Investment appraisal of technology innovations on dairy farm electricity consumption

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ABSTRACT

The aim of this study was to conduct an investment appraisal for milk-cooling, water-heating, and milk-harvesting technologies on a range of farm sizes in 2 different electricity-pricing environments. This was achieved by using a model for electricity consumption on dairy farms. The model simulated the effect of 6 technology investment scenarios on the electricity consumption and electricity costs of the 3 largest electricity-consuming systems within the dairy farm (i.e., milk-cooling, water-heating, and milking machine systems). The technology investment scenarios were direct expansion milk-cooling, ice bank milk-cooling, milk precooling, solar water-heating, and variable speed drive vacuum pump-milking systems. A dairy farm profitability calculator was combined with the electricity consumption model to assess the effect of each investment scenario on the total discounted net income over a 10-yr period subsequent to the investment taking place. Included in the calculation were the initial investments, which were depreciated to zero over the 10-yr period. The return on additional investment for 5 investment scenarios compared with a base scenario was computed as the investment appraisal metric. The results of this study showed that the highest return on investment figures were realized by using a direct expansion milk-cooling system with precooling of milk to 15°C with water before milk entry to the storage tank, heating water with an electrical water-heating system, and using standard vacuum pump control on the milking system. Return on investment figures did not exceed the suggested hurdle rate of 10% for any of the ice bank scenarios, making the ice bank system reliant on a grant aid framework to reduce the initial capital investment and improve the return on investment. The solar water-heating and variable speed drive vacuum pump scenarios failed to

produce positive return on investment figures on any of the 3 farm sizes considered on either the day and night tariff or the flat tariff, even when the technology costs were reduced by 40% in a sensitivity analysis of technology costs.

Key words: dairy technology, electricity, milk production, profitability

INTRODUCTION

Global energy prices increased steadily over the last 5 yr, resulting in increases in electricity costs on European farms of over 30% from 2007 to 2013 (Eurostat, 2013). Electricity consumption represents 60% of direct energy use, or 0.31 MJ/L of milk produced on Irish dairy farms (Upton et al., 2013). The quantity of electricity consumed per liter of milk produced on dairy farms may increase in the coming years if farmers respond to government policies in countries such as Ireland, where increases in milk output are actively encouraged as a result of the abolition of European Union milk quotas in 2015 (DAFM, 2010). Increased milk production is generally associated with investments in labor-saving technology to manage larger dairy herds, along with more industrial milk harvesting and cooling equipment, which might increase electricity consumption per liter of milk (Upton et al., 2015). The major electricity-consuming systems on Irish dairy farms were identified in previous studies as milk-cooling (31% of total), water-heating (23% of total), and milking systems (20% of total), with the remaining 26% of total electricity consumption made up of lighting, water pumping, and wintering facility electricity consumption (Upton et al., 2013). To make informed decisions, farmers need insight into the electricity consumption, electricity costs, and associated investment costs of potential technology investment strategies.

The aim of the current study, therefore, was to provide a scientific-based investment appraisal for the best combination of milk-cooling, water-heating, and milk-harvesting technologies tested in this analysis on a

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range of farm sizes in 2 different electricity pricing environments. This objective was achieved by using a model for electricity consumption on dairy farms (Upton et al., 2014) to analyze the effect of various technologies on the electricity consumption and costs on the 3 largest electricity-consuming systems within the dairy farm (i.e., milk-cooling, water-heating, and milking machine systems). These outputs were used as inputs to a farm profitability calculator using annual farm-related costs from the Teagasc Eprofit Monitor for 2011. The Eprofit monitor is a financial benchmarking tool supplied by Teagasc (Moorepark, Co. Cork, Ireland). The combined models were used to compute the return on additional investment (**ROI**) and the discounted annual net income for 5 investment scenarios compared with a base level of investment over a 10-yr period.

MATERIALS AND METHODS

Outline of the Model for Electricity Consumption on Dairy Farms

A model developed by Upton et al. (2014) was used to simulate the annual electricity consumption and associated costs of 6 technology investment scenarios on 3 representative farms in Ireland. The model for electricity consumption on dairy farms is a mechanistic mathematical representation of the electricity consumption that simulates farm equipment under the following headings: milk-cooling system, water-heating system, milking machine system, lighting systems, water pump systems, and the winter housing facilities. The main inputs to the model are milk production, cow numbers, and details relating to the milk-cooling system, milking machine system, water-heating system, lighting systems, water pump systems, and the winter housing facilities, as well as details relating to the management of the farm (e.g., season of calving, frequency of milking, and milking start time; milking end time is computed by the model). The energy consumption of each of the 7 dairy farm systems described was computed using the model for electricity consumption on dairy farms in a 12×24 matrix structure that simulated a representative day for each month of the year (12 mo $\times$ 24 h). Both of the electricity tariffs were compiled in an identical 12×24 matrix. Dairy farm electricity costs were then calculated by multiplying the energy consumption matrix by the tariff matrix. For this analysis, a technology permutation algorithm was developed and applied to the model for electricity consumption on dairy farms, which allowed for autonomous cycling through technologies and tariffs. The outputs from the model for electricity consumption on dairy farms were annual electricity consumption (kWh) and associated

costs for each of the 6 technology investment scenarios studied under 2 electricity pricing structures [flat tariff and day and night (**DN**) tariff]. The farms morning milking start time was set to 0700 h and the evening milking start time was set to 1700 h.

