energies

MDPI

Article

Energy Efficiency Outlook of New Zealand Dairy Farming Systems: An Application of Data Envelopment Analysis (DEA) Approach

Hafiz Muhammad Abrar Ilyas [1,*], Majeed Safa [1], Alison Bailey [1], Sara Rauf [1] and Azeem Khan [2]

1 Department of Land Management and Systems, Lincoln University, Lincoln 7647, New Zealand; Majeed.Safa@lincoln.ac.nz (M.S.); Alison.Bailey@lincoln.ac.nz (A.B.); Sara.Sarooh19@gmail.com (S.R.)
2 Applied Agricultural Remote Sensing Center, University of New England, Armidale 2350, NSW, Australia; AZEEM.KHAN@une.edu.au
* Correspondence: Hafiz.Ilyas@lincolnuni.ac.nz; Tel.: +64-(022)-6956392

Received: 13 December 2019; Accepted: 31 December 2019; Published: 3 January 2020

Abstract: This study evaluates energy efficiency of pastoral (PDFs) and barn (BDFs) dairy farming systems in New Zealand through application of data envelopment analysis (DEA) approach. Two models constant return to scale (CCR) and variable return to scale (BCC) of DEA were employed for determining the technical (TE), pure technical (PTE) and scale (SE) efficiencies of New Zealand pastoral and barn dairy systems. Further, benchmarking was also performed to separate efficient and inefficient dairy farms and energy saving potential was identified for both dairy systems based upon their optimal energy consumption. For this study, the energy inputs data were taken from 50 dairy farms (including PDFs and BDFs) across Canterbury, New Zealand. The results indicated that the average technical, pure technical and scale efficiencies of pastoral (PDFs) dairy systems were 0.84, 0.90, 0.93 and for barn (BDFs) systems were 0.78, 0.84, 0.92, respectively, showing that energy efficiency is slightly better in PDFs system than the BDFs. From the total number of dairy farms 40% and 48% were efficient based on the constant return to scale and variable return to scale models, respectively. Further, the energy saving potential for PDFs and BDFs dairy systems through optimal energy consumption were identified as 23% and 35%, respectively. Thus, energy auditing, use of renewable energy and precision agricultural technology were recommended for energy efficiency improvement in both dairy systems.

Keywords: energy efficiency; data envelopment analysis (DEA); pastoral dairy farming system (PDFs); barn dairy farming system (BDFs); Canterbury; New Zealand

1. Introduction

Energy consumption estimation in agriculture has been an essential tool in determining sustainable farming practices. The upsurge energy prices, strict environmental laws along with end-use energy policies increase the need for minimal and efficient energy consumption [1,2]. Energy use efficiency is seen as an important condition for sustainability of farming systems with the potential of financial savings, preservation of natural resources along with reduction in environmental impacts. It has been suggested that cost-efficient ways to save energy and related emissions can decrease one third of the global energy demand by 2050 [3–5]. Globally increasing productivity and profitability ratios are the key concerns for farming systems and both depends on the magnitude of energy consumption. The energy used in agriculture including dairy farming systems depends on the amount of agricultural work performed, the land area used and the level of farm mechanization [6–8].

Energy is a critical input and significant cost for dairy farming systems. Energy consumed in dairy systems can be classified into direct and indirect energy inputs. These energy inputs accounts for substantial direct and indirect fossil energy consumption, which produces carbon dioxide (CO_2) emissions on-farm and off-farm [7,9,10]. Moreover, the development of energy efficient farming systems helps in reducing greenhouse gas emissions (such as CO_2) besides providing financial benefits to farmers [11,12]. To minimize the greenhouse gas (GHG) emissions requires a reduction in farm energy inputs (fossil fuels, fertilizer, etc.). This goal can be achieved in two ways: either through achieving a substantial increase in energy efficiency where the same output is produced with less energy input, or through using more sustainable energy sources such as solar, wind, biomass, etc. [13]. The dairy industry is one of the most influential agricultural sectors of New Zealand's economy and is responsible for 22.5% of NZ total greenhouse gas emissions. Recently, the New Zealand government approved a "Zero Carbon Bill" in response to their Paris Accord commitments, which sets new emission reduction targets for all industries including the dairy sector to reduce emissions (such as CO_2, N_2O) to net zero by 2050 [14]. Under this situation, reducing the greenhouse gas emissions from NZ dairy farming systems has become a critical challenge for NZ dairy industry. Hence, it is necessary for NZ dairy farming systems to consider their energy expenditure and improve energy use efficiency for reduction in energy consumption and associated environmental emissions.

To estimate the efficiency of agricultural production systems, several parametric and non-parametric methods has been employed by researchers. For instance, a parametric technique the stochastic frontier production function (SFPF) employed for efficiency evaluation of crop production in Nigeria [15]. A meta-regression analysis was applied in another study for efficiency evaluation of Spanish and English dairy farms [16]. In New Zealand, stochastic frontier analysis (SFA) was employed to determine the efficiency of NZ dairy farms [17–19]. Conversely, data envelopment analysis (non-parametric technique) based on mathematical programming which determines relative efficiency of a number of decision making units (DMUs) [20]. Its application in agricultural systems has been recommended by many researchers, as it does not need any prior assumptions for the fundamental functional form among inputs and outputs [21–25]. DEA allows to contemplate multiple inputs and outputs simultaneously, where each DMU efficiency is compared to that of an ideally efficient operating unit instead of average performer unit. Thus, enabling researchers to distinguish efficient DMUs from inefficient ones and detect the amount and sources of inefficiency for each inefficient DMU [26]. For instance, Nassiri and Singh [27] estimated efficiency of paddy crop farms in India through data envelopment analysis (DEA) approach. In Canada, Cloutier and Rowley [28] compared efficiencies of 187 dairy farms between 1988–1989 and found larger farms were more efficient than the smaller ones. Barnes and Oglethorpe [29] determined Scotland dairy farms technical, cost and scale efficiency and found low technical, cost and scale efficiencies, and thus recommended changes in farm size or scale. Jaforullah and Whiteman [30] applied DEA on NZ dairy farms and found average scale efficiency around 94% with majority of dairy farms operating below the optimal scale. Based on same data set, further Jaforullah and Premachandra [31] recognized that the technical efficiency of each dairy farm was sensitive to production frontier (such as SFA and DEA) selection. In another study, Wei [32] determined the technical efficiency of NZ dairy farms through combined application of DEA and stochastic frontier analysis (SFA) for the season 2006–2007 and found average technical efficiency around 96% in SFA and 82% and 86% in DEA under constant and variable return to scale models, respectively.

