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EVALUATION OF ENERGY FOOTPRINT OF PASTORAL AND BARN DAIRY FARMING SYSTEMS IN NEW ZEALAND

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Abstract

Energy consumption is an important component in determining the sustainability of farming practices. Identification of dairy farming systems with efficient energy consumption at the same time as minimising greenhouse gas emissions is vital. In this context, it is relevant to assess the energy footprint of different dairy farming systems in order to identify a sustainable dairy system for the future of NZ dairy industry.

This research is based on comparative analysis of Pastoral (PDFs) and Barn (BDFs) dairy farming systems in Canterbury, New Zealand. A total of 50 dairy farms were investigated, using direct (fuel, electricity, labour) and indirect (fertilizer, feed supplements, machinery and equipment) energy inputs.

The results indicate that PDFs system have 9.5 percent lower energy footprint per hectare than BDFs, mainly due to their greater reliance on pasture based grazing feeding and less use of electricity, fuel and feed supplements. Of interest is that the BDFs use 39% less fertiliser energy but 80% higher feed supplement energy based on the inputs the farmers used. In terms of per kilogram milk solids produced, the PDFs shows 6 % lesser energy footprints compared to BDFs. This research suggests that energy consumption in PDFs in terms of both hectare and milk output is more efficient. However, when considering individual inputs of each system, the energy usage for fertilizer is much higher in PDFs.

Keywords: *Energy Footprint, Pastoral Dairy Farming System, Barn Dairy Farming System***,** *Canterbury' New Zealand*

1. INTRODUCTION

Energy is a critical input and significant cost in dairy production systems. Energy consumption in dairy farming systems comprises both renewable and non-renewable energy resources. It consumes large quantities of commercial energies such as diesel, electricity, fertilizer, irrigation water and machinery. Where there is efficient use of these energies, this can help to increase productivity and profitability along with reductions in environmental emissions and cost associated with milk production (Singh, Mishra, & Nahar, 2002; Todde, Murgia, Caria, & Pazzona, 2018). Among these energy inputs, fossil energy is one of the important energy inputs involved in dairy farming operations such as feed production, transportation, storage, processing and distribution. Depending on farming system, weather condition and building facilities, energy is also needed for cooling, heating or ventilation purposes in order to control the thermal environment including for livestock waste management (Frorip et al., 2012). Fossil fuel resources are becoming increasingly limited, so it is essential to replace fuel energy with new or renewable energy sources or otherwise optimize consumption of existing resources to manage future energy demand. Consequently, it is necessary to recognize the different input elements in farming systems and promote the methods to control them (Safa, Samarasinghe, & Mohssen, 2011).

Dairying is one of New Zealand's largest agricultural sectors, with around 4.8 million dairy cows on 11,748 dairy farms producing over 21 billion liters of milk (1.8 billion kgMS) per year (DairyNZ & LIC, 2017). Canterbury is one of the important and influential regions of New Zealand's dairy industry, with dairying valued around $2.3 billion in 2016-17. About 19% of NZ's total dairy cows are in Canterbury (905,076 cows) with an average herd size around 764 (DairyNZ, 2017). Over the last decades, the NZ dairy industry significantly expanded in Canterbury in both land area farmed and number of cows milked. According to a Statistics New Zealand (2018) report, the number of dairy cows are constantly rising in Canterbury region compared to overall New Zealand dairy cattle numbers which have stabilized since 2012. The reason for this intensification and expansion of the Canterbury dairy industry was due to the development of irrigation and subsequent rapid conversion of mixed livestock and cropping farms into dairying as a result of higher profitability in the dairy sector (Pangborn, 2012). As a consequence of dairy intensification, energy footprint per hectare of land or per kilogram of milk solids has increased along with rising stocking rate (Podstolski, 2015). Due to growing on-farm energy consumption along with the rising energy cost and environmental concerns, the energy footprint is becoming more important for farmers. Hence, the need for an evaluation of energy footprint of farming systems, to compare the energy cost of existing process operations with that of new or modified production operations is essential (Kythreotou, Florides, & Tassou, 2012).

