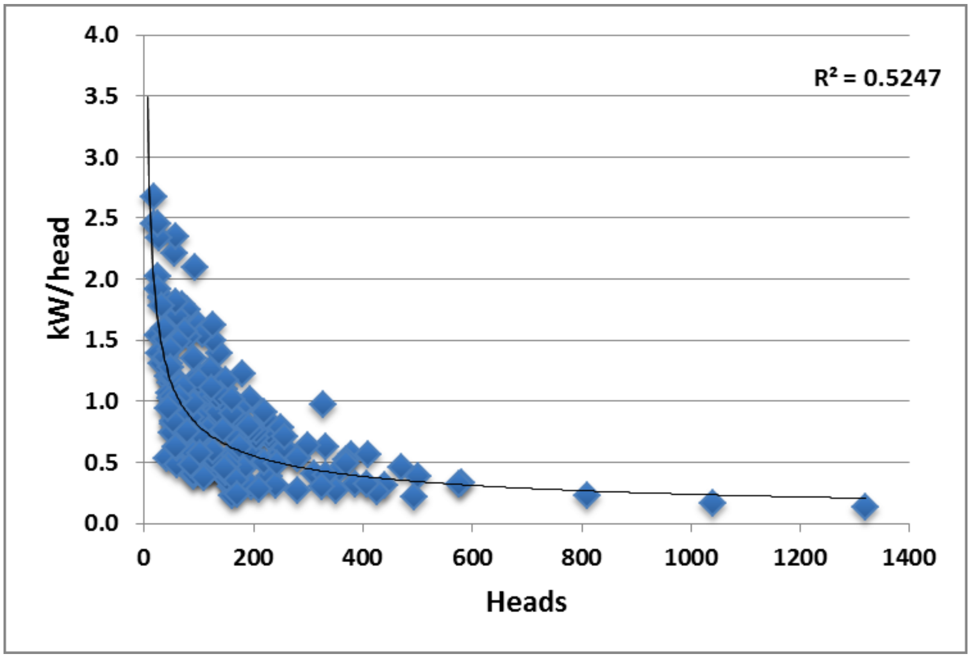


Figure 27. *Machinery power used for feed preparation and distribution per head* (kWh·head^{-1}) *against total number of heads*

Critical points of electricity consumption were found at milking parlor. Observing total electricity consumption and related indices it appears evident the advantage deriving from economies of scales.

Figure 28 shows the time spent for milking expressed as minutes per milked cow against number of milked cows. When the number of milked cows increased, the time for milking operations declined, thus demonstrating a reduction of electricity consumption in larger farms rather than farms with smaller herd size.

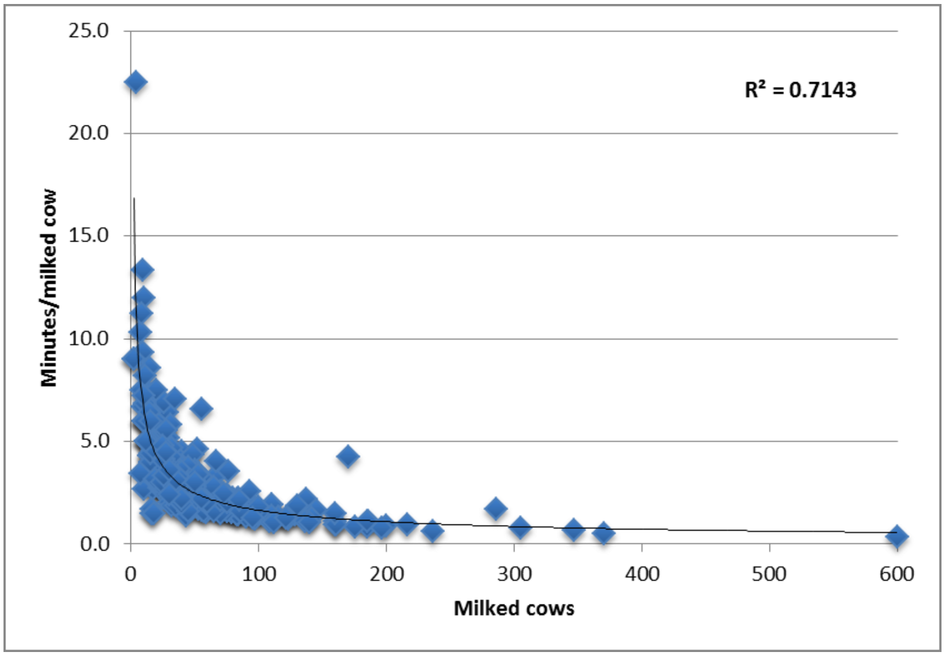


Figure 28. *Minutes spent per milking operation and number of milked cows*

The annual overall carbon dioxide emissions associated with diesel fuel inputs were, an average 819 kg CO_2-eq·LC^{-1} and 12.5 kg CO_2-eq per 100 kg of FPCM (table 43). When referred to the land extent this indicator was 1,162 kg CO_2-eq·ha^{-1}.

The global annual emissions from electricity supply were 202 kg CO_2-eq per lactating cow and 2.99 kg CO_2-eq per 100 kg of FPCM. The emissions related to the usage of LPG were 6.94 kg CO_2-eq per lactating cow and 0.09 kg CO_2-eq per 100 kg of FPCM.

The total farm average emission of carbon dioxide equivalent, due to all energy usages, accounted for 54 t CO_2-eq per year that corresponds to 1,028 kg CO_2-eq per lactating cow and 15.6 kg CO_2-eq per 100 kg of FPCM. Considering the emission avoided through the production of renewable energy (2,151 kg CO_2-eq) the overall final emissions were 52 t CO_2-eq per year, which correspond to 999 kg CO_2-eq per lactating cow and 15.2 kg CO_2-eq per 100 kg of milk sold. The avoided emissions allowed reducing 4% of total farms emission and 2.6% of CO_2-eq emission expressed for 100 kg of FPCM per year.

***Table 43**. Emission data summary for all farms, averages per farm on a yearly basis (N=285)*

Carbon dioxide emission	**Average**	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (kg CO_2-eq)	43,076	387	819	1,162	12.5
Electricity (kg CO_2-eq)	10,792	93	202	336	2.99
LPG (kg CO_2-eq)	314	3.11	6.94	10.2	0.09
Total emissions (kg CO_2-eq)	**54,182**	**483**	**1,028**	**1,509**	**15.6**
Renewable energy (kg CO_2-eq)	2,151	13.2	28.9	54.5	0.42
Total emissions (kg CO_2-eq)	**52,031**	**470**	**999**	**1,454**	**15.2**

Table 44 presents the emissions of CO_2-eq based on class of milk yield (t FPCM per lactating cow a year) for all groups. Four classes, less than 5 tonnes of milk to over 10 tonnes of milk sold, were set to identify emissions trend.

Table 44. *Milk yields class for all groups, averages per farm on a yearly basis (N=285)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	40	111	81	53
Heads (n)	55	90	167	200
Lactating cows (n)	26	42	75	89
Milk production (t)	94.3	283	674	976
Milk yield (t/LC)	3.76	6.59	8.93	11.1
Land (ha)	29	33	46	56
LPG (kg)	49	88	205	91
LPG emission (kg CO_2eq)	140	248	538	243
Diesel (kg)	7,902	9,810	17,374	20,473
Diesel emission (kg CO_2eq)	24,891	30,901	54,729	64,489
Electricity (kWh)	10,884	20,683	35,553	35,570
Electricity emission (kg CO_2eq)	4,466	8,486	14,587	14,594
Total emissions (kg CO_2eq/100 kg FPCM)	**31.3**	**14.0**	**10.4**	**8.13**
Renewable electricity (kWh)	2,999	3,290	4,243	16,543
Renewable emission avoided (kg CO_2eq)	1,144	1,232	1,498	5,832
Total emissions (kg CO_2eq/100 kg FPCM)	**30.1**	**13.6**	**10.1**	**7.53**

Most of the farms, (111) were located in the “5-8 t of FPCM” group, followed by farms with milk yield from 8 to 10 tonne of milk sold (81), 53 farms were situated in group “bigger than 10 t FPCM”, while 40 farms belonged to the group “less than 5 t of

FPCM". The study also showed that farms with higher milk yields were associated with higher herd size. Also, the results demonstrated that the emissions of carbon dioxide equivalent were negative related with milk yield, in particular: 31.3 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield lower than 5 tonnes; 14 kg CO_2-eq per 100 kg FPCM per farms belonged in class with FPCM yield between 5 and 8 tonnes; 10.4 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield produced between 8 and 10 tonnes and 8.13 kg CO_2-eq per 100 kg FPCM per farms in class with milk yield over 10 tonnes. Comparing the extremity values (31.3 vs 8.13) of carbon dioxide emissions; farms with higher milk yield were able to produce milk emitting 3.8 times less CO_2-eq than farms with lower milk yield. These results clearly showed that intensive farms held lower CO_2-eq emission when referred to the mass of milk produced.

2.3.5.1 Overall Economic Aspects

The costs related to the use of each energy source are shown in table 45. Diesel fuel accounted as the highest part of the costs related to the energy purchased, with an average of 13,589 euro per farm, which corresponds to 262 euro per lactating cow and 4.0 euro per 100 kg of milk sold. Electricity supply was responsible of 4,810 euro as average per farm, 90 euro per lactating cow and 1.4 euro per 100 kg FPCM when reported to the milk production. The purchased of LPG represent the lowest part of total energy costs, with an average of 69 euro spent per farm, which corresponds to 1.5 euro per lactating cow and 0.022 euro per 100 kg of milk produced. Expressing these values as percentage of total energy expenditure, diesel fuel represents the 73.6% of the total cost, followed by electricity usage, 26% and LPG which accounted only for the 0.37%.

Table 45. Energy economic aspects for 285 dairy farms on a yearly basis

Overall Results	**A**	**B**	**C**	**D**	**A+B+C+D**	**Min**	**Max**
Number of farms	83	88	70	44	285	-	-
Lactating cows (n)	79	55	41	53	58	2	600
Milk yield (t FPCM/LC)	9.61	8.57	6.97	7.32	7.69	1.16	15
Total Diesel (euro)	17,314	12,243	9,273	16,117	13,589	422	116,639
Diesel per Lact. Cow euro)	221	208	228	479	262	23	2662
Diesel per 100 kg FPCM (euro)	2.7	2.8	3.6	9.2	4.0	0.4	71
Total Electricity (euro)	5,789	4,218	3,891	5,560	4,810	299	114,710
Electricity per Lact. Cow (euro)	79	89	103	92	90	25	391
Electricity per 100 kg FPCM (euro)	1.1	1.2	1.6	1.6	1.4	0.4	8.5
Total LPG (euro)	38	69	25	229	69	0	4156
LPG per Lact. Cow (euro)	0.8	1.4	0.8	4.3	1.5	0	92
LPG per 100 kg FPCM (euro)	0.005	0.015	0.01	0.063	0.022	0	1.08
Total costs (euro)	**23,141**	**16,530**	**13,189**	**21,906**	**18,468**	**721**	**235,505**
Euro per Lact. Cow	**301**	**298**	**332**	**575**	**354**	**48**	**3,145**
Euro per 100 kg FPCM	**3.81**	**4.02**	**5.21**	**10.8**	**5.42**	**0.8**	**80.6**

Considering the price of milk sold in 2010, which corresponded to 31.64 euro per 100 kg (ISMEA, 2012), the average cost endured from farms for energy purchased represents the 17% (expressed per 100 kg of milk). Different results appear observing group A (10.4%) or group D (34%). However, as discussed in the previous chapters, farms which adopt renewable systems for electricity generation, may reduce costs related with energy purchased. The photovoltaic system was the renewable source more adopted from farms with 11% of presences (32 plants in 285 farms), while anaerobic digestion systems were found only in 3 farms.

Table 46. *Costs of energy usage for milk yields class, averages per farm on a yearly basis (N=285)*

Milk yield (t of FPCM/LC)	**<5**	**5-8**	**8-10**	**>10**
Farms (n)	40	111	81	53
Heads (n)	55	90	167	200
Lactating cows (n)	26	42	75	89
Milk production (t)	94.3	283	674	976
Milk yield (t/LC)	3.76	6.59	8.93	11.1
Land (ha)	29	33	46	56
LPG (kg)	49	88	205	91
LPG costs (euro)	31	56	130	58
Diesel (kg)	7902	9810	17374	20473
Diesel cost (euro)	7852	9748	17265	20343
Electricity (kWh)	10884	20683	35553	35570
Electricity cost (euro)	1992	3785	6506	6509
Total costs (euro/100 kg FPCM)	**10.5**	**4.81**	**3.55**	**2.76**

The costs associated to the energy usage were strictly related with the milk yield (expressed per tonne of FPCM per lactating cow per year), in fact, as shown in table 46 total cost were negative related with milk yield.