Worldwide, several studies have evaluated energy efficiency of dairy farming systems. For example, in Konya Turkey Uzal [8] compared energy efficiency of dairy farming systems with different housing structures (freestall, loose housing) and found the freestall dairy system to be more efficient. Meul, Nevens [12] evaluated the changes in energy consumption efficiency of Flanders dairy farms and observed decreasing trend in energy use efficiency over the considered time frame due to increasing energy productivity. Sefeedpari [33] applied the DEA technique to calculate the energy efficiency of Iranian dairy farms and found 51% of farmers efficiently using their energy inputs.

Likewise, another Iranian study applied the DEA to determine the energy efficiency and energy saving targets for dairy farms and recognized feed intake and fossil fuels among the leading energy saving inputs [22]. However, from a New Zealand perspective, several researchers have estimated energy consumption of pastoral dairy systems [9,34–37], but very little consideration was given to energy efficiency except Wells [9] and Podstolski [36] who determined the overall energy ratio (OER) for NZ pastoral (PDFs) dairy system as an energy efficiency indicator. (Overall Energy Ratio (OER): is the ratio of total energy input to the total energy output of the product. This is inverse of energy efficiency and used as energy efficiency indicator).

The New Zealand dairy industry is renowned for its low input pastoral dairy farming system (PDFs). However, the intensification of this pastoral dairy system during the previous decades, as well as rising sustainability concerns due to the challenges of nutrient leaching and greenhouse gas emissions put NZ dairy systems under high scrutiny. One response to these challenges has been the introduction of the barn dairy system (BDFs) (also known as hybrid dairy system) into New Zealand, in which animal shelter (the barn facilities) is used in combination with pasture grazing for the purposes of reducing soil damage, animal lameness and environmental impacts [10,38]. Barn facility usage intensifies the system due to higher stocking rates and subsequently more energy consumption, to maintain and achieve financial and environmental benefits simultaneously [39]. Under this situation, energy efficiency evaluation of contrasting dairy systems (PDFs versus BDFs) would be helpful to understand energy efficiency profile of NZ different dairy farming systems.

Therefore, the aim of this study was to evaluate energy efficiency of pastoral (PDFs) and barn (BDFs) dairy farming systems through application of data envelopment analysis approach. Further, benchmarking was performed to separate the efficient and inefficient dairy farms, and optimal energy consumption was determined for inefficient dairy farms in order to identify energy saving potential from different energy sources.

2. Materials and Methods

2.1. Data Collection and Processing

This study was carried out in the Canterbury province of New Zealand. In this study, 50 dairy farms were selected from Canterbury including 43 pastoral (PDFs) and 7 barn farms (BDFs). The primary data for the season 2016–2017 were collected from these dairy farmers through a survey questionnaire and face-to-face interview method. The questionnaire was developed to collect the information about various inputs including diesel, petrol, electricity, fertilizer, labour working hours, time usage of machinery, etc. This study only considered cradle-to-farm gate energy inputs that were used to produce milk up to the farm gate i.e., transport and post-processing components were not considered.

Each input recorded in the questionnaire was then converted into an energy equivalent by using their appropriate energy equivalent factors. Table 1 shows the values of energy equivalents for inputs used in both PDFs and BDFs dairy systems. In this study, energy inputs comprised of fossil fuels, electricity, human labour, feed, fertilizer and machinery, while milk product was taken as output energy. The total energy consumption estimated was the sum of all the input multiplied with their suitable energy conversion coefficient [40].

Table 1. Energy equivalents for inputs used in pastoral (PDFs) and barn (BDFs) dairy systems.

Inputs Items	Unit	Energy Coefficients (MJ unit^{-1})	References
Direct Energy Inputs			
Diesel	litres	45	MED [41]
Petrol	litres	42	MED [41]
Electricity	kWh	8.14	Saunders and Barber [37]
Human Labour	hours	1.96	Mani, Kumar [42]

Table 1. *Cont.*

Inputs Items	Unit	Energy Coefficients (MJ unit^{-1})	References
Indirect Energy Inputs **Fertilizers**			
a. Nitrogen (N)	kg	64.1	Wheeler [43]
b. Phosphorous (P)	kg	28.4	Wheeler [43]
c. Potassium (K)	kg	17.8	Wheeler [43]
d. Sulphur (S)	kg	3.24	Wheeler [43]
Feed Supplement			
a. Grass Silage	t DM	1781	Wheeler [43]
b. Maize/Cereal Silage	t DM	1564	Wheeler [43]
c. Hay	t DM	1329	Wheeler [43]
d. Grains	t DM	3905	Wheeler [43]
e. Concentrates	t DM	1800	Wheeler [43]
Machinery & Equipment			
a. Tractors	kg	160	Wells [9]
b. Utes	kg	160	Wells [9]
c. 2 Wheeler Motorbikes	kg	160	Wells [9]
d. Milking Shed	sets of cups	Shed Energy	Wells [9]

Shed energy (MJ) = (24.2 × number of cups + 293) × 1000. Ministry of Economic Development (MED); t DM (tonne dry matter).

Energy inputs can be classified as direct and indirect inputs [9]. In this study, direct energy encompassed diesel, petrol, electricity, human labour, while indirect energy involved fertilizer, imported feed supplements and machinery used in the dairy farming operations. In addition to energy efficiency of both dairy systems, energy indicators such as energy productivity (EP) and overall energy ratio (OER) were also determined through Equations (1) and (2) [8,12,36,44]:

$$\text{Energy Productivity (EP)} = \frac{\text{Milk Output }\left(\text{tMS ha}^{-1}\right)}{\text{Energy Input }\left(\text{MJ ha}^{-1}\right)} \tag{1}$$

$$\text{Overall Energy Ratio (OER)} = \frac{\text{Energy Input }\left(\text{MJ ha}^{-1}\right)}{\text{Energy Output }\left(\text{MJ ha}^{-1}\right)} \tag{2}$$

where, 'EP' is energy productivity (tMS MJ^{-1}), 'OER' is the overall energy ratio "the ratio of total energy input to the total energy output of the product". OER describes an inverse of energy efficiency, a higher OER means lower efficiency and vice versa.

2.2. Data Envelopment Analysis Approach

The data envelopment analysis (DEA) is a technique used for the assessment of non-parametric efficiency frontiers in multi-factor production analysis. DEA uses linear programming to form a non-parametric frontier above the data set, which serves as relative benchmark for evaluation of efficiency among other homogenous decision-making units (DMUs) under analysis [45,46]. Data envelopment analysis allows each DMU to select any combination of inputs and outputs to maximize its relative efficiency. The relative efficiency score of a decision-making unit (DMUs) is defined as a ratio of weighted sum of outputs to weighted sum of inputs. This relative efficiency score is a non-negative value based on the linear relationship between inputs and outputs [47]. Assume '*n*' DMUs are to be assessed, each using different combination of '*r*' outputs and '*s*' inputs. The objective function of DMU '*d*' in the set of '*j*' DMUs ($j = 1, 2, 3, \ldots, n$) can be written as Equation (3):

$$\text{Maximizing Efficiency}_d = \frac{\sum_{r=1}^{p} u_r y_{rd}}{\sum_{s=1}^{q} v_s x_{sd}} \quad (3)$$

Subject to $\frac{\sum_{r=1}^{p} u_r y_{rj}}{\sum_{s=1}^{q} v_s x_{sj}} \leq 1$, for $j = 1, 2, 3, \ldots, n$

u_r and $v_s \geq 0$, $r = 1, 2, 3, \ldots, p$ and $s = 1, 2, 3, \ldots, q$.