Model Inputs

The electricity consumption and related costs of a small farm with 45 milking cows, a medium farm with 88 milking cows, and a large farm with 195 milking cows was simulated using the model for electricity consumption on dairy farms. Background data from an on-farm energy study of these farms presented by Upton et al. (2013) was used to populate the model for electricity consumption with data pertaining to the infrastructural configuration on each of these 3 farms. The farms were spring-calving herds operating grass-based milk production systems with low supplementary feed input (mean of 540 kg of concentrate/cow), similar to most Irish dairy farms. Milk sales were 255,278 L for the small farm, 499,898 L for the medium farm, and 774,089 L for the large farm. Further data related to the scale and production levels of the farms are presented in Table 1. The farm sizes used in our analysis are based on the farm sizes used to validate the model (Upton et al., 2014).

Scenario Description

A range of technologies were commercially available to reduce the electricity consumption of these systems. In the current analysis, it was assumed that there was a requirement for investment in a milk-cooling system, milking system vacuum pumps, and a water-heating system. The scenarios analyzed were as follows.

Base. The base scenario included investment in a direct expansion milk-cooling system, standard milking system vacuum pumps (i.e., without variable speed drive; **VSD**), and an electrical water-heating system. All other options were compared with this base scenario. Direct expansion refers to a system where the evaporator plates are incorporated in the lower portion of the storage tank that is in direct contact with the milk. Liquid refrigerant expands inside the evaporator taking heat out of the milk.

Direct Expansion Cooling System with Pre-cooling of Milk. The direct expansion cooling system with precooling of milk (**DXPHE**) scenario included investment in a direct expansion milk-cooling system with a water-cooled plate heat exchanger precooling system that cooled milk to 15°C before entry to the milk storage tank; the milking system remained standard and water heating remained electric. The precooler had

Table 1. Mean values of characteristics and simulated electricity consumption values (kWh) and related costs (\$) of the 3 farms, SF (small farm), MF (medium farm), and LF (large farm), for the base scenario

Farm characteristic	SF	MF	LF
Farm area (ha)	48	70	110
Dairy herd size	45	88	195
Stocking density (LU/ha ¹)	1.68	1.90	2.43
Milk production (L/annum)	255,278	499,898	774,089
Milk cooling (kWh, % of total in parentheses)	5,237 (50%)	9,826 (39%)	15,703 (48%)
Water heating (kWh, % of total in parentheses)	2,444 (23%)	7,294 (29%)	7,842 (24%)
Milking machine (kWh, % of total in parentheses)	2,131 (20%)	3,628 (14%)	6,124 (19%)
Wash pump (kWh, % of total in parentheses)	NA ²	145 (1%)	NA (0%)
Water pump (kWh, % of total in parentheses)	NA (0%)	1,832 (7%)	2,452 (8%)
Autoscraper (kWh, % of total in parentheses)	422 (4%)	1,533 (6%)	NA
Lighting (kWh, % of total in parentheses)	179 (2%)	994 (4%)	493 (2%)
Electricity use (Wh/L)	40.8	50.5	42.2
Annual electricity consumption (kWh)	10,413	25,252	32,670
Electricity cost (\$/L of milk)	0.0072	0.0085	0.0075
Annual electricity cost (\$)	1,835	4,234	5,805

¹LU/ha = livestock units per hectare.²NA = not available.

the effect of reducing the thermal energy of the milk entering the storage tank, thereby reducing the quantity of electricity consumed by the cooling system. The cost of pumping extra water through the pre cooler was included in the calculations. The electricity consumed by the water pumps for precooling purposes in month i and hour j , $Q_{wp}(i,j)$ (kWh), was described by the equation

$$Q_{wp}(i,j) = [V_w(i,j)/P_c] \times P_{wp}, \quad [1]$$

where $V_w(i,j)$ = water used for precooling (L); P_c = total pump capacity (L/hr); and P_{wp} = total pump power (kW), which are model inputs.

Ice Bank Cooling System Without Precooling. This scenario included investment in an ice bank (IB) milk-cooling system instead of a direct expansion system; the milking system remained standard and water-heating remained electric. Ice bank cooling systems consisted of an insulated water tank that houses a copper tube evaporator array. Ice builds up around the copper tubes in a cylindrical formation. Water is circulated through the cooling device (pre cooler or bulk tank) and back to the ice bank in a closed loop (Murphy et al., 2013). Ice bank cooling systems are less efficient in terms of electricity consumed per liter of milk cooled, but when combined with precision technologies they can generate enough ice at night to meet the entire milk cooling demand the next day (MDC, 1995). This system can take advantage of significantly cheaper night rate electricity by shifting the cooling load to off peak rates (currently 0000–0900 h).

IB with Precooling of Milk. This scenario includes investment in an ice bank milk cooling system

with a pre cooler (plate-heat exchanger; **IBPHE**), which chilled milk to 15°C before entry to the milk storage tank; the milking system remained standard and water heating remained electric. The cost of pumping extra water through the pre cooler was included in the calculations.

Solar. This scenario included investment in solar thermal panels in addition to the electric water-heating system. A direct expansion milk-cooling system was included with standard milking system vacuum pumps. Solar water systems have been shown to reduce the electricity consumption of dairy water-heating systems by 40 to 50% (Morison et al., 2007); however, this can vary strongly according to latitude. It was assumed that the solar thermal collector reduced the annual electricity costs of the farms water heaters by an average of 45%.