In particular; energy cost per farms located in group “lower than 5” supported the highest level of costs with 9.89 euro per 100 kg of milk sold; farms with milk yield between 5 and 8 tonne held costs for 4.59 euro per 100 kg of FPCM; group “8-10 tonne” deal with cost of 3.43 euro per 100 kg of milk; farms with milk yield over 10 tonnes deal with costs about 2.45 euro per 100 kg of FPCM per year.

The consumption of energy lead to generate environmental impacts through emission of greenhouse gas, which were proportional related to the quantity of fossil products used, and at the same time to the costs supported from farms.

The overall relationship between carbon dioxide emissions and costs per 285 farms was equal to an expenditure of 0.346 euro for each kg of CO_2-eq emitted (SD ±0.018).

2.4 Conclusions and Perspective

Environmental sustainability is a topic whose importance has increasing more and more in the last few years. In these circumstances the study carried out could represent an important tool to help researcher and stakeholder to better understand energy trend use in dairy farms. Electricity and fuel consumption in dairy farms represent the 6% of total on-farm GHG emission into the environment. The present study determined the energy requirements for diesel, electricity and LPG at farm level, also underlining the critical point where mitigation strategies are needed. Additionally renewable electricity generation was considered as a mitigation strategy to compensate the GHG impact of milk production. Final results of carbon dioxide emissions from fossil energy usage showed that 79% of the emissions were due to the combustion of diesel, 20% to electricity supply and 1% to LPG consumption, figure 29.

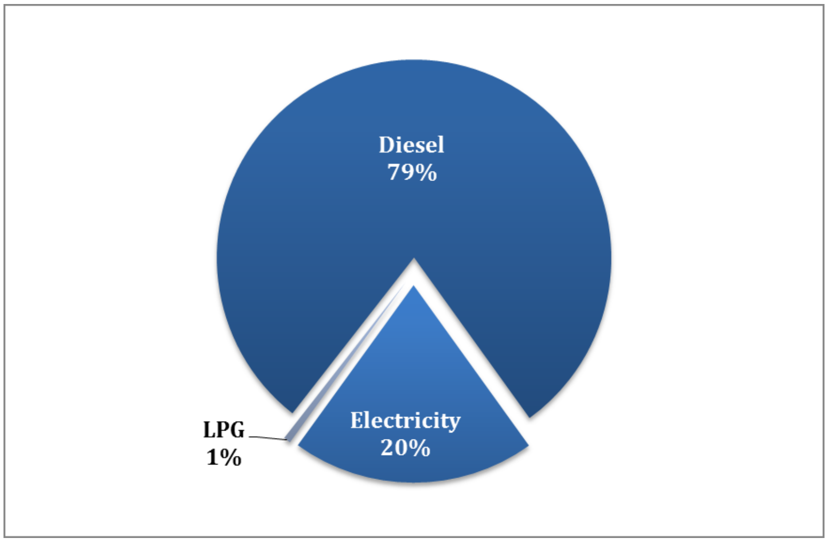


Figure 29. *Carbon dioxide emission among fossil energy consumption (N=285).*

These results underline the need to focus the mitigation strategies mainly in fuel usage, especially for those operations as feed management, land cultivation operations and irrigation, which are the most energy demanding tasks.

The operations associated to animal feeding and crop cultivation required the largest quota of total fuel consumption. The analysis carried out in this study showed lower level of machinery power per unit of cultivated land when the cultivated hectares decreased. Bodria et al., in 2006 showed 8 kW per hectare as the utilization coefficient of power used per unit of cultivated land per livestock Italian farms. In particular low level of utilization coefficient was found in farms with cultivated land was more than 20 hectares.

Appears evident how important is to size the fleet equipment for the efficiency of mechanized process, according to the real needs of the farm. High power coefficient of utilization caused high level of diesel consumption per cultivated hectare. Fuel requirement for cultivation could be reduced adopting minimum tillage techniques which decrease either the depth in tillage or the number of field operations. Also significant fuel reduction can be obtained through the use of new machineries which are more efficient in the use of fuel.

Electricity requests in the dairy farms involved in the study were mainly due to the operations regarding the milking parlour (milking, milk refrigeration and water heating), which required the major part of total electricity consumption. Figure 30 shows the power installed for the vacuum pump against the total number of milked cow, when number of lactating cow increase, the power found at milking parlour level decrease.

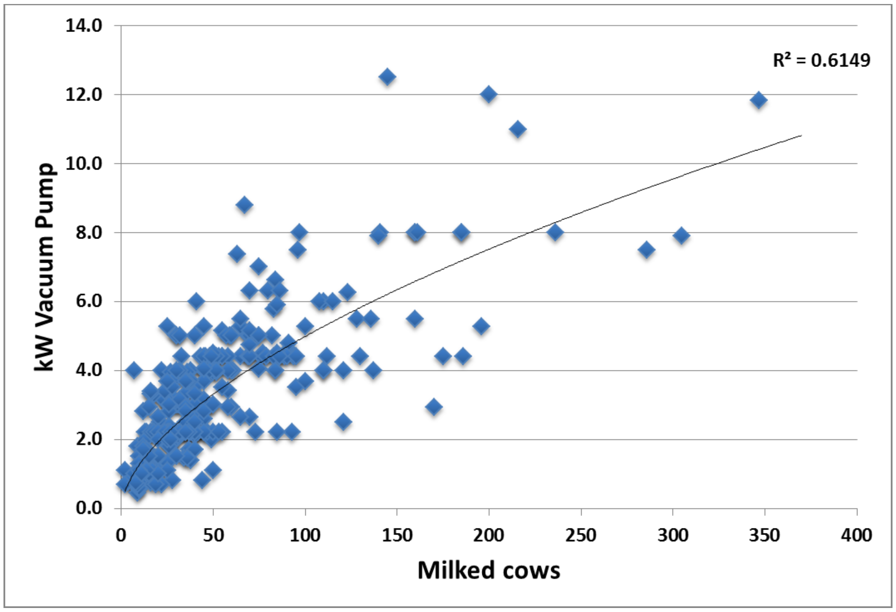


Figure 30. *Relation between power of vacuum pump installed and milked cows.*

A large number of the investigated farms already used energy saving technologies, such as heat recovery system from cooling tanks, variable drive speed connected to the vacuum pump and milk pre-coolers. Improving energy savings allow to reduce the electricity demand, especially for those equipment that need high electricity input.

The production of renewable energy represents an important tool to reduce the energy intensity and the related environmental load of dairy farms. In this study the most common renewable system adopted from farms was the photovoltaic system for electricity generation. The production of energy by photovoltaic systems is able to fit the electricity trend demand in dairy farms, as shown in the example of figure 31. Generally, the electricity consumption shows peak of request during the summer period due to the higher requests of energy for cooling the cowshed, milk refrigeration and irrigation. Photovoltaic generation follows the natural variability of solar radiation, with higher production during the summer period, peak value in July and minimum during winter months. Therefore PV energy generation can partially supply the demand of electricity during the lower peak of energy generation, but even exceed during the higher peak production. In this case, the surplus of electricity production is injected to the grid and sold.

The PV electricity generation allows decreasing the high peak demand of grid energy during summer period, reducing the emission of carbon dioxide and the cost of the electricity purchased.

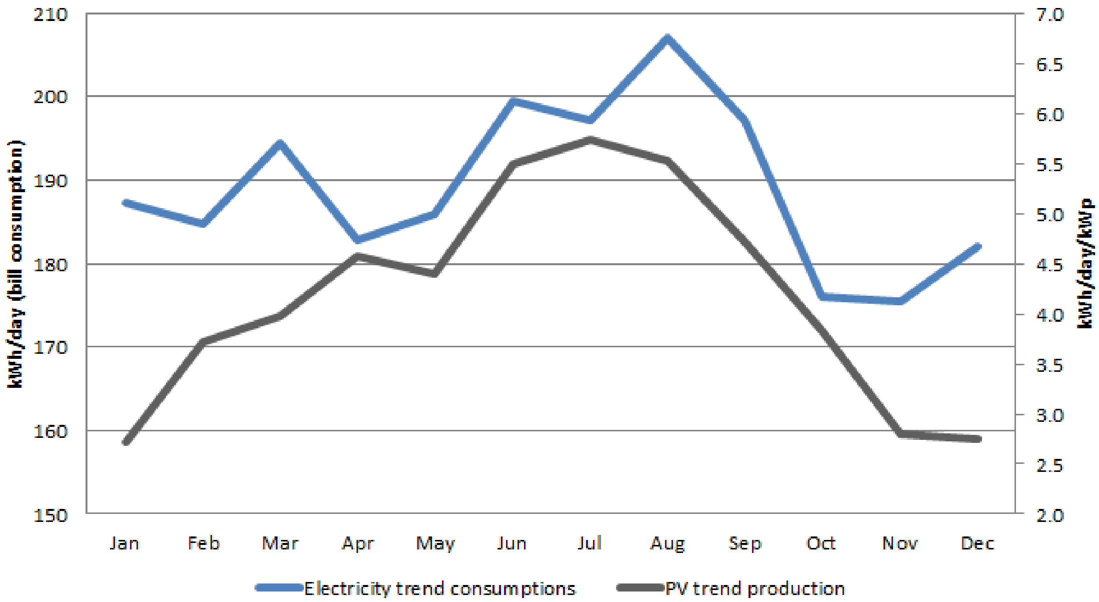


Figure 31. *Monthly electricity consumptions and photovoltaic production.*

Reducing electricity and diesel consumption leads to decrease anthropogenic gas emissions into the environment, to reduce costs for the farms and to improve the efficient use of natural resources.

CHAPTER III

LINEAR MODELS TO PREDICT DIESEL AND ELECTRICITY CONSUMPTION IN DAIRY FARMS

3.1 Introduction

Knowledge about the use of fossil fuel in the agriculture system is needed, since it could improve the understanding how to reduce the unsustainable use of non-renewable resources and the related GHG emissions (Dalgaard et al., 2001).

Find the agricultural production method with higher energy efficiency is a challenge that began years and years ago. Issues related with the use of fossil energy in agriculture came into focus in the 1970's as a result of the dramatic increase of oil price. The need of reducing energy consumption through more efficient working methods has lead to propose methodologies of energy analysis applied to agriculture process (Odum, 1971; Pimentel et al., 1973). Recent studies, associated with LCA analysis, from cradle to farm dairy gate, showed a wide range of input request.

The LCA methodology takes into account the whole process to assess the environmental impact of a product. Regarding the energy input in dairy farms, the scientific literature utilized several methodologies to include energy usage in environmental analysis. Data source comes generally from national statistic (Basset-Mens et al., 2005; Capper et al., 2009; Flysjö et al., 2011; Henriksson et al., 2011) or real farms with the collection of direct measure (Thomassen et al., 2008; Van der Werf et al., 2009; Schils et al., 2006; Kristensen et al., 2011; Haas et al., 2001).

Rotz et al., (2010) developed a model to assess production alternatives, different cropping systems, harvest strategies and feed preservation methods. Also, the model takes into account several energy indices when GHG emissions are calculated.

The lack of knowledge in the prediction of energy demand of dairy farms was found in the scientific literature. The analysis of energy receipts is not easy to carried out in dairy farms. For instance, diesel purchased receipts do not take into account the operation carried out by contractors. Diesel and electricity receipts often refer to other farm activities besides milk production (i.e. farms with dairy cows and sheep or swine or poultry), so that it is very difficult to identify the real specific requirements of milk production. The aim of this study was to develop two linear models to estimate the consumption of diesel and electricity, the related emission of carbon dioxide and costs in dairy farms.

3.2 Materials and Methods

The data collected (table 1) in 285 Italian dairy farms was used to develop linear models in order to model the electricity and diesel consumptions of dairy farms. Statistical analyses were carried out in R Studio (version: 2.15.2).