Whereas 'y_{rd}' is output amount (*r*) produced by DMU '*d*', 'x_{sd}' is input amount (*s*) consumed by DMU '*d*', 'y_{rj}' is output amount (*r*) produced by DMU '*j*', 'x_{sj}' is input amount (*s*) consumed by DMU '*j*' and 'u_r' and 'v_s' are the weight given to individual output and input [48].

The two models CCR and BCC named after the authors Charnes, Cooper [49] and Banker, Charnes [50], respectively, are commonly used in DEA technique based on return to scale parameter. Charnes, Cooper [49] introduced the CCR model based on the assumption of constant return to scale (CRS), which implies that an input increase will result in a proportional output increase. In CCR model, the efficiency frontier is a straight line which intersects the origin point and best performing unit(s) as shown in Figure 1. The best performing unit is the one with the highest output to input ratio, in Figure 1 this is P_2. This point thus serves as a reference DMU to all other units under investigation. The CCR model, allows the identification of inefficient DMUs with consideration of scale size. In CCR models, both technical and scales efficiencies are present, which are based on input/output arrangement (management techniques) and scale size. The efficiency measured under the CRS assumption named as technical efficiency.

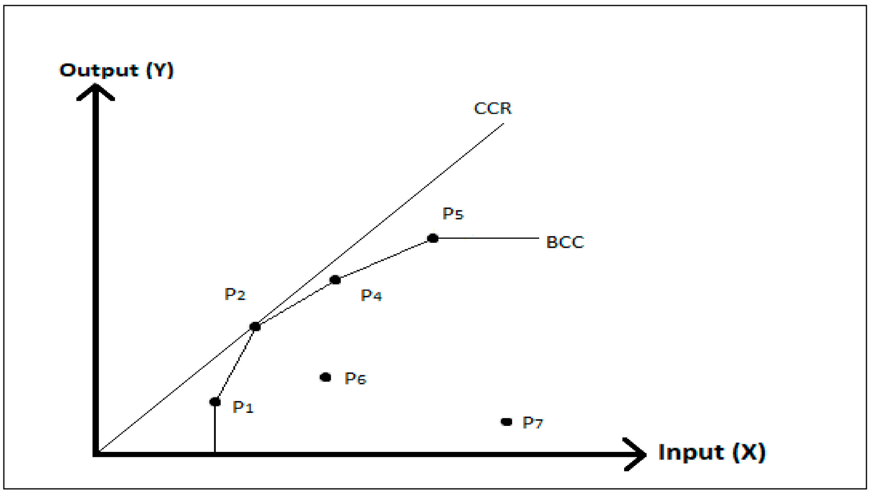


Figure 1. Efficiency frontiers based on CCR and BCC models.

Banker, Charnes [50] presented the BCC model based on the assumption of variable returns to scale (VRS), which implies that an input increase will result in a non-proportional output increase.

In BCC model, the efficiency frontier changed from a straight line to a convex structure. This convex combination of the efficient DMUs serves as reference point for other inefficient units. In Figure 1, the BCC model shows more than one efficient DMU on the frontier line (P1, P2, P4, P5) using the same DMUs as in the CCR model. The BCC model has few advantages over the CCR model. The BCC model frontier envelops more data so more efficient units than CCR and the efficiency scores of BCC model are higher or equal to those of CCR as it connects the outer most DMUs (including the one determined efficient by CCR). Due to the presence of more than one efficient DMUs in the model, the inefficient units under BCC model get the opportunity to be compared with more appropriate efficient units [47].

The pure technical efficiency (PTE) is defined as the technical efficiency of DMUs measured under variable return to scale assumption. The BCC model, also known as VRS model, gives the pure technical efficiency of DMUs without consideration of scale size. In simple words, the CCR model efficiency is the combination of technical efficiency (TE) and scale efficiency (SE), while the BCC model separates the TE and SE and measures pure technical efficiency (PTE).

Scale efficiency (SE) captures the effect of scale size on the efficiency of DMU and indicates that some portion of inefficiency belongs to the inappropriate size of a DMU. The efficiency score variation between CRS and VRS models is captured in scale efficiency. The relationship between technical (TE), pure technical efficiency (PTE) and scale efficiency (SE) can be explained as follows [23,27]:

$$\text{Scale efficiency } = \frac{\text{Technical Efficiency}}{\text{Pure Technical Efficiency}} \tag{4}$$

In DEA application, the efficiency of a unit can be attained either by input or output orientation. In input orientation models, efficiency is attained by minimizing input usage while maintaining same output levels, whereas output orientation models focus on increasing output levels while maintaining same level of inputs. Here, an input-oriented DEA approach was adopted for the efficiency measurement of dairy farms. This orientation is considered more suitable for agriculture as farmers have more control over input usage compared to output, which are often influenced by exogenous factors (rain, soil structure, climate, etc.). Likewise, this orientation choice is in accordance with current situation of New Zealand dairy farming systems, where more focus is on efficient input usage (due to environmental issues) rather than production or yield increase. In this study, the decision-making units (DMUs) are the dairy farms (PDFs and BDFs), while direct and indirect farm inputs were considered as energy inputs in mega joule per hectare ($MJha^{-1}$) and milk energy per hectare ($MJha^{-1}$) was considered as the output energy for the individual DMU or dairy farm.

To measure the efficiencies of selected DMUs (dairy farms) based on CCR and BCC models, the Data Envelopment Analysis Program (DEAP) software version 2.1 was employed [45,51]. The focus was to determine the optimal energy input efficiency with consideration of the input/output management and scale size of different dairy farming systems (PDFs and BDFs), so further analysis was based on the CCR model.

The DEA divides the DMUs (dairy farms) into efficient and inefficient sets; the inefficient DMUs are ranked on their efficiency scores; while DEA lacks distinction between efficient DMUs. Thus, to rank efficient DMUs, a benchmarking method was employed, an efficient unit is ranked higher if chosen as relative peer by many inefficient DMUs, and frequently appears in the reference set.

3. Results

3.1. Energy Use Pattern

The amount of energy inputs for pastoral (PDFs) and barn (BDFs) dairy systems are summarized in Table 2. The total energy used in each dairy system contained energy generated from direct and indirect inputs. According to the results, on average PDFs and BDFs dairy systems used energy as 50,538 $MJha^{-1}$ and 55,833 $MJha^{-1}$, respectively. The difference in total energy input of both systems is

5295 MJha^{-1} indicates 9.5% less energy consumption in the PDFs system. In comparison to previous NZ studies [9,34,37], energy use in PDFs system has increased as consequences of dairy intensification.