Several studies have assessed the energy use of the dairy farming sector both worldwide and in New Zealand. Austin (2012) determined the energy use in Australian dairy farms comparing organic and conventional dairy systems and found that organic dairies were more efficient in energy use. Likewise in the European Union, Meul, Nevens, Reheul, and Hofman (2007) performed energy analysis and found that fertilizers and animal feed contributed to a higher share in energy consumption, whereas diesel use was the highest among the direct energy sources on Flanders dairy farms. Furthermore, on average 31.73 MJ of energy was consumed to produce one kilogram of milk solids on Irish dairy farms, of which direct and indirect inputs accounted for 20 % and 80 % of energy, with electricity contributing 60% of the direct energy consumption (Upton et al., 2013). In New Zealand, the energy inputs of dairy farming has been measured by a number of researchers (McChesney, 1979; Podstolski, 2015; Saunders & Barber, 2007; Wells, 2001). The study by Wells (2001) for the first time developed energy indicators based on energy use for NZ dairy industry in order to determine sustainable agricultural activities. Later on, Saunders and Barber (2007) compared the energy use of NZ dairy industry with UK and found NZ industry had less energy consumption than UK. However, all these NZ studies were focused only on grass-based pastoral dairy system and there is no consideration to barn (BDFs) dairy system. The barn (BDFs) is a relatively new system introduced in NZ as a consequences of animal welfare and environmental concerns (Pow, Longhurst, & Pow, 2014). In spite of the large investment needed in barn (BDFs) system, perceived benefits include better control of animal feed and health, better effluent management and less soil and pasture damage during wet conditions (Longhurst, Miller, Williams, & Lambourne, 2006). Alongside the financial, welfare and environmental management implications, that are perceived, it is also important to evaluate both systems in terms of their energy footprint in order to identify a sustainable dairy farming system for the future of NZ dairy industry.

This paper presents the results of a study to determine the energy footprint of pastoral (PDFs) and barn (BDFs) systems from a comparative perspective, based on hectare and milk production basis.

2. MATERIALS AND METHODS

This study was based on data from fifty dairy farms located in Canterbury province, New Zealand. The data was collected from two different sources: questionnaire and literature review.

Two dairy farming systems were studied:

i. Pastoral Dairy Farming System (PDFs): the typical New Zealand system where animals are kept on pasture year-around through rotationally grazed irrigated paddocks.
ii. Barn Dairy Farming System (BDFs): In addition to pasture grazing, animals are housed in barn buildings such as Freestall, Herdhomes etc. for different time periods during the season, named as “Barn or Hybrid dairy system”.

2.1 System boundaries and functional units

The methodology used for this study is “cradle-to-gate” analysis, which means transportation and post-processing components of the milk production life cycle are excluded after they leave the farm gate. All information on direct and indirect energy inputs were collected through survey questionnaire and face-to-face interview with farmers. For this study, 50 dairy farms including pastoral (43) and barn (7) were selected randomly. The information gathered through the survey questionnaire included type of farming system, total land area, livestock numbers, milk production, type of machinery and time usage, milking equipment, human labour, quantity of diesel, petrol, electricity, amount of fertilizer and feed supplements. From a comprehensive literature review, the equivalent energy inputs were determined for all inputs and output parameters. Hence, the energy footprint of pastoral (PDFs) and Barn (BDFs) dairy farming systems were determined through a combination of direct and indirect energy inputs. The detailed methods for estimation of energy coefficients and calculations of direct and indirect energy inputs are described in the following sections.