Table 1. *Data summary*

Data Observed	Minimum	Mean	Maximum	N.
Diesel (kg· year^{-1})	489	13,120	92,430	241
Electricity (kWh ·year^{-1})	1,085	16,250	91,420	273
Heads (N)	6	127	1,320	285
Milking Cows (N)	2	58	600	285
Milk (t· year^{-1})	15	495	5323	285
Land (ha)	3	44	338	285

Two linear regression models were developed using total fuel consumption (TFC, kg·year^{-1}) and electricity consumption (TEC, kWh·year^{-1}) as responses and total number of heads, total number of lactating cows, milk production (kg FPCM), and land area (hectares) as primary independent variables.

$$Y_i = \beta_0 + \beta_1 X_{1i} + \ldots\ldots + \beta_p X_{pi} + e_i$$

Y_i = observed diesel (kg) or electricity (kWh) consumption in i^{th} farm

i = 1, 2, 3,……, 273 farms

β_0 = intercept

β = fixed effect of independent variables

X_{1i} = total number of heads in i^{th} farm

X_{2i} = total hectares of land in i^{th} farm

X_{3i} = total kg of milk produced in i^{th} farm

X_{pi} = total number of lactating cows in i^{th} farm

e_i = residual error $N(0, I\sigma_e^2)$

Variable selection was not based on stepwise method since the high correlation among the independent variables was observed. To avoid multicollinearity a correlation matrix was set, as a variable selection method, in order to identify the correlation among the independent variables and the dependent variables. When regressed individually, larger farms appeared to utilize electricity (figure 1) and diesel more efficiently (figure 2).

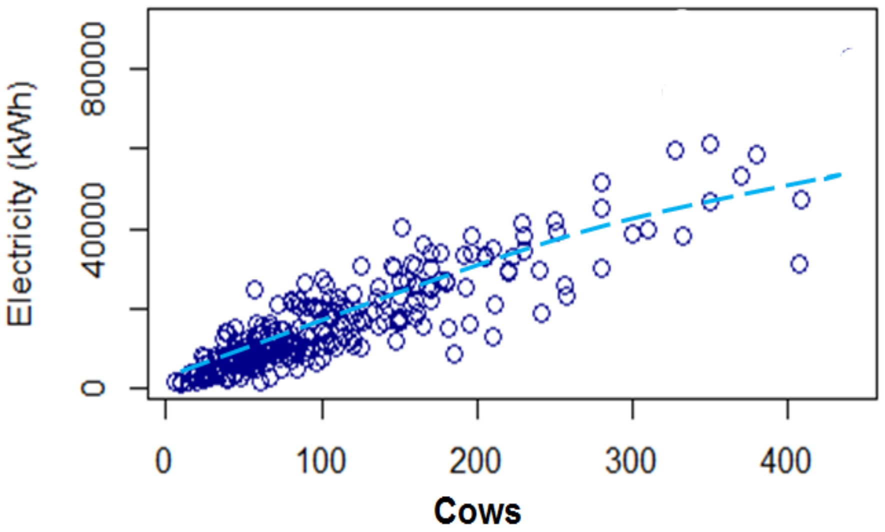


Figure 1. *Trend of electricity consumption against number of heads.*

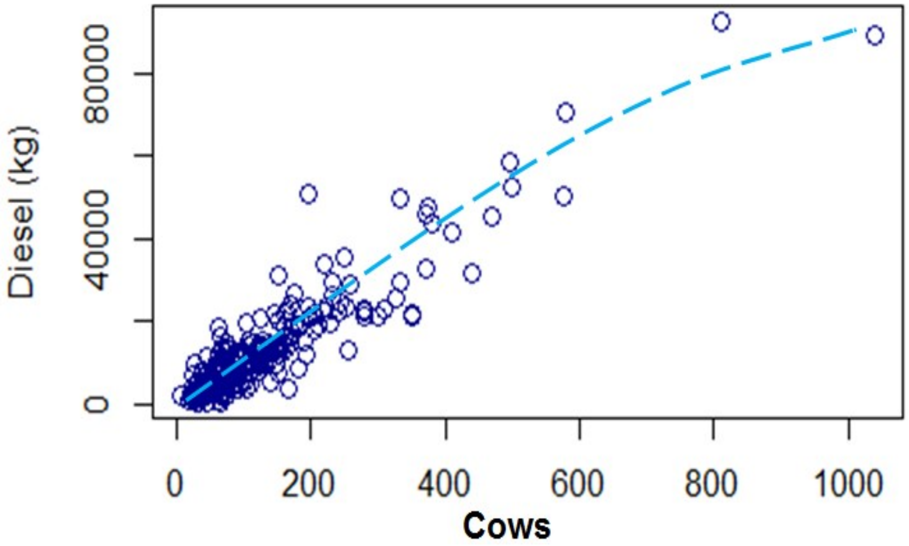


Figure 2*. Trend of diesel consumption against number of heads*

Therefore, second and third order polynomial terms of total number of heads and number of lactating cows were tested through Akaike Information Criterion (AIC) and Variance Inflation Factor (VIF). AIC is a measure of the relative quality of a set of models, lower AIC value represent models which minimize the information lost. VIF allow identifying the correlation between variables, values lower than 10 are considered not affected of multicollinearity.

Moreover, a binary variable was developed to represent presence (1) or absence (0) of mechanized diesel feed operations.

Since a significant heteroscedasticity was observed in residuals, the TFC and TEC were power-transformed ($TFCT = TFC^{0.46}$; $TECT = TEC^{0.33}$) as suggested by Breusch-Pagan test (Breusch and Pagan, 1979). The “SpreadLevelPlot” function was selected to suggest the best power transformation for each dependent variable, separately.

Finally, Leave One Out Cross Validation (LOOCV-Kohavi, 1995) was used for the models evaluation. The LOOCV estimated overall error on model predictions in terms of mean square prediction error (MSPE), which was then decomposed into systematic error including mean bias (MB), and slope bias (SB), and unexplained residual bias (RB). Root-MSPE was then expressed as a percentage (RMSPE %) of the average observed fuel and electricity consumption.

Additionally, the prediction values from the models were used to develop a mathematical function in the R software to demonstrate the applicability of the models developed in this study. The function is able to estimate and list several quantities and indices related to annual energy usage in dairy farms.

3.3 Results and Discussion

Final regression models for each response with parameter and standard errors in parentheses are listed below:

3.3.1 Diesel Model

The results observed for the diesel model showed that when analyzed together, the intercept, the total number of present cows, the total number of present cows cube, the total hectares cultivated and the binary variable for mechanized feeding were significantly ($P<0.05$) associated with diesel consumption. Therefore all these variables were included in the final model. The R^2 of the final model was equal to 0.94 which indicate that the model can explain the 94% of variation in diesel consumption in dairy farms.

$$TFC^{T} = 23.5\ (\pm 1.88) + 0.18\,(\pm 0.01) \times Total\,cows - 1.3E^{-07}\ (\pm 1.3E^{-08}) \times Total\ cows^{3} + \\ 0.34\,(\pm 0.03) \times Land\,(ha) + 15.4\,(\pm 2.03) \times Mechanized\ \ feeding$$

Where:

TFC^{T}_{i} = *kg of diesel/year in* i^{th} *farm*

Total cows$_i$ = *total number of heads in* i^{th} *farm*

Total cows$_i^3$ = *total number of heads cube in* i^{th} *farm*

Land$_i$ = *total hectares of land used in* i^{th} *farm*

Mechanized feeding$_i$ = *present (1) or absent (0) of feed mechanization in* i^{th} *farm*

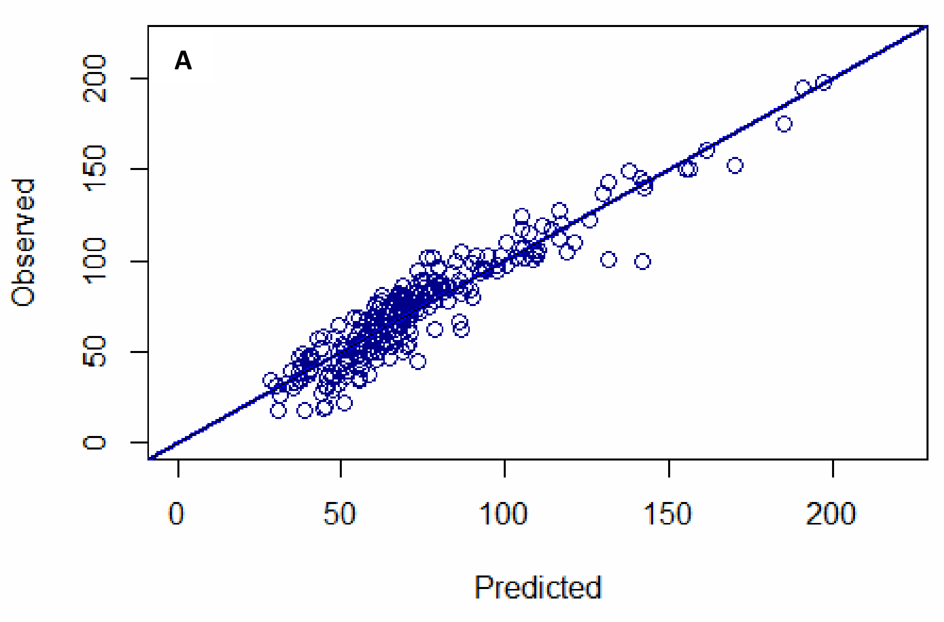


Figure 3. Prediction accuracy evaluation plots of diesel consumption

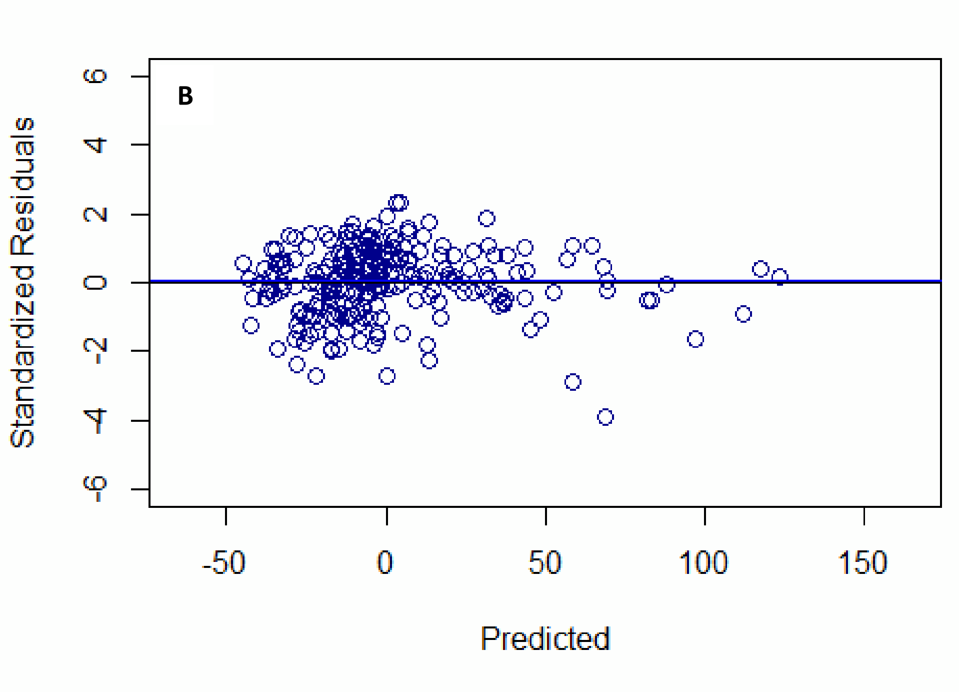


***Figure 4.** Prediction accuracy evaluation plots of diesel consumption*

As shown in figure 3, the regression line of observed value against predicted values, overlaps the line of unity (slope=1). This indicates that the model could predict diesel consumption without any under or over prediction bias. Figure 4, shows the regression line of the standardized residual versus predicted values which overlaps the line crossing zero residuals. The standardized residuals did not show evident pattern, proving that the residual are randomly distributed (homoscedasticity).

Table 2 presents prediction error analysis results from the model evaluation.

The regression model is able to predicted, with a relative slight mean error (MB), fuel consumption in dairy farms since the root mean square error (RMSPE) was 14.96% of the average observed value, while the non-systematic bias (RB) was 99.98%.