VSD Milking System. In this scenario, VSD was added to the milking system vacuum pumps and a direct expansion milk-cooling system was included with electric water heating. The VSD vacuum systems have been shown to reduce the electricity consumption of milking systems by between 56 and 65% (Ludington et al., 2004; Morison et al., 2007; Upton et al., 2010). The addition of a VSD to a standard milking system was considered. It was assumed that the VSD milking system reduced the annual electricity costs of the farms vacuum pumps by an average of 60%.

Profitability Performance Evaluation

The profitability calculator was used to assess the after-tax net income of the small, medium, and large farms arising from the 6 technology investment scenarios over a 10-yr period subsequent to investment

(2014–2023). The profitability calculator used average financial performance data and variable and fixed cost data from 1,133 dairy farms from the farm financial benchmarking tool of Teagasc, known as Teagasc Eprofit Monitor. It was assumed that the capital expenditure required for each investment scenario was borrowed from a financial institution at 5% annual percentage rate over a 10-yr period, this rate was based on consultation with the banking industry in Ireland. Income before tax was calculated using the formula:

$$\begin{aligned} \text{net income} = & \text{gross revenue} - \text{total variable costs} \\ & - \text{total fixed costs}, \end{aligned} \quad [2]$$

where gross revenue included both milk sales and livestock sales. Base milk price was set to 30 cents/L. Variable costs included costs of feed, fertilizer, veterinary support, AI, electricity, and contractors. In all cases, the electricity consumption was calculated by the model for electricity consumption on dairy farms and this was combined with electricity unit costs. Similar to all costs included in the analysis, electricity costs were inflated by 2% per annum to account for the effect of inflation in input costs (consumer price index inflation rate for Ireland).

The fixed costs included hired labor, equipment and building maintenance, depreciation and interest, costs associated with rented land, and car or phone expenses. Costs of the farmers' own labor were excluded from the calculations. When computing a farm's tax and net income, what remains after the cash costs plus depreciation is used to calculate the taxable income. Including a national average salary figure for the farm owner in this analysis would distort the tax calculations and, therefore, the overall net returns.

Income before tax was calculated under the assumption that all new investments in equipment were depreciated to zero over a 10-yr period. The financial implications of each scenario were measured annually over the 10 yr that were evaluated:

$$\begin{aligned} \text{after-tax net income} = & \text{net income} \\ & + \text{subsidies} - \text{tax paid}. \end{aligned} \quad [3]$$

The discounted net income was included in the analysis to consider the time value of income realized. This allowed visibility of the returns of each technology over each year. The discount rate was set to 2% per annum for the 10-yr period, which was arrived at through an evaluation of the consumer price index inflation rates in the Irish economy from 2000 to 2013. Discounted net income was calculated using the formula:

$$\begin{aligned} \text{discounted net income} = & (\text{after-tax net income}) \\ & \times \text{discount rate}. \end{aligned} \quad [4]$$

Taxation is included in these calculations because large farms will pay tax at a higher rate than smaller farms and it is important to take this into account when considering the value of an investment to a particular farm. Within the Irish taxation system, 2 rates of personal tax are applied: 20% of income below \$40,600 and 41% of income above \$40,600. Both rates apply to the taxable income, which is the net income earned plus depreciation and less any capital or other allowances. Therefore, the net income earned affects the ROI figure for a given investment.

ROI Calculations

The ROI is a performance measure of the efficiency of each technology investment scenario. In these calculations we compute the return on additional investment over the base level of investment by dividing the average difference in yearly after tax net income (not discounted) by the difference in investment versus the base investment for each investment scenario on an annual basis. Where ROI is described by equation 5 as

$$\begin{aligned} \text{ROI} = & [(\text{income investment} \times -\text{income base}) \\ & + (\text{interest investment} \times -\text{interest investment base})] / \\ & (\text{investment} \times -\text{investment base}), \end{aligned} \quad [5]$$

where income = after-tax net income.

Investment figures for all scenarios are presented in Table 2. The ROI is used in this analysis to provide a metric of how effectively each technology-investment scenario used capital invested to generate income over the base level of investment.

Electricity Tariffs

Two commonly used existing tariff structures were used in this analysis, a flat and a DN tariff. Reference flat rate tariffs from 2013 were used, when electricity price was \$0.25/kWh for all time periods throughout the year. The DN tariff electricity costs were \$0.25/kWh from 0900 to 0000 h and \$0.10/kWh from 0000 to 0900 h. These electricity costs were sourced from an Irish comparison of energy prices from 2013 (SEAI, 2014); we assumed that these tariff structures would remain in place over the term of the investments.