Table 2. Energy use of pastoral (PDFs) and barn (BDFs) dairy farming systems (MJha^{-1}).

	Pastoral				Barn			
Items	**Avg**	**SD**	**Min**	**Max**	**Avg**	**SD**	**Min**	**Max**
Direct Energy Inputs								
Diesel	1824	778	436	4124	5099	4776	1570	15,750
Petrol	687	379	113	1752	1178	458	900	2198
Electricity	17,917	14,626	3312	78,954	19,447	11,206	10,095	34,020
Labour	86	21	46	141	114	30	55	150
Indirect Energy Inputs								
Fertilizer	15,128	4139	3579	19,064	9206	5071	0	16,244
Feed Supplements	6937	4338	0	16,124	12,515	2035	10,580	16,655
Machinery	7959	2546	1031	15,680	8274	2252	3688	10,559
Total Energy Use	50,538	16,598	18,539	108,750	55,833	11,494	40,737	69,872
Output								
Milk	60,571	17,480	32,693	94,141	64,121	18,447	44,894	96,710

Considering total energy consumption in terms of its component parts revealed that electricity (35.5%) and fertilizer (29.9%) consumed most energy in pastoral dairy system (PDFs), followed by machinery (15.7%) and feed supplements (14.1%). However, in contrast to PDFs, total energy consumption of BDFs system indicates that most energy was consumed in electricity (34.8%), followed by imported feed supplement (24.1%) and fertilizer (16.5%). The highest share of electricity among total energy consumption indicates high consumption of electricity in irrigation and dairy shed operations. In case of BDFs system, the lower consumption of fertilizer energy was due to use of barn facilities, which provide more control on effluent collection [52]. In case of PDFs, the similar energy use trend was reported by Latham [34], where he found electricity as the leading source of energy with 73% consumption for irrigation purposes in case of irrigated farm while rest of consumed in milking parlour. Likewise, fertilizer use also increased in pastoral system (PDFs), in order to grow more pasture to meet high feed demand, resulted in higher fertilizer energy. The similar findings were reported by Saunders and Barber [37] who indicated that electricity (24%) and fertilizer (36%) were the core contributors to the total energy consumption for a PDFs system in NZ. Likewise Podstolski [36] and Wells [9] reported that the fertilizer and electricity are the two main drivers of energy intensification in NZ pastoral system (PDFs).

3.2. *Efficiency Score of Dairy Farms*

The summary and percentagewise distribution of efficiency scores (TE, PTE and SE) of 50 dairy farms (DMUs) are presented in Table 3 and Figure 2. The technical and pure technical efficiencies were based on the CCR and BCC models of the DEA, respectively.

The results of the input-oriented CCR model shows that out of 50 dairy farms (DMUs), only 20 dairy farms or DMUs (40%) were efficient revealing that the majority of the dairy farms (60%) can improve their energy inputs utilization. Moreover, the average technical efficiency score of the inefficient 30 dairy farms (DMUs) was 0.72, implying that they can save energy and reach efficiency by reducing inputs usage from different sources by up to 28%.

The results of the input-oriented BCC model of DEA showed that more dairy farms (DMUs) were efficient compared to the CCR model, as explained in Figure 2. Based on pure technical efficiency, 24 dairy DMUs (48%) were now efficient including the DMUs 5, 9, 20 and 37 (which were inefficient in the CCR model application).

Table 3. Technical, pure technical and scale efficiencies of PDFs and BDFs Systems (50 DMU's).

Particular	Pastoral				Barn			
	Avg	SD	Min	Max	Avg	SD	Min	Max
Technical Efficiency	0.84	0.19	0.36	1.00	0.78	0.20	0.51	1.00
Pure Technical Efficiency	0.90	0.13	0.58	1.00	0.84	0.18	0.55	1.00
Scale Efficiency	0.93	0.11	0.57	1.00	0.92	0.07	0.81	1.00

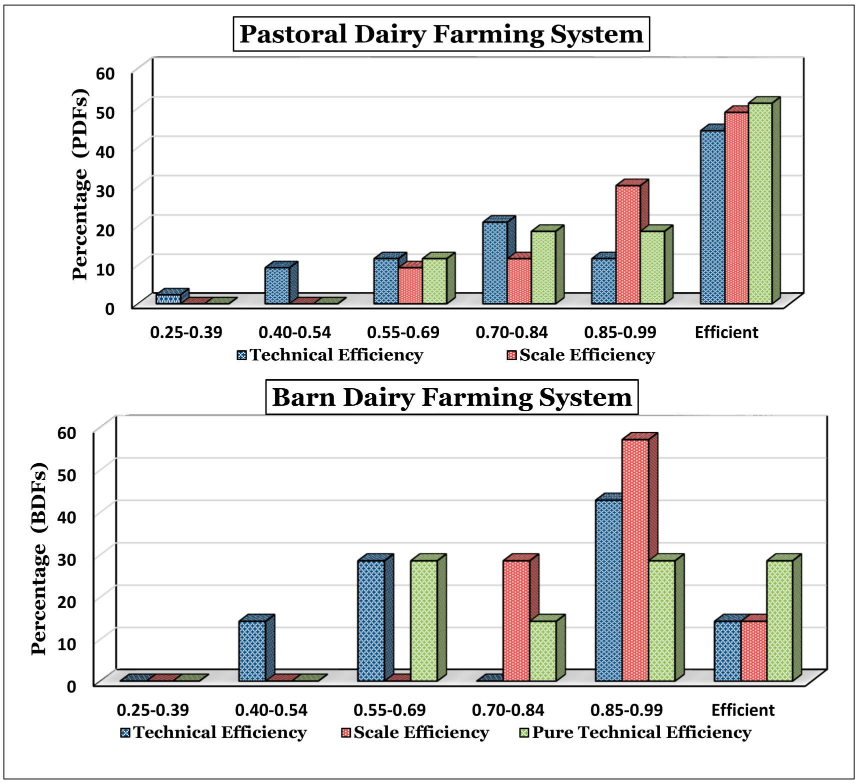


Figure 2. Efficiency score of pastoral (PDFs) and barn dairy farming systems (BDFs).

From a systems perspective, the average technical efficiency score for pastoral dairy system (PDFs) was 0.84 ranging from 0.36–1 with a standard deviation of 0.19, whereas for barn dairy system (BDFs), TE was 0.78 with a standard deviation of 0.20 and ranging from 0.51–1. The result indicates that energy efficiency of pastoral dairy system (PDFs) is slightly better than the energy efficiency of barn system (BDFs). The average of pure technical efficiency of PDFs system was 0.90 ranging from 0.58–1 while for BDFs system it was 0.84 ranging from 0.55–1.