Table 2. *Diesel model evaluation (Cross validation method) results.*

Cross Validation	**RMSPE (%)**	**MB (%)**	**SB (%)**	**RB (%)**
Diesel	14.96%	0.003%	0.01%	99.98%

3.3.2 Electricity Model

When analyzed together, the intercept, the total number lactating cows and the related polynomial term of third degree were significantly ($P < 0.05$) associated with electricity consumption in dairy farms. Therefore all these variables were included in the final model. The R^2 of the final model was equal to 0.90 which indicate that the model can explain the 90% of variation in electricity consumption in dairy farms.

$$TEC^{T} = 14.3(\pm 0.37) + 0.19(\pm 0.009) \times Lactating\ cows - 1.9E^{-06}(\pm 3.7E^{-07}) \times Lactating\ cows^{3}$$

Where:

TEC^{T}_{i} = *kWh of electricity/year in i*th *farm*

Lactating cows$_i$ = *total number of heads in i*th *farm*

Lactatingcows$_i^3$ = *total number of heads cube in i*th *farm*

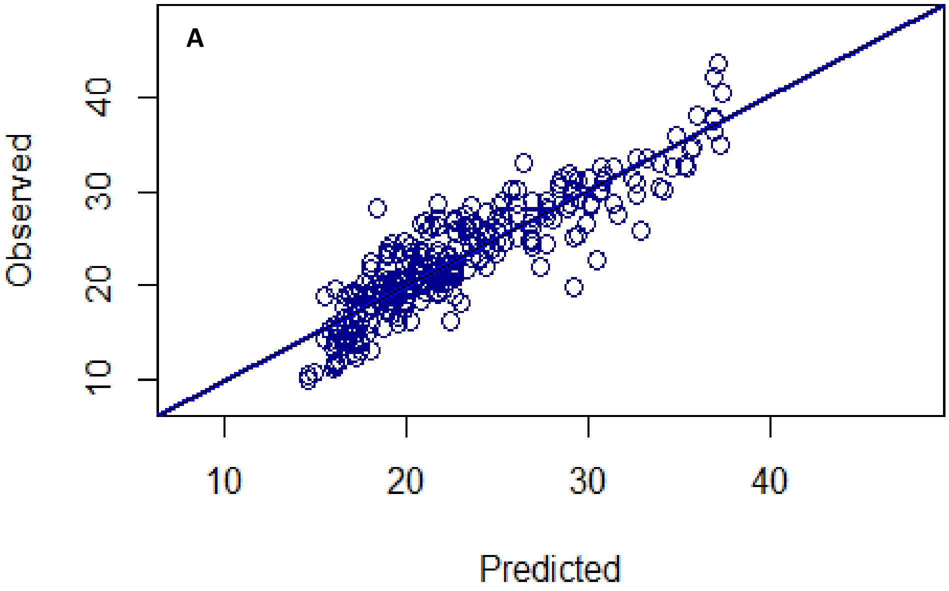


Figure 5. *Prediction accuracy evaluation plots of electricity consumption*

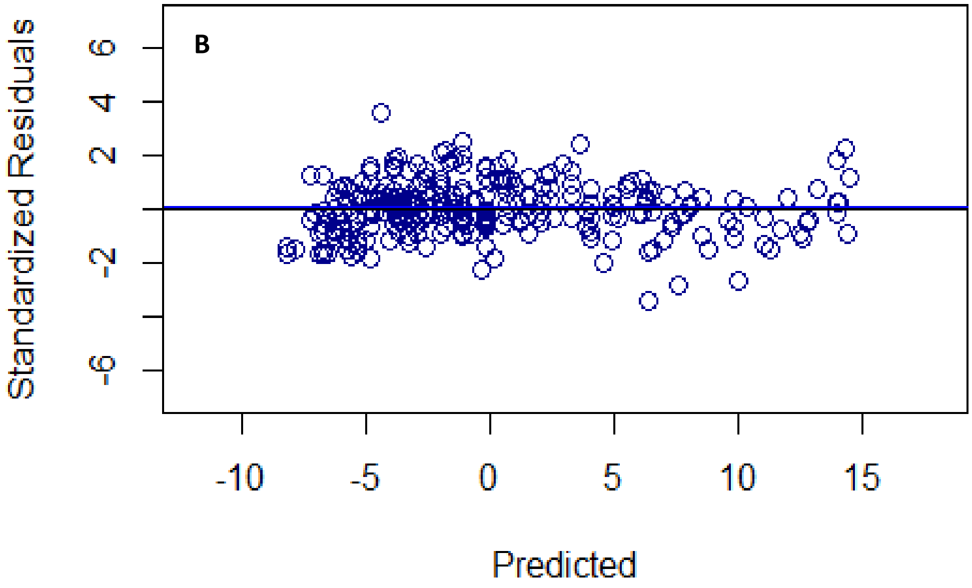


Figure 6. *Prediction accuracy evaluation plots of electricity consumption*

Figure 5 shows the regression line of observed value against predicted values, which overlaps the line of unity (slope=1). This indicates that the model could predict electricity consumption without any under or over prediction bias. Figure 6 shows the regression line of the standardized residual versus predicted values which overlaps the line crossing zero residuals. The standardized residuals did not show evident pattern, proving that the residual are randomly distributed (homoscedasticity).

Table 3. *Electricity model evaluation (Cross validation method) results.*

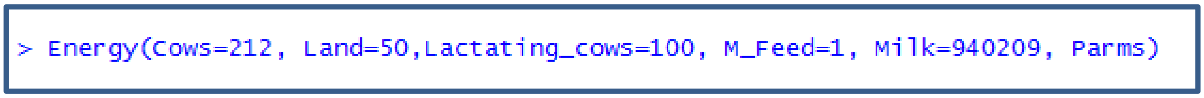
Cross Validation	RMSPE (%)	MB (%)	SB (%)	RB (%)
Electricity	11.42%	0.000%	0.001%	99.99%

As shown in table 3, the regression model is able to predicted, with a relative slight mean bias, electricity consumption in dairy farms since the root mean square bias was 11.42% of the average observed value and the non-systematic error represents the 99.99%.

3.3.3 Energy Function

The energy function built through the parameter estimate of electricity and diesel models is able to list several indices related with energy consumption in dairy farms.

A simulation of a dairy farm was created as example to observe the prediction of the function. As shown in figure 7, the simulated dairy farm held 212 heads, 50 hectares of cropped land, 100 lactating cows, 940,209 kg of milk produced per year. The binary variable was set equal to 1, indicating that the farm was equipped with mechanized feed operation. The word "Parms" contains the parameter used to assess the overall calculation, such as specific emission factor and costs for diesel and electricity.



```
> Energy(Cows=212, Land=50,Lactating_cows=100, M_Feed=1, Milk=940209, Parms)
```

Figure 7. *Energy function input request from R studio script.*

The function output (table 4) gives totals, head, land and milk production-specific estimates of diesel and electricity usage and their costs; additionally CO_2 emissions from each or both fuel and electricity usage were listed.

***Table 4**. Summary output of the energy function*

	Total	**Energy Utilization Indices**		
		Per Head	**Per Land(ha)**	**Per Milk (kg)**
Diesel kg	18,945	89	379	0.020
Diesel MJ	871,470	4,094	17,434	0.920
Diesel Emis. kgCO_2-eq	59,677	281	1,193	0.063
Diesel Cost €	21,787	103	436	0.023
Electricity kWh	34,368	162	687	0.037
Electricity MJ	311,717	1,469	6,231	0.336
Electricity Emis. kgCO_2-eq	14,101	67	282	0.015
Electricity Cost €	6,186	29	124	0.007
Total Emis. kgCO_2-eq	73,778	348	1,476	0.078
Total Costs €	27,973	132	559	0.030

The strength of this function is sited on the simplicity, with four basic information about dairy farm (number of heads, lactating cows, cultivated hectares and kg of milk production) we are able to predict electricity and diesel consumptions (unit specific and MJ), list several energy utilization indices to allow comparisons between farms, estimate carbon dioxide emission from energy uses and give an economic evaluation of costs supported for energy purchase. The energy function can be used by researcher to estimate the amount of energy required by dairy farms (i.e. LCA studies, economic evaluation, environmental assessment, etc.). As shown in the function's output the indices could help to understand the critical point of the process and identify the mitigation strategies suitable for each step of consumption.

3.4 Conclusions

Environmental sustainability is a topic whose importance has increasing more and more in the last years. In these circumstances the study carried out could represents an important tool to help researcher and stakeholder to better estimate the requirements in dairy farms.

The relationship among the energy consumption and the selected independent variables allowed to develop linear models to predict diesel and electricity consumption with small errors. The application of both models is being tested with the “Energy function” developed, which allow to determine several results regarding energy consumption in dairy farms.

Future works will be focused to develop models able to predict the distribution of electricity and diesel consumption in relation to the farm operations. That will help to understand were the critical point of the process needs to be carefully analysed, with the final aims to reduce energy consumption, CO_2 emission and related costs in dairy farms.

CHAPTER IV

A PARTIAL LIFE CYCLE ASSESSMENT APPROACH TO EVALUATE ENERGY INTENSITY AND RELATED ENVIRONMENTAL LOADS IN CONVENTIONAL AND ORGANIC FARMS

4.1 Introduction

In 2009, the agricultural sector in Unite States was responsible for about 7.4% of total GHG emissions (EPA, 2011). According to the US Environmental Protection Agency EPA, total GHG emission rose of 7.3% since 1990 to 2009 (figure 1), while the agriculture sector increased its emission of 14.2% (EPA 2011).

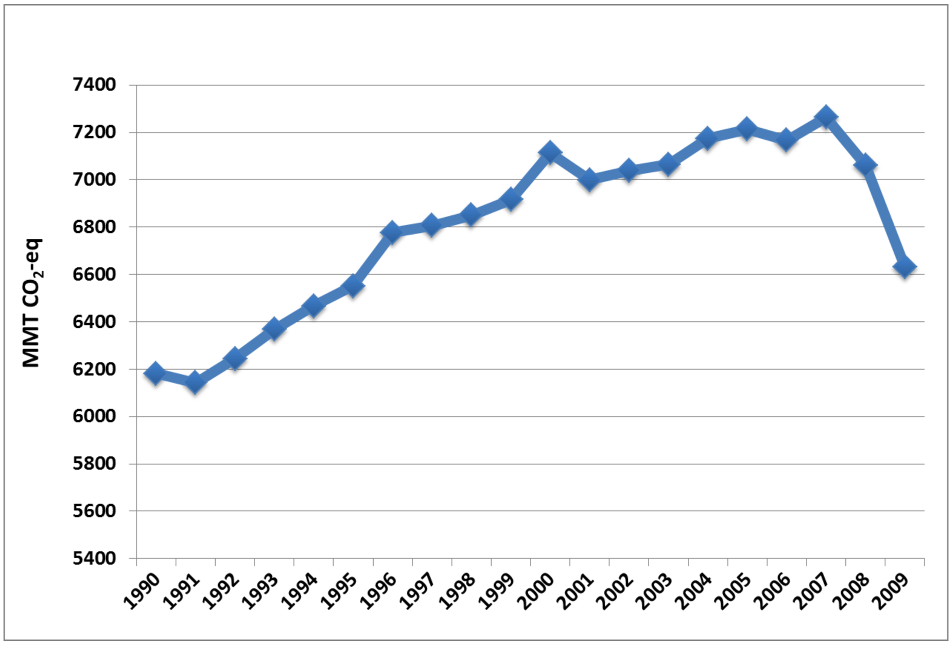


Figure 1. *US GHG trend from 1990 to 2009 (EPA 2011)*

Sustainability and environmental impact of agriculture productions represent one of the most debated issues in the last years. In this context, organic farming is considered more environmental friendly and sustainable than conventional farming systems. As defined by the United States Department of Agriculture (USDA) National Organic Standards, organic dairy products are made from milk of animals raised under organic management. The cows are raised in a herd separate from conventional dairy cows and are not given growth hormones or antibiotics. The animals do receive preventive medical care, such as vaccines, and dietary supplements of vitamins and minerals. All organically raised dairy cows must have access to pasture, the outdoors, shade, shelter, exercise areas, fresh air, and direct sunlight suitable to their stages of production, the climate, and the environment (Federal Register, 2008).

The organic food sector has consistently risen between 15% and 20% annually over the past decade. In particular the organic dairy food has grown between 16% and 34% in the last years (Dimitri and Oberholtzer, 2009).

A suitable methodology to assess environmental impact of products, process or services is represented to a Life Cycle Assessment (LCA). The LCA methodology has been used to assess complex agricultural systems including milk production. Several studies were carried out to assess the environmental burden in conventional and organic farms all over the world. In accordance to Pirlo, (2012) several studies, which compared the GHG emissions in organic and conventional dairy farming, showed in 2 cases (Netherlands and Denmark) that GHG emission associated with organic farming were higher than conventional milk system (Thomassen et al., 2008; Kristensen et al., 2011), while (Cedeberg and Mattsson, 2000; Haas et al., 2001) showed lower GHG emission from organic dairy farming in Sweden and Germany. Comparing organic and conventional farming through LCA methodology and considering the environmental impacts based only on Global Warming Potential, lead to weak the general benefit of organic farming. Nemecek et al., (2011) showed that organic farming produce benefit in terms of environmental impact. Lack of knowledge was found in the scientific literature regarding specific analysis in energy consumption for organic farms and in particular, studies about energy intensity comparison between conventional and organic dairy systems.

Therefore, the objectives of this study were to assess the energy intensity in organic and conventional dairy cattle, to identify the allocation of energy usages among the different on-farm operation, to evaluate the emission of carbon dioxide associated to the energy usage and give an economic evaluation, related to energy costs, for organic and conventional dairy system production.