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2.2 Direct Energy Inputs

2.2.1 Fuel

In agriculture, energy from fuel consumption is of great importance due to its influence on production cost (Nguyen & Haynes, 1995; Safa, Samarasinghe, & Mohssen, 2010). In NZ dairy systems, diesel and petrol are the main fuel inputs used in farming operations for operating farm machinery (tractors, motorbikes, trucks). The primary energy content of diesel and petrol were 45 and 42 MJ per litre respectively, encompassed consumer energy plus energy spent for extraction, processing, refining and transportation (MED, 2012). In this study, the fuel amount consumed during the season was estimated through the survey questionnaire, and the primary energy input from fuel calculated by multiplying the fuel amount with the appropriate energy equivalent (Table 1).

Table 1: Energy coefficient for inputs used in pastoral and barn dairy systems

Inputs items	Unit	Energy Coefficients (MJ unit^{-1})	References
Diesel	liters	45	MED (2012)
Petrol	liters	42	MED (2012)
Electricity	kWh	8.14	Saunders and Barber (2007)
Human Labour	hours	1.96	Mani, Kumar, Panwar, and Kant (2007)
Fertilizers			
a. Nitrogen (N)	kg	64.1	D M Wheeler (2018)
b. Phosphorous (P)	kg	28.4	D M Wheeler (2018)
c. Potassium (K)	kg	17.8	D M Wheeler (2018)
d. Sulphur (S)	kg	3.24	D M Wheeler (2018)
Feed Supplement			
a. Grass Silage	t DM	1781	D M Wheeler (2018)
b. Maize/Cereal Silage	t DM	1564	D M Wheeler (2018)
c. Hay	t DM	1329	D M Wheeler (2018)
d. Grains	t DM	3905	D M Wheeler (2018)
e. Concentrates	t DM	1800	D M Wheeler (2018)
Machinery & Equipment			
a. Tractors	kg	160	Wells (2001)
b. Utes	kg	160	Wells (2001)
c. 2 Wheeler Motorbikes	kg	160	Wells (2001)
d. Quadbikes	kg	160	Wells (2001)
Milking Shed	sets of cups	*Shed Energy	Wells (2001)

2.2.2 Electricity

In Canterbury dairy farming systems, the electricity mainly consumed in irrigation and milking shed operations. In milking shed, electrical energy is mainly used for water heating, lighting, cooling and milk harvesting purposes. Moreover in Barn systems (BDFs), it is also used for lighting, ventilation, cleaning, and operating some barn equipment's (animal brushing, effluent scraper etc.).

The basic conversion factor for electricity is 3.6 MJ kWh^{-1}, however this conversion factor does not account efficiencies for electricity generation. In New Zealand, the primary energy content of electricity was found to be 8.14 MJ kWh^{-1} (Saunders & Barber, 2007). In this study, the total amount of electricity used in PDFs and BDFs systems were determined through survey questionnaire and then the total electrical energy input was calculated by multiplying electricity amount with relevant energy equivalent (Table 1).

2.2.3 Human Labour

In agricultural energy analysis, several studies have considered human labour as an important energy input resource with an energy equivalent of 1.96 MJ ha^{-1} (Mani et al., 2007; Ozkan, Akcaoz, & Karadeniz, 2004; Safa et al., 2011). In dairy farming systems, human labour is involved in almost every task on the farm such as driving machinery, repairs and maintenance, feed distribution, milking cows, animal care, fertilizer, irrigation and farm management etc. In this study, the amount of labour input (hours) was obtained through survey questionnaire and the value for labour energy equivalent was taken as 1.96 MJ ha^{-1} (Mani et al., 2007). Thus, the labour energy was estimated by multiplying the energy coefficient with total hours of labour involved in different farming activities.