Among pastoral farms, the number of least inefficient farms (scores between 0.70 and 0.99) were 14 (58%) and 16 (59%) farms based on technical and pure technical efficiency scores, respectively. Similarly, among barn farms, a total of 3 (50%) and 3 farms (50%) were least inefficient based on technical and pure technical efficiencies, respectively (as shown in Figure 2). These dairy units have great potential to become efficient as their scores are nearer to reaching efficiency.

3.3. Benchmarking Categorization

DEA determines the relative efficiency of DMUs (dairy farms); meaning it ranks (weights) other DMUs according to the highly efficient DMU. The highly efficient DMU thus serves as the reference for the other units. Benchmarking of the DMUs (dairy farms) was done and it allowed us to identify the most appropriate (efficient) units by assessment and comparison with others units performing similar functions [20,53]. In benchmarking, the efficient DMUs (dairy farm), which appear most in the referent set, are considered superior and achieve a higher rank than the others. This identification and ranking can then help to identify the improvements in practices that may help in the attainment of higher performance. The efficiency benchmarking categorization of the 50 dairy farms (DMUs) including PDFs and BDFs dairy systems is given in Table 4.

Table 4. Benchmarking results of technical efficiency analysis.

DMU	System	TE Score	Frequency in Referent Set	Benchmarking *
1	P	1	9	
2	P	1	10	
3	P	1	10	
4	P	1	11	
5	P	0.68		1 (0.2) 2 (0.2) 6 (0.1)
6	P	1	7	
7	P	1	8	
8	P	0.36		2 (0.2) 3 (0.0) 4 (0.0) 6 (0.1) 14 (0.0) 23 (0.1)
9	P	0.98		1 (0.6)
10	P	1	2	
11	P	0.54		2 (0.1) 3 (0.1) 27 (0.0) 28 (0.2) **33 (0.1)** 49 (0.1)
12	P	0.81		4 (0.1) 28 (0.3) **33 (0.4)**
13	P	1	2	
14	P	1	2	
15	P	1	0	
16	P	1	3	
17	P	0.52		2 (0.2) 3 (0.0) 6 (0.4) 14 (0.0) 36 (0.0)
18	B	0.56		2 (0.1) 3 (0.0) 7 (0.1) 27 (0.3) **33 (0.1)** 36 (0.1)
19	B	0.63		1 (0.2) 13 (0.3) 27 (0.1)
20	B	0.94		3 (0.3) 4 (0.0) 28 (0.3) **33 (0.1)**
21	B	0.90		7 (0.7) 27 (0.2) 28 (0.0)
22	B	0.91		7 (0.6) 13 (0.0) 27 (0.2)
23	P	1	2	
24	P	0.97		2 (0.6) 4 (0.0) 6 (0.1) **33 (0.1)** 43 (0.3) 49 (0.0)
25	B	0.51		1 (0.2) 4 (0.1) 43 (0.0) 49 (0.3) 50 (0.2)
26	P	0.56		1 (0.1) 2 (0.1) 4 (0.1) 6 (0.4) 49 (0.0) 50 (0.1)
27	B	1	9	
28	P	1	9	
29	P	0.93		2 (0.2) 3 (0.3) 27 (0.0) **33 (0.3)** 36 (0.1)
30	P	0.69		4 (0.1) 6 (0.5) 43 (0.1) 49 (0.2)
31	P	0.70		3 (0.3) 28 (0.2) **33 (0.3)** 36 (0.1) 49 (0.1)
32	P	0.53		6 (0.1) 16 (0.5) 36 (0.1)
33	**P**	**1**	**13**	
34	P	0.76		1 (0.3) 16 (0.4) 36 (0.1)
35	P	0.71		2 (0.1) 3 (0.1) 27 (0.1) **33 (0.3)** 36 (0.0)
36	P	1	11	
37	P	0.92		7 (0.4) 28 (0.3) 43 (0.1) 49 (0.4)
38	P	0.91		3 (0.2) 10 (0.1) **33 (0.3)** 36 (0.3) 40 (0.2)
39	P	0.56		3 (0.1) 7 (0.2) 27 (0.0) 28 (0.0) **33 (0.2)** 36 (0.0)
40	P	1	1	
41	P	0.66		1 (1.0)
42	P	0.81		1 (0.3) 4 (0.1) 43 (0.3) 49 (0.3)
43	P	1	6	
44	P	0.53		7 (0.5) 27 (0.1) 28 (0.1) 49 (0.0)
45	P	0.79		2 (0.2) 4 (0.3) 10 (0.0) **33 (0.2)**
46	P	0.70		1 (0.0) 4 (0.4) 23 (0.3) **33 (0.0)** 36 (0.0) 43 (0.1)
47	P	0.70		7 (0.0) 16 (0.1) **33 (0.6)** 36 (0.0)
48	P	0.74		4 (0.0) 7 (0.7) 28 (0.0)
49	P	1	9	
50	P	1	2	

*: To simplify, the benchmarking composite units for DMU 5 are expressed as 1 (0.2) 2 (0.2) 6 (0.1), whereas 1, 2 and 6 are DMU numbers (which are efficient) and values in parenthesis represent the intensity vectors of the respective DMUs. The intensify vector indicates that the inputs usage and output production of the DMU 5 (inefficient unit) is closer to DMU 1, 2 and 6 compared to other DMUs. By using benchmarked DMUs and intensity vector, the optimum energy requirement for the inefficient DMU 5 can be worked out to attain efficiency.

The benchmarking categorization shows that the DMU 33 emerges as the most efficient DMU (dairy farm) by appearing in the benchmark referent set of the majority of the inefficient DMUs. The dairy farm representing the DMU 33 tops the ranking by 13 repetitions. This efficient DMU and other efficient units close to this can serve as appropriate efficient units for the inefficient DMUs. This implies that an inefficient unit (dairy farm) can improve energy use efficiency by following this composite set of efficient units rather than just following a single unit as benchmark. For instance, it can be said that DMU 5 should follow the practices of composite DMUs 1, 2 and 6 to achieve energy efficiency because the DMU 5 is closest to the efficiency frontier of these efficient DMUs. Thus, by using efficient dairy farms as benchmark the inefficient dairy farms can identify ways to acquire best management practices and reducing energy consumption and associated greenhouse gas emissions.

3.4. Optimal Energy Requirements and Energy Saving Capacity

The optimal energy requirements and energy saving capacity for the inefficient pastoral and barn dairy systems are summarized in Table 5, based on CCR model. The results revealed that total optimal energy required for PDFs system was 38,964 MJha^{-1} (actual energy used 50,538 MJha^{-1}), whereas for BDFs system the optimal energy required was 36,469 MJha^{-1} (actual energy used 55,833 MJha^{-1}). The difference indicates inefficient use of energy inputs in both dairy systems. It is evident from the results that there is potential for a total of 11,574 MJha^{-1} of energy that could be saved by pastoral dairy farms, whereas for barn dairy farms it was 19,364 MJha^{-1} by efficient utilization of energy inputs while keeping the output unchanged. Thus, the efficient utilization of on-farm energy inputs can be achieved in both dairy systems through several ways such as identification of energy wastage through energy auditing along with upgradation of older equipment and machinery, application of precision agriculture technology in order to apply required amount of energy inputs (such as fertilizer, irrigation, etc.) along with more use of renewable energy sources (solar, etc.).