4.2 Materials and Methods

4.2.1 Data and Farm Characteristic

A study was conducted in 8 dairy farms located in the State of California, USA. The survey involved 4 conventional dairy farms and 4 organic dairy farms located in the northern Central Valley and northern California (figure 2). The data collection regards harvest year 2011-2012. The approach used for the current study followed the LCA methodology as described in chapter 2.2.

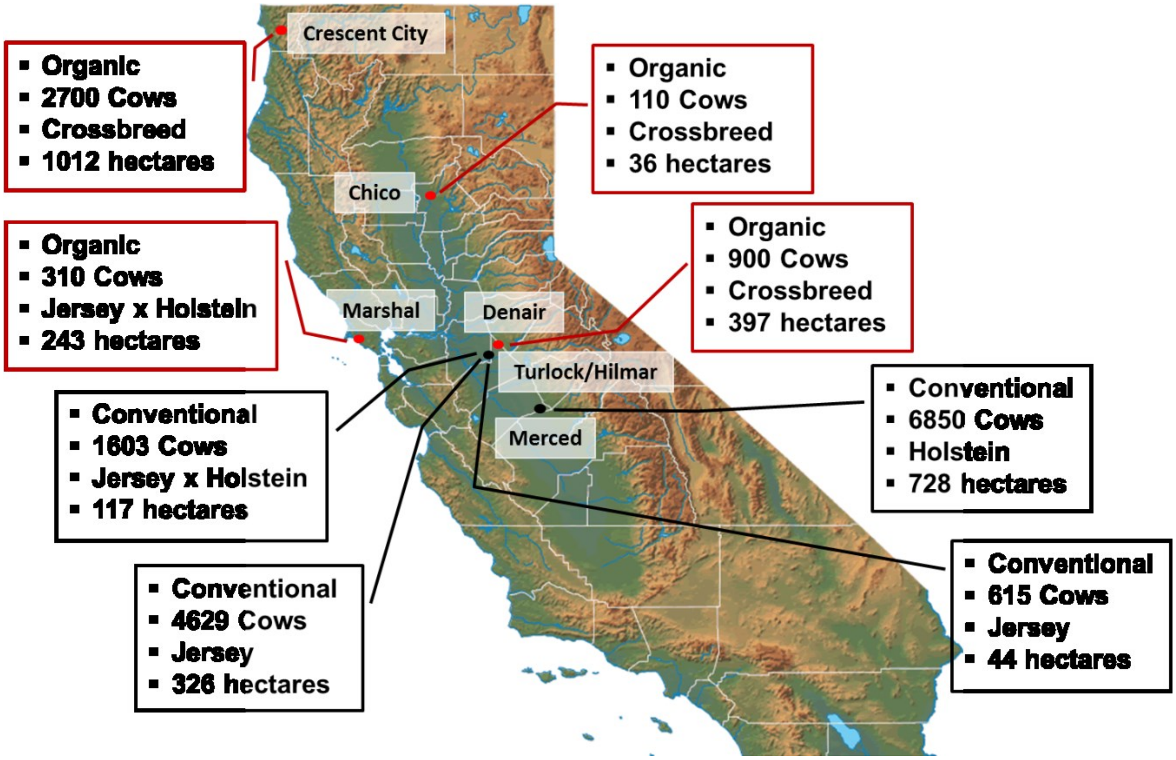


Figure 2. *Conventional and organic farms involved in the study*

4.2.2 Goal and Scope Definition

The goals of this study were to define the energy (electricity, diesel, gas and renewable energy) intensity of the investigated farms, to identify the distribution of energy usage among on-farm activities, to estimate the emission of GHG related to the use of energy. Moreover, an economic evaluation associated to the energy costs was carried out in the investigated farms. The final objective of this study was to compare the energy impact of organic and conventional dairy farms.

4.2.3 System Boundaries

The system boundaries were set at farm level, from cradle to farm gate and include all the facilities utilized for (figure 3):

- on farm feed production;
- on farm feed preparation and distribution;
- manure management;
- milk extraction (milking operations and refrigeration);
- water supply;
- systems for the production of renewable energy.

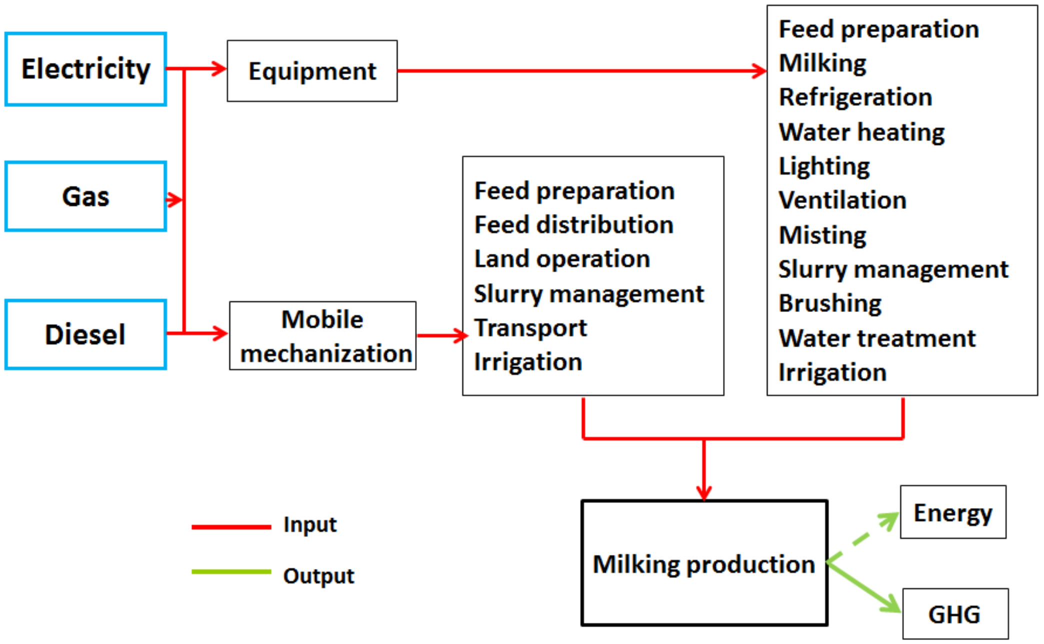


***Figure 3**. Energy flows in dairy milk production*

4.2.4 Functional Unit

The functional unit adopted for this study was 1 kg of Fat and Protein Corrected Milk (FPCM) which allows comparing results among farms.

The equation used to assess the FPCM was derived from IDF 2010 and take into account the yearly production of milk expressed in kg, the percentage of protein and the percentage of fat content.

$$\text{Kg FPCM} = (\text{Milk kg} * ((0.1226 * \text{Fat \%}) + (0.0776 * \text{Protein \%}) + 0.2534)$$

4.2.5 Inventory Analysis (LCI)

Data collection was performed through a questionnaire which required general information such as herd size, animal categories, land used, milk quality and production, and a detailed description of cultivated crops, farm structures, equipment and machinery. The questionnaire utilized in the study described in chapter 2.2, has been converted and adapted to the characteristic of California dairy farms.

Receipts of diesel, electricity, LPG and renewable electricity production were also collected in this study.

4.2.5.1 Electricity Audit

A meticulous electricity auditing was done to allocate the energy consumptions among the different on-farm activities. The overall electrical appliances operating at farm level have been inventoried, reporting the power of each equipment and its usage time (hours per day, days per year) to obtain the annual electricity consumption. Additionally, comparison between the audit data and the electricity receipt were performed to evaluate the conformity of the results.

The detailed explanation of the electricity audit is explained in chapter 2.2.

4.2.5.2 Diesel Audit

A detailed diesel audit was performed to allocate the combustion of fuel among farm activities.

All diesel equipment have been collected, reporting the machinery's power and the usage time of each farm operation (i.e. type of machinery used, power of the machinery, hours per activities and day per year). The estimation of on-farm diesel usage was grouped in four main process, explained in chapter 2.2.

4.2.6 Impact Assessment

To determine the contribution to greenhouse effect from the carbon dioxide emitted, the Global Warming Potential (GWP) was selected. The specific emission factors specific for the State of California were: 0.238 kg CO_2-eq kWh^{-1} (PG&E, 2012) for electricity consumption, 3.15 kg CO_2-eq kg^{-1}(Rotz et al., 2010) to assess the emission from diesel combustion and 2.87 kg CO_2-eq kg^{-1} to calculate the emission from Liquefied Petroleum Gas (LPG).

The related cost accounted for 0.12 euro per kWh of electricity consumed. Diesel costs accounted for 0.67 euro per kg, while LPG usage corresponded to an expenditure of 0.44 euro per kg of product. Cost from renewable energy were set to 0.12 euro per kWh.

4.2.7 Renewable Energy

The study also included the assessment of on-farm renewable energy production of each system ($kWh \cdot year^{-1}$), in order to calculate the reduction of carbon dioxide emitted into the environment and to evaluate the economic benefit derived. To assess the environmental benefit of renewable systems, a net emission factor of -0.2087 kg

CO_2-eq·kWh^{-1} produced was considered, derived from the difference between the index of the California energy mix (0.238 kg CO_2-eq·kWh^{-1}) and the CO_2 emitted during the renewable system production 0.029 kg CO_2-eq·kWh^{-1} (Raugei et al., 2009). Energy production from renewable systems was distributed for the whole group of farm (and related benefit in terms of carbon dioxide avoided) in order to obtain an average values of energy and emissions avoided by the whole group. However, benefits derived from renewable systems have been also analysed separately among farms which adopted that technology.

4.2.8 Allocation

No allocation between milk and meat production were considered in this study, since the farms were specialized exclusively for milk production, therefore meat production were strictly related to the sold of surplus calves and culled cows.

4.2.9 Energy Efficiency, Sustainability and Economic Indicators

The overall data were organized in a data base created on Microsoft Excel. Further calculations were done to determine energy efficiency, sustainability and economic indicators.

The EUIs considered to express electricity consumption were: kWh·head^{-1}, kWh·Lactating Cow^{-1} (LC), kWh·hectare^{-1} and kWh per kg FPCM. In relation to the combustion of diesel fuel the EUIs considered were: kg·head^{-1}, kg·LC^{-1}, kg·hectare^{-1} and kg per kg FPCM. The usage of LPG where structured into EUIs in the same way:

kg·head^{-1}, kg·LC^{-1}, kg·hectare^{-1}, kg per kg FPCM. Renewable energy production was also express with the EUIs system: kWh·head^{-1}, kWh·LC^{-1}, kWh·hectare^{-1} and kWh per kg FPCM.

As Sustainability Indicator (SI) the emissions of carbon dioxide equivalent was expressed as: kg CO_2-eq·head^{-1}, kg CO_2-eq·LC^{-1}, kg CO_2-eq·hectare^{-1}, kg CO_2-eq per kg FPCM.

The economic evaluation was carried out in this study utilized the follow Economic Indicators (ECI): euro·head^{-1}, euro·LC^{-1}, euro·hectare^{-1} and euro per kg FPCM. The costs per unit of each source considered for the economic evaluation where obtained from the energy receipt analysis. The average values calculated over 2012 prices were: 0.12 euro per kWh, 0.67 euro per kg of diesel fuel, 0.44 euro per kg of LPG.

4.3 Results and Discussion

General informations about dairy farms involved in the study are summarized in table 1. Conventional and organic farms were divided into two separate groups to underline the major difference in terms of herds type, productivity and environmental impacts. The total average herd dimension was 3,424 heads for conventional farms, while organic farms held 1,005 heads as average per farm. The yearly average of milk yield, expressed in tonnes of FPCM per lactating cow, accounted for 12.2 in the conventional farm group and 7.12 in organic farms. Conventional farms used, as average per farm, more land than organic farms: 572 hectares against 422, respectively. Observing the number of workers, it appears evident that conventional farms held a bigger number of personnel rather than organic farms (28 vs 11 units). However, organic farms held a larger number of family workers as average per farm than conventional farms (1.75 vs 0.5 units).

Table 1. *Data summary of the farms participating to the study*

General Information	Unit	Conventional	Organic
Farms	N	4	4
Total heads	N	3,424 (±2,852)	1,005 (±1,179)
Lactating cows	N	1,845 (±1370)	537 (±507)
Milk yield	t FPCM/LC	12.2 (±0.45)	7.12 (±2.5)
Total land used	ha	572 (±550)	422 (±420)
Total workers	N	28 (±22)	11 (±10)
Family workers	N	0.5 (±1)	1.75 (±1.5)

Great differences were observed in relation to the type of herd management (table 2), where conventional farms showed 100% of farms with the cattle confined in barn, while organic farms held 100% of animal on pasture (the confinement of cows into the barn occurs only during the night).

The ratio between number of total cows and the land extent in hectares confirms that conventional farms held the most intensive type of management. Likewise conventional farms showed the highest ratio between number of heads per worker, while the highest ratio between land extent and worker belonged to the organic farms.