Table 2. Total technology investments (\$) for all 6 investment scenarios on 3 farms, SF (small farm), MF (medium farm), and LF (large farm), with and without grant aid

Scenario ¹ (\$)	SF		MF		LF	
	Standard cost	Grant aid cost	Standard cost	Grant aid cost	Standard cost	Grant aid cost
Base	25,602	15,361	30,451	18,270	37,738	23,039
DXPHE	26,979	16,187	32,450	19,470	40,776	24,862
IB	27,488	16,492	32,337	19,402	39,884	25,185
IBPHE	29,629	17,777	35,665	21,400	45,194	28,371
Solar	30,141	18,085	35,815	21,488	44,623	27,169
VSD	29,094	17,456	38,452	23,071	41,993	25,592

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

Technology Costs and Sensitivity Analysis

Investment figures for direct expansion and IB milk-cooling systems as well as precooling systems were sourced from Irish government reference cost guidelines (DAFM, 2013). Costs associated with appropriately sized water-heating systems and vacuum pump systems for the small, medium, and large farms were sourced from local equipment suppliers in November 2013. Details of these costs are included in Table 2. From time to time the Department of Agriculture Food and the Marine in Ireland operate a capital grant scheme for the installation of milk-harvesting and milk-cooling systems. The grant rates that applied to the targeted agricultural modernization scheme administered by DAFM in 2012 and 2013 were applied to create the grant aided reduced technology costs sensitivity analysis. The targeted agricultural modernization scheme grant rate was 40% for milk-cooling systems up to a maximum of \$31,750 and 40% for milking systems including water-heating systems up to a maximum of \$50,800.

Sensitivity analysis was completed with a 40% reduction in investment costs, and even though no grants were available for solar water-heating systems, costs of the solar water-heating systems were reduced by 40% in the sensitivity analysis to simulate potential future schemes. Likewise, a sensitivity analysis was carried out on increased electricity costs, where a 4% per year increase in electricity cost was included rather than the 2% included in the base analysis. The reduced technology costs and increased electricity costs parameters were combined to examine the cumulative effect of both reduced technology costs arising from the grant aiding of equipment and the 4% per annum rate of increase in electricity costs. The effect of increased interest rates and lower milk prices were tested through sensitivity analysis. For interest rate on borrowed capital, 6.5%

over the term of the investment rather than 5% was used. This figure was chosen as the maximum interest rate applied to Irish consumer loans longer than 5 yr over the 10-yr period from 2003 to 2013 (CBI, 2014). Finally, the sensitivity of the results to milk price was tested by applying a milk price of \$0.31 per liter rather than the \$0.38 per liter used in the main analysis. This milk price was identified as the lowest average annual milk price during the 10-yr period from 2003 to 2013 (CSO, 2014).

RESULTS

Electricity Consumption and Costs

Table 1 shows the simulated electricity consumption (kWh) for each of the 7 main infrastructural systems on each of the 3 farms under the base scenario. On average, milk cooling made up 45% of total electricity consumption across all 3 farms (range: 39–50%), which was 26% for water heating (range: 23–29%) and 17% for the milking machine (range: 14–20%). Other electricity consumption by wash pumps, water pumps, automatic scrapers, and lighting consumed 12% (range: 4–18%). The simulated electricity consumption and costs per liter of milk were lowest for the small farm (i.e., 41 Wh/L and \$0.0072/L). The corresponding figures for the medium farm were 51 Wh/L and \$0.0085/L, whereas for the large farm they were 42 Wh/L and \$0.0075/L. Simulation results pertaining to total annual electricity consumption and electricity costs under the DN and flat tariff structures for each of the 6 technology investment scenarios are presented in Table 3. The annual discounted income for the 10-yr period after investment for each investment scenario for the DN tariff is presented in Table 4 and for the flat tariff in Table 5.

Table 3. Deviation from the base scenario for total annual electricity consumption (kWh) and electricity costs (\$) for day and night (DN) and flat tariffs for all investment scenarios on 3 farms, SF (small farm), MF (medium farm), and LF (large farm)

Scenario ¹	SF			MF			LF		
	Electricity consumed (kWh)	Cost DN (\$)	Cost flat (\$)	Electricity consumed (kWh)	Cost DN (\$)	Cost flat (\$)	Electricity consumed (kWh)	Cost DN (\$)	Cost flat (\$)
Base	10,413	1,835	2,645	25,252	4,234	6,414	32,670	5,805	8,298
DXPHE	-2,877	-724	-730	-5,643	-1,375	-1,434	-9,010	-2,177	-2,289
IB	389	-526	99	1,047	-893	265	2,107	-988	535
IBPHE	-2,707	-848	-687	-5,258	-1,599	-1,336	-8,489	-2,596	-2,156
Solar	-806	-81	-204	-2,269	-231	-577	-5,764	-585	-1,464
VSD	-1,047	-170	-265	-1,840	-302	-467	-3,168	-544	-805

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

Effect of Technology Investments on Electricity Consumption and Electricity Costs

Small Farm. In the base scenario, the total annual electricity consumption was 10,413 kWh (Table 3). The DXPHE resulted in the largest savings in annual electricity consumption, 28% (2,877 kWh) over the base scenario, whereas IBPHE reduced electricity consumption by 26% (2,707 kWh), VSD by 10% (1,047 kWh), and solar by 8% (806 kWh). The IB, however, increased electricity consumption by 389 kWh (4%).

The total annual electricity cost was \$1,835 on the DN tariff and \$2,645 on the flat tariff (44% higher than the DN tariff). The IBPHE on the DN tariff resulted in the largest annual cost reduction, saving 46% (\$848) on electricity costs versus the base scenario on DN. The DXPHE saved 39% (\$724) and IB saved 29% (\$526) of annual electricity costs versus the base scenario on DN. Solar and VSD scenarios resulted in savings of 4 (\$81) and 9% (\$170) of total annual electricity costs on the DN tariff.