2.3 Indirect Energy

2.3.1 Fertilizer

In New Zealand, chemical fertilizer is one of the most significant indirect energy inputs used on dairy farms. As a result of dairy intensification, annual use of N fertilizer in New Zealand increased from 59,265 tons to 366,600 tons from 1990 to 2007 (Ministry for the Environment, 2016). The embodied energy involved in manufacturing each fertilizer component N, P, K, S were considered as 64.1, 28.4, 17.8, 3.24 MJ kg^{-1} respectively (D M Wheeler, 2018). In this study, fertilizer amount used in both PDFs and BDFs systems was recorded by fertilizer type. Subsequently fertilizer energy input associated with each fertilizer type were estimated by breaking down each fertilizer into their essential components (N, P, K, S), and then multiplied with their relevant energy coefficient (Table 1).

2.3.2 Imported Feed Supplements

Imported Feed supplements have a strong influence on energy consumption of NZ dairy farming systems. In general, the feed supplements used in dairy farming systems fall under two situations: to combat a feed deficit or for achieving higher milk production per cow. However, the intensification of NZ dairy industry and increased stocking rate has resulted in high usage of imported feed supplements in NZ dairy systems. In New Zealand, the most common types of feed supplements are Maize Silage, Grass Silage and Hay etc.

In this study, the energy equivalents for grass silage, maize silage and hay were considered as 1781, 1564, 1329 per tonne dry matter (D M Wheeler, 2018). Thus energy consumption associated with imported feed supplements for both PDFs and BDFs were estimated through multiplying the amount of feed consumed with relevant energy equivalents (Table 1).

2.3.3 Machinery and Equipment

In agriculture, commercial energy is mainly used in the manufacturing operations of farm machinery, which can be classified into energy requirements for manufacturing, repair and maintenance (Conway, 1991; Safa et al., 2011). In New Zealand pastoral and barn dairy systems, farmers used different types of agricultural machinery (tractors, Ute, quadbikes etc.).

To estimate the energy input of tractors and other machinery, it is necessary to know the mass (kg), energy equivalent, economic life and working hours of machinery used during the milking season. In this study, the economic life of different machinery was taken from the ASAE (2011), the annual use of machinery was estimated through survey questionnaire, while energy equivalents and average mass of different machinery were considered from (Wells, 2001). Thus, energy consumption for each machinery and equipment were calculated by using equation 1 (Uzal, 2013).

$$ME = ms \times EE \times t/T \quad (1)$$

Where ME represents the machinery energy (MJ ha^{-1}), ms is the mass of machinery (kg), T is the economic life (hour), t is annual working hours of machinery (h ha^{-1}) and EE is the energy equivalent of the machinery (MJ kg^{-1}).

According to Wells (2001), the tractors used in NZ farming systems have power ranges between 25 to 400 hp, and there is strong correlation between tractor mass and horse power (hp), hence in this study, mass of different tractors is estimated through equation 2 (Wells, 2001).

$$Mass\ (kg) = 40.8 \times Power\ (hp)\ + 190 \qquad (2)$$

In New Zealand dairying, the most popular milking parlor types are rotary and herringbone. According to Wells (2001), the embodied energy involved in dairy sheds increases linearly with the number of cups in the milking parlor. Hence energy consumption in dairy sheds of PDFs and BDFs is estimated according to the following equation; which considered embodied energy required for construction of the dairy sheds including yards, roof, walls, backing gates, floor of milking area, tanker pad, vat stand and milking plant (Wells, 2001):

$$S.E\ = 24.2\ x\ + 293\ GJ \qquad (3)$$

Where x = number of cups of the milking parlor

Assumed working life of milking parlors = 20 years

3. RESULTS

3.1 Characteristics of pastoral (PDFs) and barn (BDFs) dairy systems

The characteristics of the PDFs and BDFs systems are summarized in Table 2. The average farm size for PDFs was 252 hectare whereas for BDFs it was 232 hectares. The average number of cows was also greater in PDFs (855) compared to BDFs (846). However the BDF systems were having more cows per hectare (3.6) on an average than the PDF system (3.4). The average milk production per cow was slightly higher in BDFs compared to PDFs. Likewise; the average milk production per effective hectare for BDFs (1,687) was also more than the PDFs (1,594).