Table 5. Optimal energy requirements and energy savings capacity for both systems (50 DMUs).

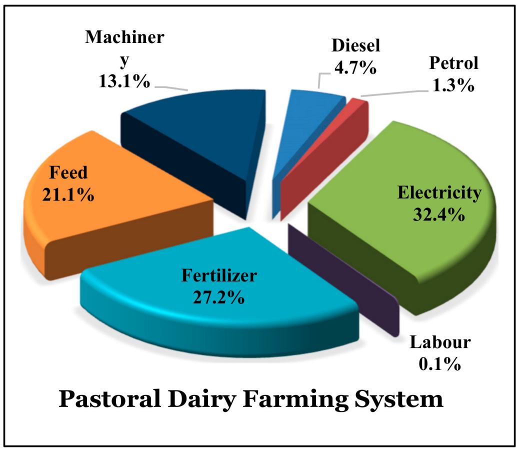
Inputs	Actual Energy Consumption (MJha^{-1})		Optimal Energy Requirements (MJha^{-1})		Saving Energy (MJha^{-1})	
	Pastoral	**Barn**	**Pastoral**	**Barn**	**Pastoral**	**Barn**
Diesel	1824	5099	1278	1782	546	3317
Petrol	687	1178	537	633	150	544
Electricity	17,917	19,447	14,173	14,586	3745	4861
Labour	86	114	70	79	15	36
Fertilizer	15,128	9206	11,975	6766	3153	2440
Feed Supplements	6937	12,515	4491	6422	2446	6093
Machinery	7959	8274	6440	6201	1519	2073
Total	50,538	55,833	38,964	36,469	11,574	19,364

The distribution of the various energy inputs based on total energy saving potential for both pastoral (PDFs) and barn (BDFs) dairy systems is illustrated in Figure 3. Evidently, the highest energy saving contribution was from electricity (32.4%), followed by fertilizer (27.2%) and feed supplements (21.1%) for pastoral dairy system (PDFs). While for barn dairy system (BDFs), imported feed supplement (31.5%) contributed the major portion, followed by electricity (25.1%) and diesel (17.1%) for energy savings.

3.5. Improvement of Energy Indices

Energy indices calculated for pastoral (PDFs) and barn (BDFs) dairy systems with actual and optimal energy consumption are presented in Table 6. Energy productivity based on actual and optimal energy consumption was found as 0.035 kgMS MJ^{-1} and 0.046 kgMS MJ^{-1}, and 0.031 kgMS MJ^{-1} and 0.048 kgMS MJ^{-1} for PDFs and BDFs dairy systems, respectively, showing an improvement of 31% and 55% can be made in energy productivity of both pastoral and barn dairy systems, respectively. The overall energy ratios (OER) based on optimal energy use were computed as 0.66 and 0.57 for

PDFs and BDFs systems, respectively. Thus, the results shows that compared with actual energy use in pastoral and barn dairy systems, OER can be improved by 27% and 38% with usage of optimal suggested energy requirements estimated by using DEA method. In other words, the overall energy ratio (OER) would decrease from 0.90 to 0.66 for pastoral and 0.92 to 0.57 for barn dairy systems, when farmers of both dairy systems move from actual energy consumption to optimal energy requirements. This indicates that improvements in energy consumption can occur for both systems, however the OER results indicate that energy efficiency of pastoral systems were slightly better than the barn systems. However, when comparing OER results of PDFs system with previous NZ studies, it showed an arbitrary trend as reported by different researchers McChesney and Sharp [35] as 0.57, Wells [9] as 0.99, Latham [34] as 0.65 and Podstolski [36] as 0.91. Over the decades, it is clear that OER has increased in the pastoral system which means energy efficiency has decreased over the previous years (as OER is reverse of energy efficiency). Thus, energy efficiency improvements are necessary for NZ dairy systems to retain their competitive advantage of energy efficiency over its counterpart dairy industries, such as those in the European Union.



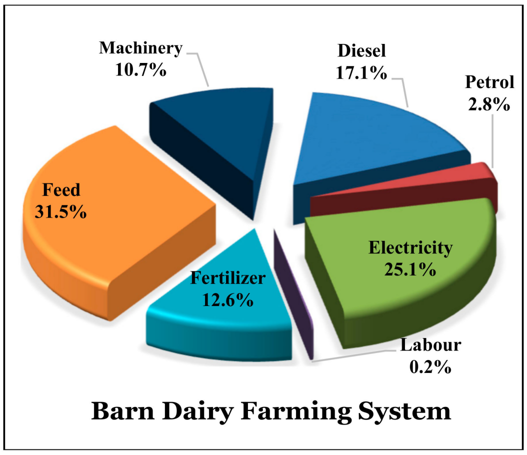


Figure 3. Percentage distribution of energy savings potential for PDFs and BDFs.

Table 6. Energy indices improvement for pastoral and barn dairy systems (50 DMUs).

Items	Unit	Actual Energy Consumption		Optimal Energy Requirement	
		Pastoral	Barn	Pastoral	Barn
Energy Productivity	kgMS MJ^{-1}	0.035	0.031	0.046	0.048
Overall Energy Ratio	MJ_{in}/MJ_{out}	0.90	0.92	0.66	0.57
Direct Energy	$MJha^{-1}$	20,514	25,838	16,058	17,080
Indirect Energy	$MJha^{-1}$	30,024	29,995	22,906	19,389

Further, optimal energy use reduces energy percentages for direct and indirect energies as 22% and 24%, and 34% and 35% in PDFs and BDFs systems, respectively. Thus, applying the DEA method for energy optimization can save the energy resources for both pastoral and barn dairy systems. Overall, the application of DEA model suggests that energy efficiency improvements are possible in both pastoral (PDFs) and barn (BDFs) dairy systems, which would help to reduce overall energy consumption and related environmental footprints along with providing financial benefits to farmers through cutting their energy costs. Hence, for energy efficiency improvement in both dairy systems, especially for inefficient dairy farms energy auditing, the use of renewable energy sources along with application of precision agriculture technology were recommended to achieve sustainable and environmentally friendly dairy system for NZ dairy industry.