Table 4. Annual (\$) for 10 yr after investment) and total discounted net income (\$) with % relative to the base scenario in parentheses) for the 6 investment scenarios on 3 farms, SF (small farm), MF (medium farm), and LF (large farm), on the day and night (DN) tariff

Scenario ¹	Year										Total
	1	2	3	4	5	6	7	8	9	10	
SF											
Base	38,416	36,878	35,437	33,894	32,186	30,631	29,232	28,072	27,088	26,222	318,054 (0.0%)
DXPHE	38,583	37,019	35,556	34,149	32,415	30,844	29,432	28,227	27,245	26,387	319,857 (0.6%)
IB	38,396	36,824	35,353	33,800	32,057	30,480	29,065	27,937	26,956	26,100	316,968 (−0.3%)
IBPHE	38,227	36,615	35,113	33,434	31,653	30,048	28,693	27,581	26,603	25,758	313,724 (−1.4%)
Solar	37,739	36,119	34,517	32,546	30,757	29,233	27,981	26,867	25,890	25,048	306,697 (−3.6%)
VSD	37,953	36,350	34,856	32,959	31,187	29,590	28,336	27,225	26,246	25,399	310,100 (−2.5%)
MF											
Base	57,892	55,632	53,496	51,482	49,588	47,812	46,152	44,607	41,843	40,547	489,052 (0.0%)
DXPHE	58,303	56,008	53,842	51,803	49,891	48,101	46,434	44,886	42,037	40,753	492,056 (0.6%)
IB	58,066	55,772	53,607	51,570	49,658	47,870	46,203	44,654	41,811	40,526	489,736 (0.1%)
IBPHE	57,912	55,557	53,343	51,264	49,320	47,509	45,830	44,279	41,295	40,028	486,338 (−0.6%)
Solar	57,163	54,806	52,588	50,508	48,564	46,751	45,071	43,520	40,530	39,263	478,761 (−2.1%)
VSD	56,782	54,378	52,120	50,006	48,036	46,208	44,517	42,964	39,863	38,609	473,484 (−3.2%)
LF											
Base	84,404	81,218	78,191	75,322	72,611	70,052	67,644	65,385	61,622	59,687	716,136 (0.0%)
DXPHE	85,077	81,835	78,762	75,857	73,115	70,537	68,118	65,855	61,965	60,046	721,164 (0.7%)
IB	84,588	81,361	78,303	75,409	72,676	70,103	67,687	65,425	61,572	59,648	716,771 (0.1%)
IBPHE	84,599	81,275	78,135	75,175	72,393	69,784	67,348	65,081	61,004	59,108	713,900 (−0.3%)
Solar	83,622	80,310	77,179	74,225	71,449	68,844	66,410	64,144	60,091	58,191	704,465 (−1.6%)
VSD	84,018	80,753	77,662	74,742	71,989	69,402	66,979	64,714	60,772	58,859	709,889 (−0.9%)

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

Table 5. Annual (\$) for 10 yr after investment) and total discounted net income (\$) with % relative to the base scenario in parentheses) for the 6 investment scenarios on 3 farms, SF (small farm), MF (medium farm), and LF (large farm), on the flat tariff

	Year										
Scenario ¹	1	2	3	4	5	6	7	8	9	10	Total
SF											
Base	37,987	36,449	34,992	33,127	31,417	29,864	28,572	27,470	26,486	25,618	311,983 (0.0%)
DXPHE	38,156	36,593	35,131	33,387	31,653	30,082	28,736	27,629	26,647	25,789	313,804 (0.6%)
IB	37,635	36,063	34,350	32,441	30,698	29,213	27,977	26,869	25,889	25,033	306,168 (−1.9%)
IBPHE	37,713	36,101	34,473	32,515	30,733	29,219	27,970	26,858	25,880	25,036	306,498 (−1.8%)
Solar	37,376	35,754	33,866	31,896	30,114	28,721	27,469	26,356	25,380	24,538	301,469 (−3.4%)
VSD	37,574	35,973	34,229	32,282	30,510	29,050	27,804	26,693	25,715	24,868	304,698 (−2.3%)
MF											
Base	56,735	54,475	52,341	50,326	48,433	46,656	44,996	43,451	40,686	39,392	477,490 (0.0%)
DXPHE	57,178	54,882	52,716	50,678	48,764	46,975	45,307	43,760	40,912	39,627	480,800 (0.7%)
IB	56,295	54,002	51,836	49,799	47,888	46,098	44,432	42,884	40,041	38,755	472,031 (−1.1%)
IBPHE	56,615	54,262	52,046	49,968	48,025	46,214	44,534	42,983	40,000	38,731	473,379 (−0.9%)
Solar	56,190	53,833	51,615	49,535	47,591	45,778	44,098	42,548	39,557	38,291	469,033 (−1.8%)
VSD	55,714	53,308	51,050	48,938	46,968	45,140	43,448	41,895	38,793	37,541	462,796 (−3.1%)
LF											
Base	83,082	79,894	76,869	74,000	71,289	68,730	66,322	64,063	60,300	58,364	702,916 (0.0%)
DXPHE	83,814	80,571	77,499	74,593	71,853	69,273	66,854	64,592	60,701	58,782	708,534 (0.8%)
IB	82,457	79,231	76,172	73,278	70,546	67,973	65,556	63,296	59,442	57,518	695,470 (−1.1%)
IBPHE	83,043	79,719	76,580	73,619	70,837	68,229	65,792	63,525	59,449	57,553	698,348 (−0.6%)
Solar	82,766	79,454	76,322	73,369	70,592	67,988	65,554	63,288	59,235	57,335	695,903 (−1.0%)
VSD	82,833	79,569	76,478	73,557	70,805	68,218	65,794	63,530	59,588	57,676	698,050 (−0.7%)