Table 2: Characteristics of Pastoral and Barn Dairy FarmingSystems

Categories	Units	Pastoral	Barn
Farm Area	**Effective ha**	252	232
Herd Size	**No. of cows**	855	846
Stocking Rate	**Cows ha^{-1}**	3.4	3.6
Milk Solid Production	**kgMS ha^{-1}**	1594	1687
	kgMS cow^{-1}	460	462

3.2 Energy Footprint Patterns

The energy footprint of NZ pastoral and barn dairy systems were estimated by summation of direct and indirect energy inputs. Table 3 demonstrates the energy footprint per hectare for both dairy systems based on different energy inputs. The result shows that on average the total energy consumed by pastoral dairy systems (PDFs) was 50,538 $MJha^{-1}$ and for barn dairy systems (BDFs) was 55,833 MJ ha^{-1}. The difference in total energy footprint is 5295 MJ ha^{-1} indicates that 9.5% less energy was consumed in the PDFs compared to BDFs. In other words, barn system using almost 11% more energy per hectare than the pastoral system.

Table 3: Energy Footprint of Pastoral and Barn Dairy Farming Systems(MJ ha^{-1})

	Direct Energy Inputs (MJ ha^{-1})				Indirect Energy Inputs (MJ ha^{-1})			Total
	Diesel	Petrol	Electricity	Human Labour	Fertilizer	Feed Supplements	Machinery & Equipment	
Pastoral	1824	687	17917	86	15128	6937	7959	50538
Barn	5099	1178	19447	114	9206	12515	8274	55833

Among the direct energy sources, electricity consumption was higher in BDFs (19,447 MJ ha^{-1}) compared to PDFs (17,917 MJ ha^{-1}). The reason for this higher electricity usage in BDFs was due to more use of electrical equipment's in barn facilities. However in both dairy systems, the high energy share of electricity indicates its heavy consumption is due to irrigation and dairy shed operations. Fuel energy in the form of diesel and petrol was also higher in BDFs compared to PDFs. As in pastoral systems (PDFs), cows mainly fed through the grazing of pasture paddocks, which requires lower machinery usage (for pasture production and feed distribution) resulting in lower fuel consumption. In barn systems (BDFs), higher fuel consumption was due to more use of machinery involved in feed production and distribution to cows using barn facilities. Considering labour energy, results indicates that barn farming costs more than pastoral, as more labour may be required to operate the barn or distribute the feed to cows inside the barn.

Among the indirect energy inputs, fertilizer and imported feed supplements were the main contributors to total energy footprints. The proportion of both varied between the two dairy systems, as illustrated in table 3. The energy associated with fertilizer consumption was 15,128 MJ ha^{-1} for pastoral dairy farms whereas for barn it was 9,206 MJ ha^{-1}. This difference refers to one of the barn benefits, probably due to better control on effluent collected under barn facilities, resulted in less use of synthetic fertilizers.

However, the energy use from imported feed supplements for BDFs was 12,515 MJ ha^{-1} and for PDFs it was 6937 MJ ha^{-1}. The higher energy consumption from feed supplements in BDFs, was due to number of factors such as using barn facilities which requires more feed supplements to feed the cows for the duration of using the barn, higher stocking rate, longer lactation period of cows and different feed rations. On the other hand, cows under PDFs systems mostly rely on pastoral paddocks (for pasture eating) and may only have feed supplements during feed deficit conditions or in winter at the time they are dried-off. However, there is little difference in machinery energy between the two systems; the BDFs systems possessed higher machinery energy, probably due to higher use of machinery for feed distribution to cows using the barn facilities.