Conventional farms held specialized breed for milk production like Holstein and Jersey (25 and 50%, respectively), while organic farms raise 100% a mix of breeds to improve the adaptation for pasture.

Terrain position showed that conventional farms were all located in valley, while organic farms were located for 50% in valley and 50% in hills. Irrigation practices occurred in all the conventional farms, while organic held 58.4% of irrigated land expressed as percentage of the total cultivated land.

***Table 2**. Data summary of farm information*

Farm Information	**Conventional**	**Organic**
Head/hectares	5.98	2.38
Head/worker	123	93
Hectares/worker	20.6	39

The analysis carried out for fleet equipment used for on-farm activities (table 3) showed that conventional farms held the highest number of tractors and self-propelled machinery per farm (5.50 units). However, observing the ratios of machinery power against number of total cows and hectares, the results showed that organic farms held the highest index (0.29 $kW \cdot head^{-1}$), while conventional farms detained the highest ratio for kW per land extent (1.12 $kW \cdot hectare^{-1}$).

Feed preparation and distribution involve different type and categories of equipment. The results show conventional farms with the highest power installed (422 kW as average per farm), however, organic farms belonged the higher ratio of power utilized for feed management per head (0.204 $kW \cdot head^{-1}$).

Table 3. *Data for Fleet equipment and feed management; averages per farms and related indices.*

Fleet equipment	**Conventional**	**Organic**
Tractors + Self-Propelled (n)	5.50	3.75
Total Power (kW)	640	293
kW/head	0.19	0.29
kW/hectare	1.12	0.69
Hectares/machinery	104	113
Feed Preparation-Distribution		
Total power (kW)	422	205
kW/head	0.123	0.204

The information of milking parlour system was listed in table 4. The average number of milking unit was 55 per conventional farms and 32 per organic farms. The related index of lactating cow per milking unit corresponded to 42 per conventional farms and 16 lactating cows per milking unit. Several type of milking parlour were observed during the survey; the most common was the herringbone type for both groups, only one conventional farms was equipped with a rotary milking system.

The average power installed for vacuum pumps showed that conventional farms held the highest value (22 kW), while organic farms were equipped with an average power of 12 kW. The related indices between the power (Watt) installed per lactating cow and the milking time per cow agree with the fact that farms with higher values of Watt·LC^{-1} spent higher time in milking operations. The effect of the economy of scale influences the mechanization level when reported to the herd dimension. Likewise, larger farms are equipped with more appliances holding higher level of power installed per farms, but when reported to the number of heads or land extent (hectares) as indices, larger farms appear utilizing less power per unit.

Table 4. *Milking parlour information. Data for type of milking system and refrigeration*

Milking Parlor	**Conventional**	**Organic**
Milking units (n)	55	32
LC/milking unit	42	16
Total power vacuum pump (kW)	22	12
Watt/LC	14	43
Milking time (minutes/LC)	1.56	2.29

Information in table 5 shows the presence of other equipment as fan and misting system for controlling the temperature comfort of cows in cowshed. Conventional farms were all equipped with fan and misting systems, while organic farms recorded a low presence of fan system (25%). In organic farming cows spent most of the time of the pasture, thus, cowsheds present low level of power installed for fan and misting system as well as lighting and slurry removals. The power for fan and misting system (Watt) referred to the number of total cows, showed that conventional farms held the higher ratio for fan system (10.5 Watt·head^{-1}), while organic farms detained the highest index for misting system (3.37 Watt·head^{-1}).

Electrical brush and water treatment systems were not present in any farms

Table 5. *Other equipment information. Data for fan and misting system*

Other Equipment	**Conventional**	**Organic**
Fan system %	100	25
Total power Watt	44,159	281
Watt/head	10.5	2.55
Misting system %	100	75
Total power Watt	7,875	2,465
Watt/head	2.3	3.37

The removal of slurry from cowsheds was based on the use of flushing systems in all the conventional farms, while half of the organic farms were equipped with flushing system and used of scrapers driven by tractors.

The geographical position of the sampled analysed lead to adopt an irrigation system to supply water during the dry season. Table 6 showed that all the conventional farms utilized an irrigation systems, while in organic farms irrigation occurred for the 75% of the farms. Water sources occurred in different ways among farms; in particular, 75% of conventional farms drew water from the net system where no energy consumption was needed. Organic farms, with irrigation system, were all equipped with electrical pumps to supply irrigation water to crop cultivation.

Table 6. *Irrigation systems*

Irrigation	**Conventional**	**Organic**
Presence %	100	75
Hectares irrigated	304	244
Net system %	75	0
Diesel pumping %	0	0
Electricity pumping %	25	100

Saving devices allow reducing energy consumption in several farm operations. As shown in table 7 all the conventional farms were equipped with variable drive speed (VDS), connected to the vacuum pump of the milking machines, milk pre-coolers (MP) and heat recovery system (HRS) from the refrigeration process, while organic farms showed low presences of VDS device (25%). However, organic farms were all equipped with milk pre-cooler and heat recovery system devices.

The generation of energy from a renewable source was found only in one organic farm, where an anaerobic slurry digester produces biogas for electricity production.

***Table 7.** Saving device information and renewable energy systems*

Saving Devices	Conventional	Organic
Variable Drive Speed (VDS) %	100	25
Milk Pre-cooler %	100	100
Heat Recovering System %	100	100

4.3.1 Energy Intensity

The average annual energy consumption per conventional farms amounted for 145,756 kg of diesel fuel, 1,045,703 kWh of electricity and 18,831 kg of LPG (table 8). Energy consumption for organic farms showed a request of 49,467 kg of diesel, 449,791 kWh of electricity and 11,128 kg of LPG. The energy intensity of dairy farms represents the measure of energy efficiency and it is calculated as index of energy used (EUI) per unit of herd size or milk production. Diesel combustion accounted for 52 $kg{\cdot}head^{-1}$ and 73 $kg{\cdot}head^{-1}$ for conventional and organic farms, respectively. The amounts of fuel per cultivated hectare were 350 kg per conventional farms and 162 kg per organic farms, while diesel consumption, per kg of milk sold, was 0.0071 kg and 0.0164 per conventional and organic farms, respectively. Observing diesel EUIs, results underline higher fuel consumption per head and kg of milk sold in organic farms but lower consumption when expressed in kg of diesel per hectare. Wide use of pasture in organic farms allowed obtaining several benefit in term of fuel saved. Natural pasture does not need many mechanized operation and also, cows self-provide forage in the pasture reducing fuel usage in barn operations.

The electricity EUIs for conventional farms was 293 kWh per head and 0.043 kWh per kg FPCM, while organic farms recorded higher level of electricity consumption: 860 kWh·head^{-1} and 0.189 kWh per kg FPCM.

Table 8. *Energy data summary for Conventional and Organic farms, averages per farm on a yearly basis (N=4+4)*

	Conventional	**Organic**
Diesel (kg)	145,756	49,467
kg/head	52	73
kg/Hectare	350	162
kg/kg FPCM	0.0071	0.0164
Electricity (kWh)	1,045,703	449,791
kWh/head	293	860
kWh/Hectare	1,890	2,189
kWh/kg FPCM	0.043	0.189
LPG (kg)	18,831	11,128
kg/head	9.3	24
kg/Hectare	65	48
kg/kg FPCM	0.0012	0.0041
Renewable energy (kWh)	0	63,198
kWh/head	0	204
kWh/Hectare	0	260
kWh/kg FPCM	0	0.025

The conventional farms EUIs related with LPG consumption was 9.3 kg per cow and 0.0012 per kg of FPCM, while for the organic farms LPG consumption accounted for 24 kg·head^{-1} and 0.0041 kg per kg of FPCM per year. The production of electricity from a biogas plant in one organic farm allowed producing the: 204 kWh per cow and 0.025 kWh per kg of milk sold.

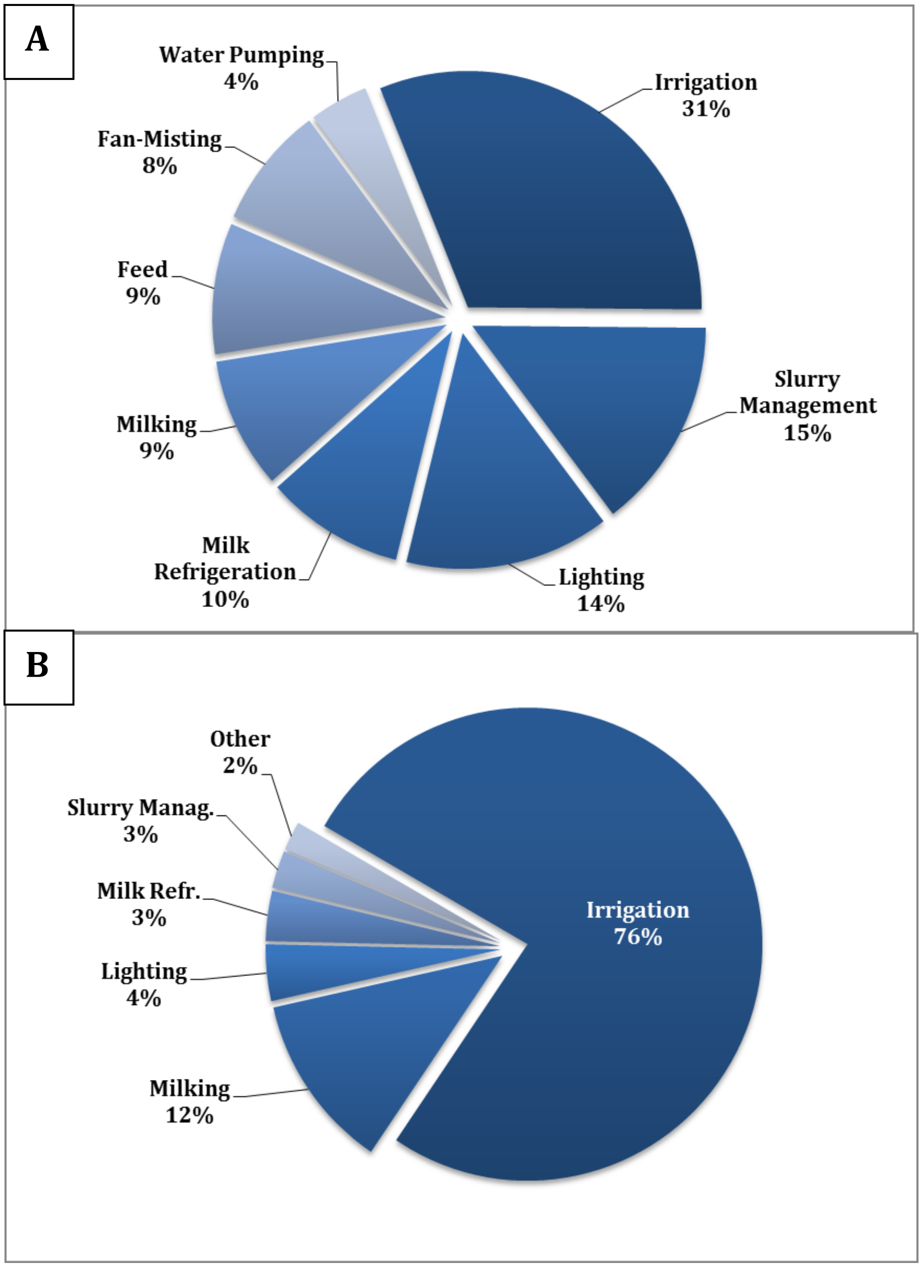


Figure 4. *Allocation of electricity usage among on-farm operations for conventional (A) and organic (B) farms*

As shown in figure 4, irrigation was the most demanding operation requiring 31% and 76% of the annual electricity consumption in conventional and organic farms, respectively. Other processes that affect significantly the electricity requirements in conventional farms were: slurry management (15%), lighting (14%), milk refrigeration (10%), milking and feed management (9% individually), fan-misting (8%) and water pumping (4%). Electricity requirements in organic farms showed wide difference; milking operation accounted for 12%, lighting 4%, milk refrigeration 3% and slurry management 3% of the total electricity consumption.

Analysing the diesel fuel consumption associated to farm and field processes (figure 5), feed preparation and distribution accounted for 71%, land operations related to crop production represented 25% of the total fuel utilization, while manure management accounted for 4% of the total diesel consumption in conventional farms. Diesel consumption related to organic farms accounted for 55% for land operation, 40% for feeding operations and 5% for slurry management.