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

The flat tariff, however, was not as favorable to the IBPHE scenario, resulting in cost savings of only 26% (\$687); the IB scenario increased electricity costs by 4% (\$99) and the DXPHE scenario resulted in the largest cost saving of 28% (\$730) over the base. Solar and VSD scenarios resulted in savings of 8 (\$204) and 10% (\$265) of electricity costs on the flat tariff.

Medium Farm. In the base scenario the total annual electricity consumption was 25,252 kWh (Table 3). The DXPHE resulted in the largest electricity savings, 22% (5,643 kWh) in total electricity consumption over the base scenario, whereas IBPHE reduced electricity consumption by 21% (5,258), VSD by 7% (1,840) and solar by 9% (2,269 kWh). The IB, however, increased electricity consumption by 4% (1,047 kWh).

The total annual electricity cost was \$4,234 on the DN tariff and \$6,414 on the flat tariff (51% higher than DN tariff). The IBPHE on the DN tariff resulted in the largest annual cost reduction, saving 38% (\$1,599) on electricity costs versus the base. The DXPHE saved 32% (\$1,375) and IB saved 21% (\$893) of annual electricity costs versus the base scenario. Solar and VSD scenarios resulted in savings of 5 (\$231) and 7% (\$302) of total annual electricity costs on the DN tariff.

The flat tariff, however, was not as favorable to the IBPHE scenario, resulting in cost savings of 21% (\$1,336); the IB scenario increased electricity costs by 4% (\$265) and the DXPHE scenario resulted in the

largest cost saving of 22% (\$1,434) over the base. Solar and VSD scenarios resulted in savings of 9 (\$577) and 7% (\$467) of electricity costs on the flat tariff.

Large Farm. In the base scenario the total annual electricity consumption was 32,670 kWh (Table 3). The DXPHE resulted in the largest electricity savings, 28% (9,010 kWh) in total electricity consumption over the base scenario, whereas the IBPHE scenario reduced electricity consumption by 26% (8,489 kWh), VSD by 10% (3,168 kWh), and solar by 18% (5,764 kWh). The IB, however, increased electricity consumption by 6% (2,107 kWh).

The total annual electricity cost was \$5,805 on the DN tariff and \$8,298 on flat tariff (43% higher than the DN tariff). The IBPHE on the DN tariff resulted in the largest annual cost reduction, saving 45% (\$2,596) on electricity costs versus the base scenario. The DXPHE saved 38% (\$2,177) and IB saved 17% (\$988) of annual electricity costs versus the base scenario. Solar and VSD scenarios resulted in savings of 10 (\$585) and 9% (\$544) of total annual electricity costs on the DN Tariff.

The flat tariff, however, was not as favorable to the IBPHE scenario, resulting in cost savings of 26% (\$2,156); the IB scenario increased electricity costs by 6% (\$535) and the DXPHE scenario resulted in the largest cost saving of 28% (\$2,289) over the base. Solar and VSD scenarios resulted in savings of 18 (\$1,464) and 10% (\$805) of electricity costs on the flat tariff.

Table 6. Return on additional investment (%) for day and night (DN) and flat tariffs for all 6 investment scenarios on 3 farms, SF (small farm), MF (medium farm), and LF (large farm)

Farm	Tariff	Return on investment over base ¹					
		Base	DXPHE	IB	IBPHE	Solar	VSD
SF	DN	0	17	-3	-9	-25	-22
	Flat	0	17	-31	-12	-23	-20
MF	DN	0	19	7	-3	-18	-19
	Flat	0	21	-29	-6	-15	-17
LF	DN	0	21	6	-1	-16	-13
	Flat	0	23	-35	-4	-8	-10

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

ROI Analysis and Farm Income

The total discounted net income (TDNI) over a 10-yr period for all 6 investment scenarios are displayed in Table 4 for the DN tariff and in Table 5 for the flat tariff, whereas the ROI for all 6 scenarios on both the DN and flat tariffs are displayed in Table 6.

Small Farm. The level of investment required in the base scenario was \$25,602 (Table 2). Under the DN tariff, the highest ROI was delivered by the DXPHE investment scenario, which was 17%. All other investment scenarios lead to negative ROI values. The ROI of the IB scenario was -3%, IBPHE was -9%, solar was -25%, and VSD was -22%. The DXPHE investment scenario increased the TDNI by 0.6% over the base scenario. All other investment scenarios lead to a reduction in TDNI.

Under the flat tariff the trend was the similar, with DXPHE delivering the highest ROI of 17%. The largest difference between tariffs was the ROI of the IB scenario, which dropped to -31% as it could not benefit from lower night rate electricity tariffs. Under the flat tariff the TDNI of the Base scenario reduced by 1.9% to \$311,983 (Table 5). The DXPHE investment scenario increased the TDNI by 0.6% over the base scenario. All other investment scenarios lead to a reduction in TDNI.