3.3 Energy Footprint per Kilogram Milk Solids

The results presented so far have focused on energy use per hectare basis. However, for a better evaluation of the different dairy farming systems, it is necessary to compare their energy footprint on production basis as well (Bos, de Haan, Sukkel, & Schils, 2014; Gomiero, Paoletti, & Pimentel, 2008). Hence, the energy footprint of both PDFs and BDFs were compared on a kilogram milk solids (kg MS) basis to examine the energy variation among both systems. The energy footprint per kilogram milk solids for both PDFs and BDFs systems are illustrated in Table 4. The result shows that on average to produce one kilogram milk solid, 33.7 MJ of energy was required in pastoral systems whereas for barn it was 35.8 MJ of energy. Thus, again depicting lower energy footprint in PDFs compared to BDFs, the pastoral systems used 6% less energy inputs to produce the one kilogram of milk solid. The energy footprint results based on kilogram milk solids almost exhibited the same pattern as presented by energy footprint per hectare basis.

Table 4: Energy Footprint per kg MS in Pastoral and Barn Dairy Systems (MJ $KgMS^{-1}$)

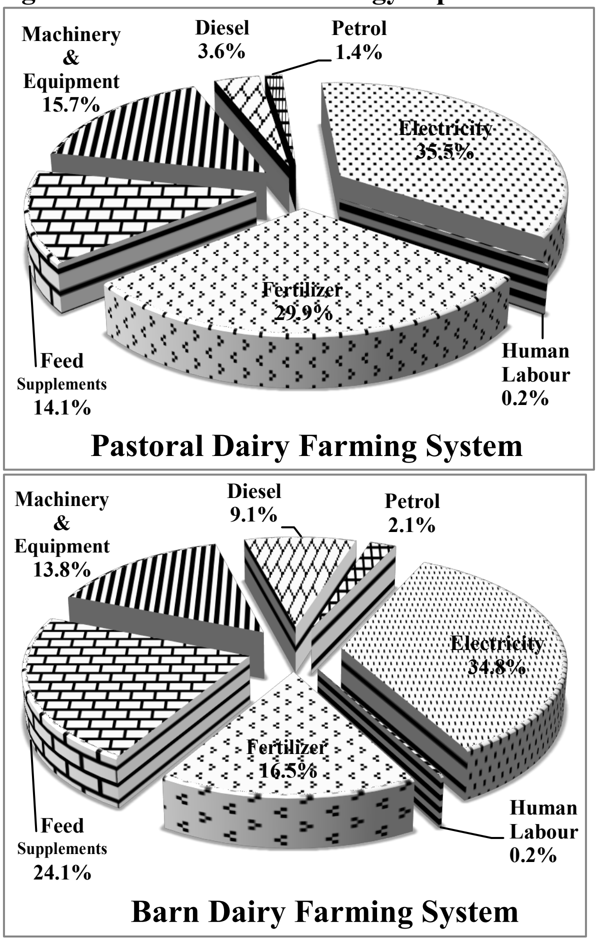
	Direct Energy Inputs (MJ $KgMS^{-1}$)				Indirect Energy Inputs(MJ $KgMS^{-1}$)			Total
	Diesel	Petrol	Electricity	Human Labour	Fertilizer	Feed Supplements	Machinery & Equipment	
Pastoral	1.2	0.4	12.1	0.1	10.0	4.6	5.3	33.7
Barn	3.4	1.0	12.0	0.1	6.1	8.1	5.1	35.8

3.3 Distribution of Energy Sources

The breakdown of total energy footprint into its input sources for PDFs reveals that electricity (35.5%) and fertilizer (29.9%) consumed most energy, followed by machinery

(15.7%) and feed supplements (14.1%). Similar findings were reported by Saunders and Barber (2007) who indicated that electricity (24%) and fertilizer (36%) were the core contributors to the total energy requirements for a pastoral dairy system (PDFs) in NZ. Likewise Podstolski (2015) and Wells (2001) reported that the fertilizer and electricity are the two main drivers of energy intensification in NZ PDF system. However in contrast to PDFs, input sources for BDFs indicates that most energy was consumed in electricity (34.8%), followed by feed supplement (24.1%) and fertilizer (16.5%).