4. Conclusions

Dairy farming systems with better energy efficiency would help to reduce energy costs and environmental footprints along with improving productivity and profitability of farming systems. The main purpose of this study was to evaluate energy efficiency of NZ contrasting dairy systems such as pastoral (PDFs) and barn (BDFs) and finding their optimal energy requirements through data envelopment analysis (DEA) approach. The average technical, pure technical and scale efficiencies of pastoral and barn dairy systems were found as 0.84, 0.90, 0.93 and 0.78, 0.84, 0.92, respectively, indicating that energy efficiency is slightly better in PDFs compared to BDFs system. Based on CCR and BCC models, 20 and 24 dairy farms respectively out of 50 selected farms were efficient, indicating that the majority of farms were not technically efficient due to using more energy inputs than required. The inefficient farmers need to pay attention towards their energy inputs (electricity, fertilizer and imported feed supplements), as they showed higher potential for energy savings. From systems perspective, when comparing actual and optimal energy use of pastoral (PDFs) and barn (BDFs) dairy systems, results shows that 23% and 35% energy can be saved in both dairy systems respectively, with optimal energy consumption. Thus, for energy efficiency improvement in both dairy systems, energy auditing and the use of more renewable energy sources along with application of precision agricultural technology were recommended.

Author Contributions: H.M.A.I. performed the majority of the work including conceptualization of the data collection and analysis, along with writing the initial draft of the manuscript. M.S. and A.B. supervised the work providing methodological guidance throughout the study. They also contributed to the writing of the manuscript. S.R. helped in data analysis and in the writing of the manuscript. A.K. helped in writing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding and the APC was funded by Lincoln University, New Zealand.

Acknowledgments: The authors gratefully acknowledge the support provided by Marvin Pangborn (Alderbrook Farm Ltd.) and Helen Thoday (DairyNZ) for data collection of this project and appreciate the farmer's participation.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liang, Q.M.; Fan, Y.; Wei, Y.M. Multi-regional input–output model for regional energy requirements and CO2 emissions in China. *Energy Policy* **2007**, *35*, 1685–1700. [CrossRef]
2. Mohammadi, A.; Rafiee, S.; Jafari, A.; Keyhani, A.; Mousavi-Avval, S.H.; Nonhebel, S. Energy use efficiency and greenhouse gas emissions of farming systems in north Iran. *Renew. Sustain. Energy Rev.* **2014**, *30*, 724–733. [CrossRef]
3. Esengun, K.; Gündüz, O.; Erdal, G. Input–output energy analysis in dry apricot production of Turkey. *Energy Convers. Manag.* **2007**, *48*, 592–598. [CrossRef]
4. Uhlin, H.E. Why energy productivity is increasing: An IO analysis of Swedish agriculture. *Agric. Syst.* **1998**, *56*, 443–465. [CrossRef]
5. Lackner, M. Energy Efficiency: Comparison of Different Systems and Technologies. In *Handbook of Climate Change Mitigation and Adaptation*; Springer: New York, NY, USA, 2017; pp. 1309–1384.
6. Alam, M.S.; Alam, M.; Islam, K. Energy flow in agriculture: Bangladesh. *Am. J. Environ. Sci.* **2005**, *1*, 213–220. [CrossRef]
7. Todde, G.; Murgia, L.; Caria, M.; Pazzona, A. A Comprehensive Energy Analysis and Related Carbon Footprint of Dairy Farms, Part 2: Investigation and Modeling of Indirect Energy Requirements. *Energies* **2018**, *11*, 463. [CrossRef]
8. Uzal, S. Comparison of the energy efficiency of dairy production farms using different housing systems. *Environ. Prog. Sustain. Energy* **2013**, *32*, 1202–1208. [CrossRef]
9. Wells, C. Total energy indicators of agricultural sustainability: Dairy farming case study. In *Technical Paper 2001/13*; MAF: Wellington, New Zealand, 2001; Volume 13.

10. Ilyas, H.M.A.; Safa, M.; Bailey, A.; Rauf, S.; Pangborn, M. The carbon footprint of energy consumption in pastoral and barn dairy farming systems: A case study from Canterbury, New Zealand. *Sustainability* **2019**, *11*, 4809. [CrossRef]
11. Dalgaard, T.; Halberg, N.; Porter, J.R. A model for fossil energy use in Danish agriculture used to compare organic and conventional farming. *Agric. Ecosyst. Environ.* **2001**, *87*, 51–65. [CrossRef]
12. Meul, M.; Nevens, F.; Reheul, D.; Hofman, G. Energy use efficiency of specialised dairy, arable and pig farms in Flanders. *Agric. Ecosyst. Environ.* **2007**, *119*, 135–144. [CrossRef]
13. Corré, W.; Schröder, J.J.; Verhagen, A. Energy use in conventional and organic farming systems. In Proceedings of the Open Meeting of the International Fertiliser Society, London, UK, 3 April 2003.
14. DairyNZ. *Zero Carbon Bill*; DairyNZ Limited: Hamilton, New Zealand, 2019.
15. Ajibefun, I.A.; Daramola, A.G.; Falusi, A.O. Technical efficiency of small scale farmers: An application of the stochastic frontier production function to rural and urban farmers in Ondo State, Nigeria. *Int. Econ. J.* **2006**, *20*, 87–107. [CrossRef]
16. Moreira López, V.H.; Bravo-Ureta, B.E. A study of dairy farm technical efficiency using meta-regression: An international perspective. *Chil. J. Agric. Res.* **2009**, *69*, 214–223. [CrossRef]
17. Jaforullah, M.; Devlin, N.J. Technical efficiency in the New Zealand dairy industry: A frontier production function approach. *N. Z. Econ. Pap.* **1996**, *30*, 1–17. [CrossRef]
18. Jiang, N. Efficiency Analysis of NZ Dairy Farming and the Issue of Climate Change Policy. Ph.D. Thesis, The University of Auckland, Auckland, New Zealand, 2011.
19. Jiang, N.; Sharp, B. Cost Efficiency of Dairy Farming in New Zealand: A stochastic frontier analysis. *Agric. Resour. Econ. Rev.* **2014**, *43*, 406–418. [CrossRef]
20. Adler, N.; Friedman, L.; Sinuany-Stern, Z. Review of ranking methods in the data envelopment analysis context. *Eur. J. Oper. Res.* **2002**, *140*, 249–265. [CrossRef]
21. Seiford, L.M.; Thrall, R.M. Recent developments in DEA: The mathematical programming approach to frontier analysis. *J. Econ.* **1990**, *46*, 7–38. [CrossRef]
22. Hosseinzadeh-Bandbafha, H.; Safarzadeh, D.; Ahmadi, E.; Nabavi-Pelesaraei, A. Optimization of energy consumption of dairy farms using data envelopment analysis–A case study: Qazvin city of Iran. *J. Saudi Soc. Agric. Sci.* **2018**, *17*, 217–228. [CrossRef]
23. Chauhan, N.S.; Mohapatra, P.K.; Pandey, K.P. Improving energy productivity in paddy production through benchmarking—An application of data envelopment analysis. *Energy Convers. Manag.* **2006**, *47*, 1063–1085. [CrossRef]
24. Hosseinzadeh-Bandbafha, H.; Safarzadeh, D.; Ahmadi, E.; Nabavi-Pelesaraei, A.; Hosseinzadeh-Bandbafha, E. Applying data envelopment analysis to evaluation of energy efficiency and decreasing of greenhouse gas emissions of fattening farms. *Energy* **2017**, *120*, 652–662. [CrossRef]
25. Nabavi-Pelesaraei, A.; Hosseinzadeh-Bandbafha, H.; Qasemi-Kordkheili, P.; Kouchaki-Penchah, H.; Riahi-Dorcheh, F. Applying optimization techniques to improve of energy efficiency and GHG (greenhouse gas) emissions of wheat production. *Energy* **2016**, *103*, 672–678. [CrossRef]
26. Angulo-Meza, L.; Lins, M.P.E. Review of methods for increasing discrimination in data envelopment analysis. *Ann. Oper. Res.* **2002**, *116*, 225–242. [CrossRef]
27. Nassiri, S.M.; Singh, S. Study on energy use efficiency for paddy crop using data envelopment analysis (DEA) technique. *Appl. Energy* **2009**, *86*, 1320–1325. [CrossRef]
28. Cloutier, L.M.; Rowley, R. Relative technical efficiency: Data envelopment analysis and Quebec's dairy farms. *Can. J. Agric. Econ. Revue Canadienne D'agroeconomie* **1993**, *41*, 169–176. [CrossRef]
29. Barnes, A.; Oglethorpe, D. Scale Efficiencies and the Mid-Term Review: An Analysis of Scottish Dairy Farming. In Proceedings of the 78th Agricultural Economics Society, South Kensington, London, UK, 2–4 April 2004.
30. Jaforullah, M.; Whiteman, J. Scale efficiency in the New Zealand dairy industry: A non-parametric approach. *Aust. J. Agric. Resour. Econ.* **1999**, *43*, 523–541. [CrossRef]
31. Jaforullah, M.; Premachandra, E. *Sensitivity of Technical Efficiency Estimates to Estimation Approaches: An Investigation Using New Zealand Dairy Industry Data*; Economics Discussion Papers Series No. 306; University of Otago: Dunedin, New Zealand, 2003; p. 23.
32. Wei, X. Efficiency Measurement of New Zealand Dairy Farms. Ph.D. Thesis, Auckland University of Technology, Auckland, New Zealand, 2014.