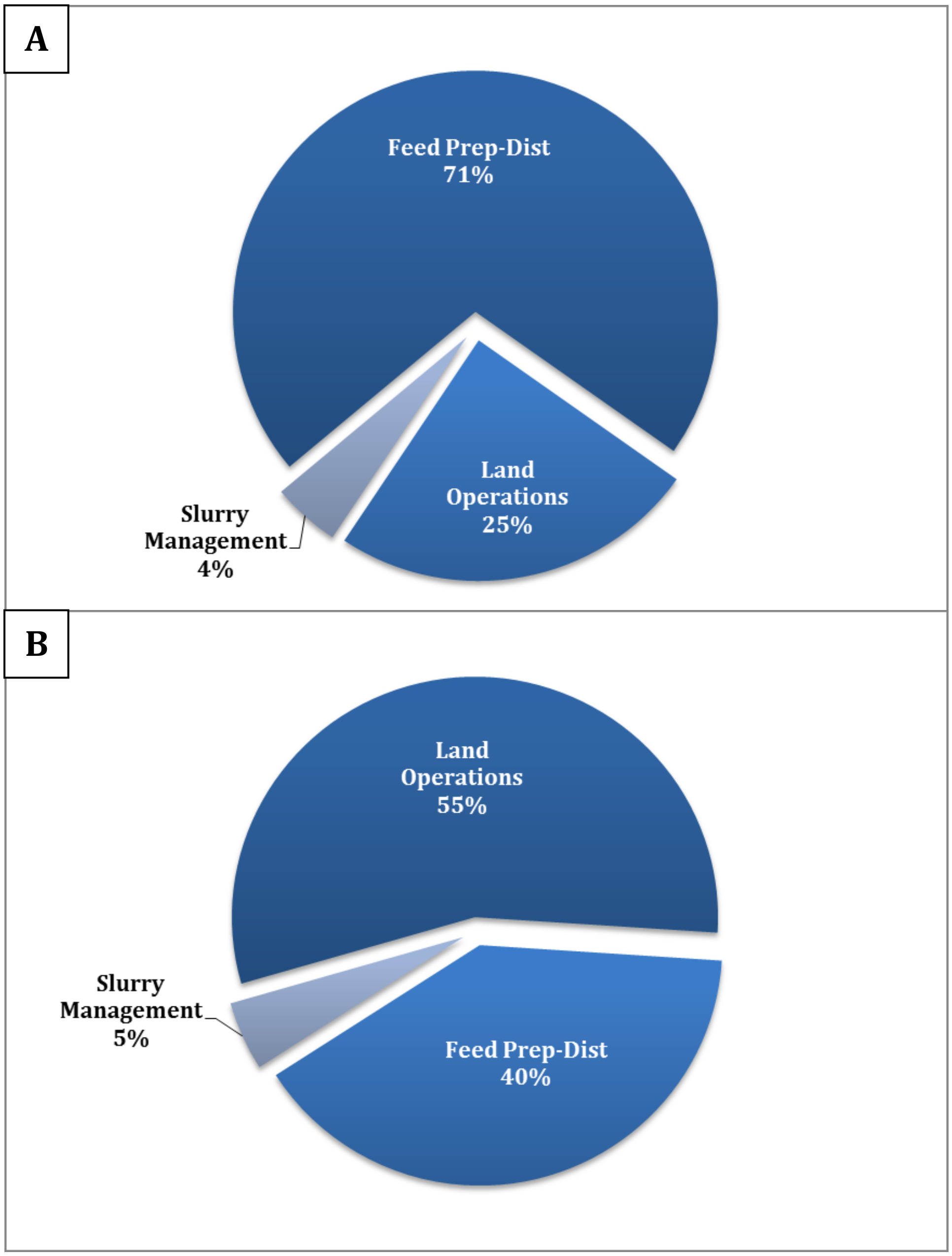


Figure 5. *Allocation of diesel consumption among on-farm operations for conventional (A) and organic (B) farms*

Crop selection of the investigated conventional farms was based on (percentage of the total hectares cultivated; figure 6):

- 48% spring silage (*Lolium spp., Triticum spp., Hordeum Vulgare L.,*)
- 48% corn silage (*Zea Mays L.,*)
- 4% alfalfa hay (*Medicago Sativa L.*,).

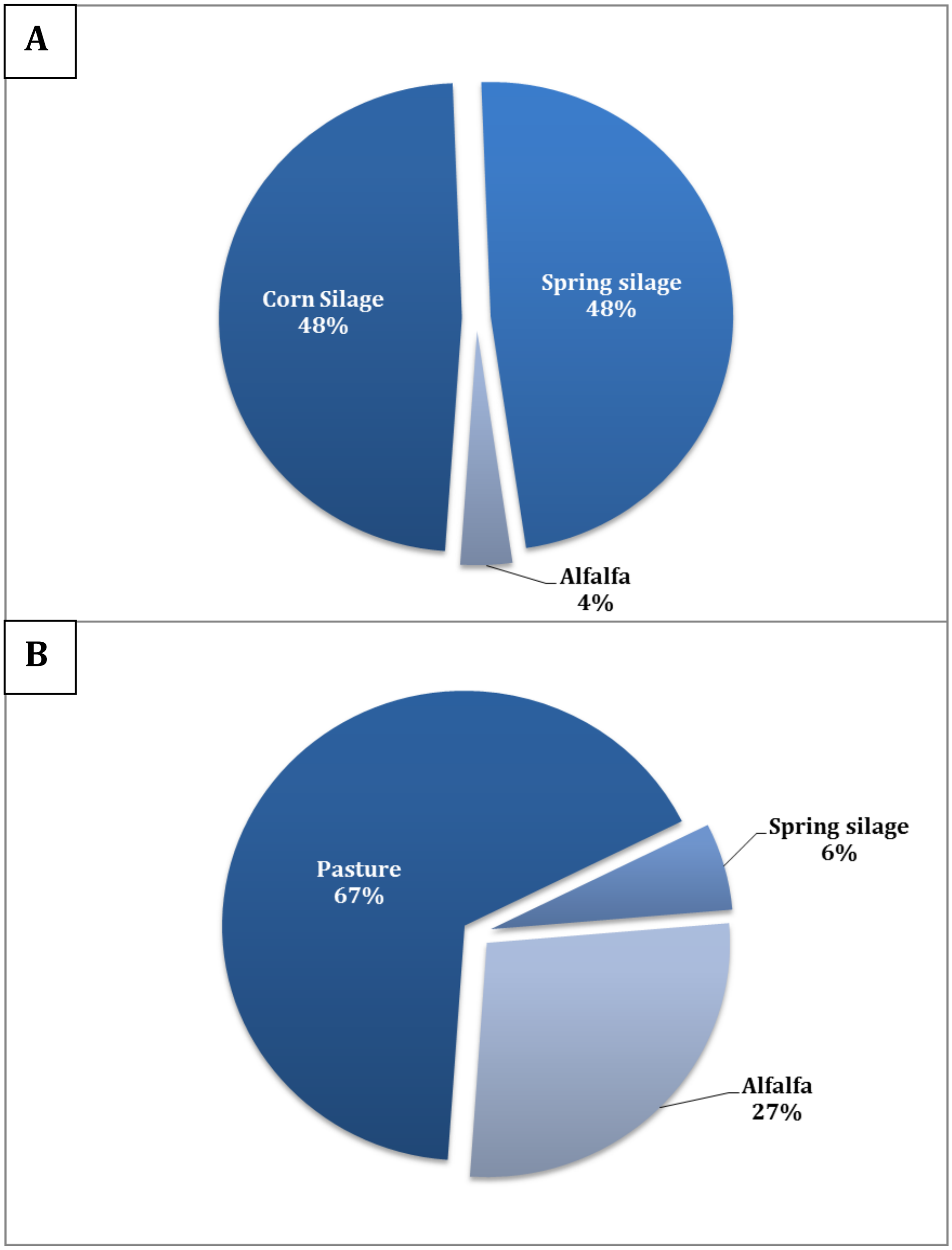


Figure 6. *Average crops selection for Conventional (A) and Organic (B) Farms*

Crop selection for organic farms was based on (percentage of the total hectares cultivated; figure 6):

- 67% pasture *(Lolium spp., Triticum spp., Avena sativa L., Trifolium spp.,*);
- 27% alfalfa hay (*Medicago Sativa L.,*);
- 6% spring silage *(Lolium spp., Triticum spp., Hordeum Vulgare L.,*).

4.3.2 Carbon Dioxide Emission

The annual carbon dioxide emissions associated with diesel fuel inputs in conventional farms were 270 kg CO_2-eq·LC^{-1} cow and 0.022 kg CO_2-eq per kg of FPCM (table 9). When referred to the cultivated land, this index accounted for 1,084 kg CO_2-eq·ha^{-1}.

The annual emissions from electricity consumption were 124 kg CO_2-eq per lactating cow and 0.0102 kg CO_2-eq per kg of FPCM. The emissions related to the usage of LPG were 43 kg CO_2-eq per lactating cow and 0.0035 kg CO_2-eq per kg of FPCM.

Table 9*. Emission data summary for conventional farms, averages per farm on a yearly basis (N=4)*

Carbon dioxide emission	Average	Head	LC	Hectare	kg FPCM
Diesel (kg CO_2-eq)	451,845	160	270	1,084	0.0220
Electricity (kg CO_2-eq)	248,564	70	124	449	0.0102
LPG (kg CO_2-eq)	54,044	27	43	186	0.0035
Total emissions (kg CO_2-eq)	**754,453**	**257**	**437**	**1,720**	**0.0357**
Renewable energy (kg CO_2-eq)	0	0	0	0	0
Total emissions (kg CO_2-eq)	**754,453**	**257**	**437**	**1,720**	**0.0357**

The farm average emission of carbon dioxide equivalent, due to all energy usages for conventional farms, was 754.4 t CO_2-eq per year that corresponds to 437 kg CO_2-eq per lactating cow and 0.0357 kg CO_2-eq per kg of FPCM.

The annual emissions of carbon dioxide related with diesel fuel combustion in organic farms were 330 kg CO_2-eq·LC^{-1} cow per year and 0.059 kg CO_2-eq per kg of FPCM per year (table 10). When referred to the land used, this index accounted for 501 kg CO_2-eq·ha^{-1}.

The annual emissions from electricity consumption were 298 kg CO_2-eq per lactating cow and 0.449 kg CO_2-eq per kg of FPCM per year. The emissions related to the usage of LPG were 93 kg CO_2-eq per lactating cow and 0.0119 kg CO_2-eq per kg of milk sold.

Table 10*. Emission data summary for organic farms, averages per farm (N=4)*

Carbon dioxide emission	**Average**	**Head**	**LC**	**Hectare**	**kg FPCM**
Diesel (kg CO_2-eq)	153,348	228	330	501	0.0509
Electricity (kg CO_2-eq)	106,915	205	298	520	0.0449
LPG (kg CO_2-eq)	31,937	69	93	137	0.0119
Total emissions (kg CO_2-eq)	**292,200**	**501**	**721**	**1,158**	**0.1077**
Renewable energy (kg CO_2-eq)	13,189	43	51	54	0.0052
Total emissions (kg CO_2-eq)	**279,011**	**458**	**670**	**1,104**	**0.1025**

The average emission of carbon dioxide equivalent, due to all energy usages for organic farms, was 292.2 t CO_2-eq per year that corresponds to 721 kg CO_2-eq per lactating cow and 0.1077 kg CO_2-eq per kg of FPCM. The emissions avoided through the production of renewable energy (from the organic farm with the anaerobic digester) where distributed among to the whole group of organic farms, obtaining a reduction of CO_2 emissions of 13,189 kg, therefore the final emissions were 279 t CO_2-eq per year, which correspond to 670 kg CO_2-eq per lactating cow and 0.1025 kg CO_2-eq per kg of milk sold. The avoided emissions accounted for 4.5% of reduction for total farm emission and 4.8% of CO_2-eq emission avoided express per kg of FPCM per year. Comparing the conventional and organic groups of farms, diesel emissions were higher in the organic groups, where: 330 kg of CO_2-eq per lactating cow and 0.0509 kg CO_2-eq per kg of milk produced, while conventional farms were able to produce milk emitting 18% (270 kg $CO_2 \cdot LC^{-1}$) and 57% (0.0220 kg CO_2 per kg FPCM) less carbon dioxide than organic. However, when diesel emissions are referred to the cultivated land, organic farming emitted 54% less carbon dioxide than conventional farms (due to the wide use of pasture in organic system). The emissions associated to the electricity consumption were 124 kg $CO_2 \cdot LC^{-1}$ and 0.0102 kg CO_2 per kg FPCM in conventional farms, while organic farm consumed 298 kg $CO_2 \cdot LC^{-1}$ and 0.0449 kg CO_2 per kg $FPCM^{-1}$ (2.4 and 4.4 times higher than conventional, respectively). Observing total annual emissions of carbon dioxide, conventional farms show 437 kg $CO_2\text{-eq} \cdot LC^{-1}$ which correspond to 0.0357 kg $CO_2\text{-eq} \cdot$kg $FPCM^{-1}$, while organic farms emitted 670 kg $CO_2\text{-eq} \cdot LC^{-1}$ and 0.1025 kg $CO_2\text{-eq} \cdot$kg $FPCM^{-1}$. Organic system was responsible to produce milk emitting 2.9 times more carbon dioxide per kg of FPCM.