Figure 1: Distribution of Energy Inputs for PDFs and BDFs Dairy Systems



4. DISCUSSION

The initial studies of energy estimation carried out on Canterbury dairy farms have showed an energy consumption about 9,100 $MJha^{-1}$ (McChesney, 1979). Wells (2001) research on energy intensity of dairy farms served as a baseline and shaped the energy analysis for sustainable agriculture in New Zealand, they reported total energy use for Canterbury dairy farms to be 36,500 $MJha^{-1}$. Similarly, another study estimated energy intensity as 51,300 $MJha^{-1}$ for Canterbury PDFs systems (Podstolski, 2015). In this current study, the energy consumption of both BDFs and PDFs is higher than the studies from previous years. This increasing trend in the energy footprint of Canterbury dairy systems over the decades may be attributed to the increased stocking rates, number of dairy cows and effective milking hectares, resulting in increased intensification within dairy systems both pastoral (PDFs) and barn (BDFs) dairy systems. Although energy intensification has been observed in this study, pastoral system (PDFs) do consume less energy per hectare and in relation to milk production when compared to barn dairy system (BDFs).

Considering the energy footprint for both PDFs and BDFs systems, the main source of direct energy was electricity in both systems due to its significant importance in irrigation and milking sheds operations. Among the indirect energy sources, fertilizer and feed supplements showed the greatest variation between the both dairy systems, with PDFs having greater energy usage in relation to fertilizers, and BDFs greater usage of imported feed supplements. BDFs also have higher milk solid production per cow and per hectare, in part due to the longer lactation period of the cows, although this does not compensate for the greater use of energy inputs.

5. CONCLUSIONS

Energy footprint estimation in agriculture has emerged as an important tool for sustainable farming. In this study, the energy footprint of NZ pastoral (PDFs) and barn dairy systems were evaluated. The results indicate that the energy footprint was better in PDFs compared to BDFs both per hectare and milk production basis, as PDFs consumed 9.5% and 6% lower energy inputs respectively, compared to BDFs. However, the BDFs used 80% more feed supplements energy than the PDFs and the PDFs used 64% more fertilizer energy than the BDFs. Nevertheless, from an energy footprint perspective, results are in the favor of the New Zealand low-input pastoral based grazing systems, showing that energy can be conserved by 9.5% in PDFs over BDFs system, through less energy usage.

Management is an important factor to reduce energy footprint on farms, so by using new technologies and efficient methods energy conservation can considerably be enhanced in both dairy systems. Further for achieving farm sustainability or improving energy footprints in both dairy systems, consideration needs to be given to the following areas:

- **Electricity:** As irrigation and milking shed equipment are the main electricity consuming events in both systems, using modern and more efficient electrical equipment and irrigation methods may have the potential to reduce electricity consumption.

- **Fuel:** As tractors and vehicles are the main fuel users in both systems, selection of machinery and vehicles to reduce the number of tractor passes in farming operations could significantly reduce fuel consumption in both dairy systems.

- **Fertilizer:** As fertilizer is one of the most important energy inputs, especially in NZs pastoral based dairy system, fertilizer management, particularly the amount and selection of fertilizer product along with fertilizer application method requires a focus to reduce fertilizer consumption on farms. Improving fertilizer efficiency could result in improved environmental impacts as well as financial benefits.

- **Imported Feed supplement:** Off-farm the production of imported feed supplements involved energy consumption through inputs like fossil fuel, fertilizer, machinery & equipment's etc. Thus, with changes to feed types (low energy crops), which require less energy consumption for their off-farm production, would lower energy footprints for dairy systems. Further, for reducing the energy footprints of dairy systems especially in Barn, precision feeding method recommended for improving feed efficiency, productivity and thus farm profitability.

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