33. Sefeedpari, P. Assessment and optimization of energy consumption in dairy farm: Energy efficiency. *Iran. J. Energy Environ.* **2012**, *3*, 213–224. [CrossRef]
34. Latham, N.L. Carbon Footprints in the New Zealand Dairy Industry: A Comparison of Farming Systems. Master's Thesis, Lincoln University, Lincoln, New Zealand, 2010.
35. McChesney, I.G.; Sharp, B.M.; Hayward, J.A. Energy in New Zealand agriculture: Current use and future trends. *Energy Agric.* **1981**, *1*, 141–153. [CrossRef]
36. Podstolski, M. The Evolution of Total Energy Inputs in the New Zealand Dairy Industry. Master's Thesis, Lincoln University, Lincoln, New Zealand, 2015.
37. Saunders, C.M.; Barber, A. *Comparative Energy and Greenhouse Gas Emissions of New Zealand's and the UK's Dairy Industry*; Lincoln University: Lincoln, New Zealand, 2007.
38. Pow, T.; Longhurst, B.; Pow, Z. The future of NZ dairy farming systems: Self managing cows with access to partial housing. In Proceedings of the Fertilizer and Lime Research Centre (FLRC) Workshop, Wellington, New Zealand, 2–3 September 2014.
39. Newman, M.; Journeaux, P. *Wintering Barns No Quick Fix for Profit*; DairyNZ: Hamilton, New Zealand, 2015.
40. Kazemi, H.; Shahbyki, M.; Baghbani, S. Energy analysis for faba bean production: A case study in Golestan province, Iran. *Sustain. Prod. Consum.* **2015**, *3*, 15–20. [CrossRef]
41. MED. *Energy Data File 2011*; Ministry of Economic Development: Wellington, New Zealand, 2012.
42. Mani, I.; Kumar, P.; Panwar, J.; Kant, K. Variation in energy consumption in production of wheat–maize with varying altitudes in hilly regions of Himachal Pradesh, India. *Energy* **2007**, *32*, 2336–2339. [CrossRef]
43. Wheeler. *OVERSEER Technical Manual: Carbon Dioxide, Emboided and Other Gaseous Emissions*; AgResearch Ltd.: Hamilton, New Zealand, 2018.
44. Jekayinfa, S.; Bamgboye, A. Energy use analysis of selected palm-kernel oil mills in south western Nigeria. *Energy* **2008**, *33*, 81–90. [CrossRef]
45. Coelli, T.J.; Rao, D.S.P.; O'Donnell, C.J.; Battese, G.E. *An Introduction to Efficiency and Productivity Analysis*; Springer Science & Business Media: Berlin, Germany, 2005.
46. Alzamora, R.M.; Apiolaza, L.A. A DEA approach to assess the efficiency of radiata pine logs to produce New Zealand structural grades. *J. For. Econ.* **2013**, *19*, 221–233. [CrossRef]
47. Zhu, J. *Quantitative Models for Performance Evaluation and Benchmarking: Data Envelopment Analysis with Spreadsheets*; Springer International Publishing: Cham, Switzerland, 2014.
48. Allen, R.; Thanassoulis, E. Improving envelopment in data envelopment analysis. *Eur. J. Oper. Res.* **2004**, *154*, 363–379. [CrossRef]
49. Charnes, A.; Cooper, W.W.; Rhodes, E. Measuring the efficiency of decision making units. *Eur. J. Oper. Res.* **1978**, *2*, 429–444. [CrossRef]
50. Banker, R.D.; Charnes, A.; Cooper, W.W. Some models for estimating technical and scale inefficiencies in data envelopment analysis. *Manag. Sci.* **1984**, *30*, 1078–1092. [CrossRef]
51. Coelli, T. *A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer) Program*; Centre for Efficiency and Productivity Analysis, University of New England: Armidale, Australia, 1996.
52. Ilyas, H.M.A.; Safa, M.; Bailey, A.; Rauf, S.; Cullen, M. Evaluation of Energy Footprint of Pastoral and Barn Dairy Farming Systems in New Zealand. In Proceedings of the 22nd International Farm Management Association (IFMA) Congress, Tasmania, Australia, 3–8 March 2019.
53. Keehley, P. *Benchmarking for Best Practices in the Public Sector: Achieving Performance Breakthroughs in Federal, State, and Local Agencies*; Jossey-Bass Inc. Pub: Parow, South Africa, 1997.