Medium Farm. The level of investment required in the base scenario was \$30,451 (Table 2). Under the DN tariff the highest ROI was delivered by the DXPHE investment scenario, which was 19%. The IB scenario also returned a positive ROI of 7%. All other investment scenarios lead to negative ROI values. The ROI of the IBPHE was -3%, solar was -18%, and VSD was -19%. The DXPHE investment scenario increased the TDNI by 0.6% and the IB scenario increased the TDNI by 0.1% over the base scenario. All other investment scenarios lead to a reduction in TDNI relative to the base case.

Under the flat tariff the trend was similar, with DXPHE delivering the highest ROI of 21%. The largest difference between tariffs was the ROI of the IB scenario, which dropped to -29% as it could not benefit from lower night rate electricity tariffs. Under the flat tariff the TDNI of the base scenario reduced by 2.4% to \$477,490 (Table 5). The DXPHE investment scenario increased the TDNI by 0.7%. All other investment scenarios lead to a reduction in TDNI relative to the base.

Large Farm. The level of investment required in the base scenario was \$37,738 (Table 2). Under the DN tariff the highest ROI was delivered by the DXPHE investment scenario, which was 21%. The IB scenario also returned a positive ROI of 6%. All other investment scenarios lead to negative ROI values. The ROI of the IBPHE was -1%, solar was -16%, and VSD was -13%. The DXPHE investment scenario increased the TDNI by 0.7% and the IB scenario increased the TDNI by 0.1% over the base scenario. All other investment scenarios lead to a reduction in TDNI relative to the base.

Under the flat tariff the trend was similar, with DXPHE delivering the highest ROI of 23%. The largest difference between tariffs was the ROI of the IB scenario, which dropped to -35% as it could not benefit from lower night rate electricity tariffs. Under the flat tariff the TDNI of the base scenario reduced by 2.1% to \$702,916 (Table 5). The DXPHE investment scenario increased the TDNI by 0.8%. All other investment scenarios lead to a reduction in TDNI relative to the base case.

Sensitivity Analysis

Table 7 presents the TDNI and ROI based on the large farm only for the sensitivity analysis of (1) reduced technology costs, (2) increased electricity costs, (3) a combination of both (i.e., reduced technology costs and

Table 7. Total 10-yr discounted net income (\$) and return on additional investment to both reduced technology costs and higher electricity costs after applying the 6 investment scenarios on the LF (large farm) on the day and night (DN) tariff¹

Case ²	Metric ³	Base	DXPHE	IB	IBPHE	Solar	VSD
RTC	TDNI (\$)	747,687	755,324	748,323	750,010	741,928	745,092
	ROI (%)	0	49	6	8	-13	-8
IE	TDNI (\$)	712,612	718,962	713,848	711,952	701,297	706,695
	ROI (%)	0	26	9	2	-15	-12
RTC&IE	TDNI (\$)	744,164	753,121	745,399	748,062	738,759	741,900
	ROI (%)	0	57	9	11	-12	-7
II	TDP (\$)	705,900	710,104	705,954	701,642	692,361	698,499
	ROI (%)	0	19	4	-3	-18	-15
DMP	TDP (\$)	255,185	258,909	255,572	253,114	246,068	250,195
	ROI (%)	0	16	5	0	-12	-10

¹Base = investment in direct expansion (DX) milk-cooling system, standard milking system vacuum pumps and electric water heating system; DXPHE = as per base with the addition of a milk precooling system; IB = as per base but includes an ice bank (IB) milk-cooling system instead of a DX milk-cooling system; IBPHE = as per IB with the addition of a precooling system; Solar = as per base with the addition of solar thermal panels; VSD = as per base with the addition of variable-speed drive on the milking systems vacuum pumps.

²RTC = reduced technology costs; IE = increased electricity costs (i.e., 4% per annum instead of 2% per annum), RTC&IE = reduced technology costs and increased electricity costs, II = increased interest rate (i.e., 6.5% APR instead of 5% APR), DMP = decreased milk price (i.e., a milk price of \$0.31 per liter instead of \$0.38 per liter).

³TDNI = total 10-yr discounted net income, ROI = return on investment.

increased electricity costs), (4) increased interest rate, and (5) decreased milk price.

Reduced Technology Costs Sensitivity Analysis. When technology investments on the large farm were grant aided, TDNI for the base scenario was 4.7% higher than the base scenario when standard investment figures were applied. The scenarios DXPHE, IB, and IBPHE showed increases in TDNI over the base scenario of 1.2, 0.1, and 0.4%, respectively. Even with a significant grant rate of 40%, the solar and VSD options did not result in an increase in TDNI; in fact, the solar scenario reduced TDNI by 0.9% and the VSD scenario reduced TDNI by 0.4% when compared with the base. The ROI figures were positive for DXPHE (49%), IB (6%), and IBPHE (8%), but were negative for solar (-13%) and VSD (-8%).

Increased Electricity Costs Sensitivity Analysis. When electricity price was increased by 4% per annum, the TDNI of the base scenario was 0.6% lower than the base scenario when 2% electricity price increases per annum were included. The scenarios DXPHE and IB showed increases in TDNI over the base scenario of 1.0 and 0.2%, respectively. The solar and VSD options did not result in an increase in TDNI in this sensitivity analysis; in fact, the solar scenario reduced TDNI by 1.8% and the VSD scenario reduced TDNI by 0.9%. The ROI figures were positive for DXPHE (26%), IB (9%), and IBPHE (2%), but were negative for solar (-15%) and VSD (-12%).