Figure 7 illustrates the total diesel and electricity carbon dioxide emission attributed to each farm.

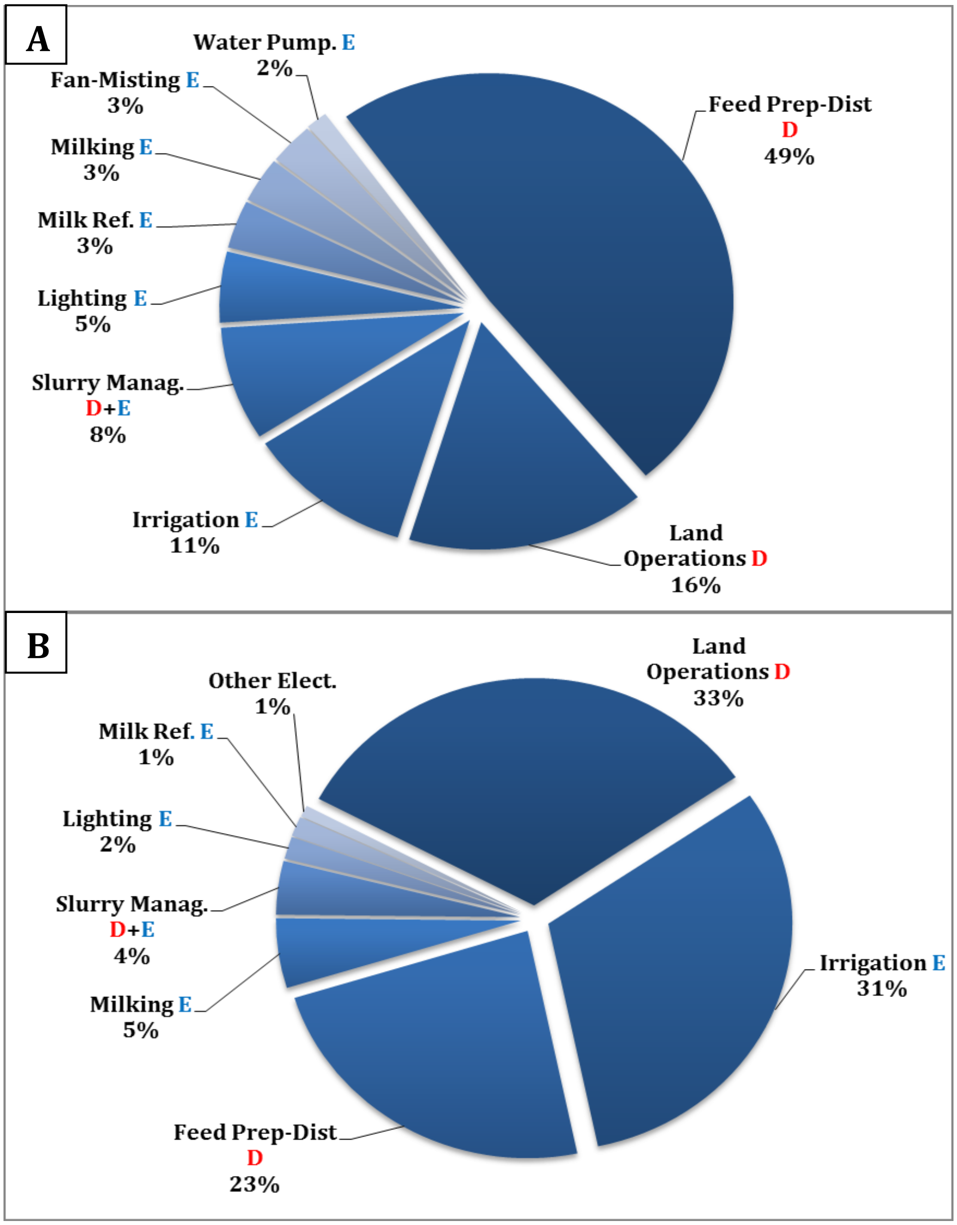


Figure 7. *Allocation of GHG emissions from electricity (E) and Diesel (D) to different operations in conventional (A) and organic (B) farms.*

Feed preparation and distribution showed 49% of the total carbon dioxide emissions, followed by land operations (16%). The electricity usage accounted for a lower part of the total carbon dioxide emissions. Irrigation represented 11% of CO_2 emissions, followed by lighting (5%), milk refrigeration, milking and fan-misting (3% individually), water pumping (4%), while slurry management represented 8% of total CO_2 emissions (operation which were carried out through the use of electricity and diesel fuel.

Figure 7 also showed total carbon dioxide emission related to each farm operations in organic farms. Field cultivation represents the 33% of the total carbon dioxide emissions, followed by feeding operations (23%). The electricity emissions that affect significantly the carbon dioxide emissions were: irrigation (31%), milking (5%), lighting (2%), while milk refrigeration represented 1% of total CO_2 emissions.

4.3.2 Economic Aspects

The annual costs related to the use of different energy sources in conventional farms are shown in table 11. Electricity accounted as the highest part of the cost related to the energy purchased, with an average of 125,484 euro per farm, which correspond to 62 euro per lactating cow and 0.51 euro per 100 kg of milk sold. Diesel fuel was responsible of 97,657 euro as average per farm, 58 euro per lactating cow and 0.47 euro per 100 kg FPCM when reported to the milk production. The purchased of LPG represent the lowest part of the energy expenditure, the average euro spent per farm were 8,286, which correspond to 127 euro per lactating cow and 0.05 euro per 100 kg of milk produced. Expressing the energy costs in percentage, electricity supply represented the 54% of the total costs, followed by diesel usage 42% and LPG which accounted only for the 3.4%.

Table 11. *Costs of energy usage for conventional farms, averages per farm on a yearly basis (N=4)*

Conventional	Average	Head	LC	Hectare	100 kg FPCM
Diesel (Euro)	97,657	35	58	234	0.47
Electricity (Euro)	125,484	35	62	227	0.51
LPG (Euro)	8,286	4	7	29	0.05
Total Costs (Euro)	**231,427**	**74**	**127**	**490**	**1.04**
Renewable energy (Euro)	0	0	0	0	0
Total Costs (Euro)	**231,427**	**74**	**127**	**490**	**1.04**

Table 12 reported the costs related to the use of different energy sources in organic farms, electricity supply accounted as the highest part of the cost related to the energy purchased, with an average of 53,975 euro, which correspond to 150 euro per lactating cow and 2.27 euro per 100 kg of milk sold. Diesel fuel was responsible of 33,143 euro as average per farm, 71 euro per lactating cow and 1.10 euro per 100 kg FPCM when reported to the milk production. LPG usage represents the lower part of total energy costs, where the average euro spent per farm were 4,896, which correspond to 14 euro per lactating cow and 0.18 euro per 100 kg of milk produced. Expressing the energy costs in percentage, electricity supply represented the 61% of the total costs, followed by diesel usage 36% and LPG which accounted only for the 5.3%.

Table 12. *Costs of energy usage for Organic farms, averages per farm (N=4)*

Organic	**Average**	**Head**	**LC**	**Hectare**	**100 kg FPCM**
Diesel (Euro)	33,143	49	71	108	1.10
Electricity (Euro)	53,975	103	150	263	2.27
LPG (Euro)	4,896	11	14	21	0.18
Total Costs (Euro)	**92,014**	**163**	**236**	**392**	**3.55**
Renewable energy (Euro)	7,584	24	29	31	0.30
Total Costs (Euro)	**84,430**	**139**	**207**	**361**	**3.25**

On-farm renewable energy productions were considered into the analysis, showing an average profit, in terms of money saved, of 7,584 euro per farm, which correspond to 29 euro per lactating cow and 0.30 euro per 100 kg of milk sold. Thanks to the production of one renewable system (anaerobic digester), the average total costs of the whole organic farms were reduced to 84,430 euro (8.2% of reduction), which represent a decreased of 8.5% of costs per 100 kg of milk sold

4.4 Conclusions

The study conducted in conventional and organic dairy farms shows great difference in farm size, conventional farms resulted larger, in terms of herd dimension, than organic. Moreover, conventional farms also held the highest milk yield and land extent. The study showed the farm's characteristic, organic systems are pasture based and the use of electrical appliance in the farm's buildings were lower than conventional system. However, electrical irrigation systems results more conspicuous in organic farms, since 3 out of the 4 conventional farms analysed supply irrigation water from the net system without energy usage. Thanks to the large use of pasture, organic farming used less fuel for land and feeding operations than conventional farms. When the amounts of energy usage were divided through the use of indicators, organic farms held the highest value in terms of energy demand per heads and kg of milk sold. The milk yields highly influence the efficiency of energy consumption in dairy farms, especially for the organic system. Emissions of carbon dioxide associated to the energy usage were: 0.035 kg CO_2-eq per kg of FPCM per conventional farms and 0.103 kg CO_2-eq per kg of FPCM for the organic system. In this study organic farms emitted, per kg of milk produced, 2.94 times more carbon dioxide than conventional farms.

CHAPTER V

OVERALL CONCLUSIONS

5.1 Concluding Remarks and Future Perspective

The rational use of energy is the key issue of the last years for the overall production sectors. Agriculture and livestock activities are responsible about 3% of the total energy consumed in the United States (Edens et al., 2003) and about 2.3% of total energy consumed in Italy (ISPRA, 2008).

The studies carried out in this project focused on energy usage in dairy farms. The aims of the work were to conduct a detailed analysis on the energy intensity in the milk production sector, in order to give a contribution to promote the efficient use of energy, decreasing the emission of carbon dioxide and the costs for the energy purchased.

The main study explained in section one involved 285 conventional Italian dairy farms with about 36,300 cows and 12,788 hectares. Results showed an average diesel consumption per farm of 13,675 kg which corresponded to 0.040 kg per kg of FPCM. The electricity supply accounted for 26,283 kWh and 0.075 kWh per kg of milk sold, while LPG consumption amounted about 109 kg, which corresponded to $3.5e^{-4}$ kg per milk produced. The energy carbon footprint expressed as carbon dioxide emission in relation to the functional unit, amounted for 0.156 kg CO_2-eq per kg of FPCM. Diesel consumption represented the 79% of the total on-farm energy related emissions, while electricity consumption accounted for the 20%. The contribution of energy consumption accounted for 6% of the total GHG emission emitted at farm level in the dairy farms examined. Further analysis demonstrated that milk yield strongly affect the environmental load for the functional unit considered. Most of the farms (N=111) held a milk yield between 5 and 8 tonnes of FPCM, and an emission of 0.136 kg CO_2-eq per kg of FPCM. Farms with milk yield over 10 tonnes (N=53) were able to produce milk emitting 0.075 kg CO_2-eq per kg of FPCM (-44.6%).

Observing the study in section three, results for conventional and organic farms recorded fuel diesel consumption about 0.0071 and 0.0164 kg per kg of milk sold, respectively. The electricity purchased accounted for 0.043 and 0.189 kWh per kg of FPCM, for conventional and organic respectively. Consumption of LPG was 0.0012 kg for conventional farms and 0.0041 kg per organic, both values are expressed per kg of milk sold. Comparing organic against conventional farming, results showed higher request of energy input in organic farms rather than conventional. The main differences in energy request are also attributable to the different milk yield, 12.2 and 7.12 tonnes per lactating cow for conventional and organic farms respectively. Comparing Californian organic and conventional farms (section three) with the Italian study (section one), must be carefully done, since the large difference in herd size dimension, land extent, milk production and management. However, emissions from the Italian study were higher than the conventional and organic from California (0.152 against 0.035 and 0.103 kg CO_2-eq per kg of FPCM). Even Californian organic farms were more sustainable, in terms of energy usage, than the conventional Italian farms analyzed. In this case, economies of scale give a large contribution reducing energy intensity and associated carbon dioxide emission in dairy farms.

The study carried out in this work wants deeply analyze the energy intensity in dairy farms, with particular attention to the usage of diesel and electricity and the related distribution among the on-farm activities. Direct emissions of carbon dioxide were also quantified with the final objective to give a contribution to understand the environmental load due to milk production. The analysis involved the calculation of direct energy consumptions, while indirect emissions were not included in the study. Future studies will be focus to analyze and quantify the energy embodied in building and machinery.

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