Reduced Technology Costs and Increased Electricity Costs Sensitivity Analysis. When the technology costs were reduced and the electricity price was increased, the TDNI of the base scenario was 4.2% higher than the base scenario when 2% electricity price

increases per annum and full technology costs were included. The scenarios DXPHE, IB, and IBPHE showed increases in TDNI over the base scenario of 1.2, 0.2, and 0.5%, respectively. The solar and VSD options did not result in an increase in TDNI in this sensitivity analysis; in fact, the solar scenario reduced TDNI by 0.8% and the VSD scenario reduced TDNI by 0.3%. The ROI figures were positive for DXPHE (57%), IB (9%), and IBPHE (11%), but were negative for Solar (-12%) and VSD (-7%).

Increased Interest Rate Sensitivity Analysis. When the interest rate on borrowed capital was increased from 5 to 6.5%, the TDNI of the base scenario reduced by 2%; the TDNI of the DXPHE, IB, IBPHE, solar, and VSD scenarios reduced by 1.2, 1.9, 2.4, 3.9, and 3%, respectively. The ROI figures were positive for DXPHE (24%), IB (7%), and IBPHE (0%), but were negative for solar (-17%) and VSD (-15%).

Decreased Milk Price Sensitivity Analysis. When milk price was reduced from \$0.38 per liter to \$0.31 per liter, the TDNI of the base scenario reduced by 183%; the TDNI of the DXPHE, IB, IBPHE, solar, and VSD scenarios reduced by 178, 182, 184, 194, and 189%, respectively. The ROI figures were positive for DXPHE (19%), IB (7%), and IBPHE (1%), but were negative for solar (-12%) and VSD (-9%).

DISCUSSION

Application of Our Study

Applying a simple payback approach to generate an ROI figure (in years) for an energy efficiency investment, as applied by Houston et al. (2014), can be some-

what misleading, as the value of money over time decreases, an expected increase in electricity costs occurs, and the interest rate or opportunity cost of money are not taken into account. The analysis presented in our study, therefore, included these components in relation to the on-farm technology investments while evaluating the investments over their expected useful lives (10 yr). Farm profitability, electricity consumption, electricity costs and capital costs of equipment, and taxation were taken into account.

ROI and the Hurdle Rate

The ROI calculation methodology can be used to provide farmers with a robust approach to investment appraisal in relation to technologies over the useful life of the investment. The ROI, in conjunction with a minimal acceptable rate of return or hurdle rate, can be used as an investment appraisal metric to aide in the decision-making process regarding a selection of investment options. A general guideline used in economic modeling is that an investment must return at least 3 to 7.5% above the cost of funds (Schall et al., 1978; Hayes and Garvin, 1982; Lang and Merino, 1993; Barker, 1999; Meier and Tarhan, 2006), which in this case would be 8 to 12.5%, as the loan interest rate was 5%. For our analysis, we suggest that a hurdle rate of 10% could be applied. For each individual farm business, however, the manager must decide if this 10% threshold is applicable or not based on the specific economic environment and financial circumstances in which the farm operates. This approach allows dairy farmers to appraise different investment options on farm while at the same time benchmarking investment against potential investments that could be made outside the farm.

Application of the Results to Precision Livestock Farming

The benefits of the application of precision livestock farming were described as increased efficiency, reduced costs, improved product quality, minimized environmental effects, and improved animal health and well-being (Bewley, 2010). Efforts have been directed toward developing animal specific wireless sensors for monitoring body temperature (Ipema et al., 2008), automatic blood sampling (Fønss and Munksgaard, 2008), and prediction of milk yields (Olori et al., 1999; Grzesiak et al., 2006; Sharma et al., 2007). The sphere of precision livestock farming has not yet encompassed the area of electricity consumption or facility running costs. Improving the efficiency of electricity consumption through application of new technologies, and their

management, would meet the objectives of precision livestock farming while improving understanding among the farming community about the effect of changing farm infrastructure on electricity consumption, electricity costs, and long-term profitability.

Scenario Analysis

Cooling Systems. The scenario DXPHE consistently yielded the highest TDNI and ROI values across farm sizes and across all tariffs, indicating that, where possible, a precooling system should be used to cool milk to 15°C before the milk enters the milk storage tank. It is important to note that correct management of a milk precooler is critical to achieving precooling to 15°C. A system of controlling water flow rates during pumping of milk similar to that developed by Murphy et al. (2013) would be required to ensure the maximum precooling performance while minimizing water use. Where farms experience poor precooling performance, the efficiency of the milk-cooling system is reduced, resulting in increased electricity consumption (MDC, 1995), which in turn would affect the TDNI and ROI figures reported in our study.

Where a DN tariff was considered, the IB scenario offered TDNI gains over the base scenario for the medium and large farms, even though the electricity consumption of the IB scenario was higher. However, it is important to note that many farms struggle to operate large milking systems and cooling systems simultaneously on a single phase electricity supply (230 V), which may lead a farmer to choose an IB system with an ROI of less than 10% for operational reasons. Power upgrade availability can be a problem for more remote areas, where dairy farm conversions are likely to occur, as milk production expands out from the more traditional milk producing areas after European Union quota abolition.

When the flat-rate tariff was considered, the DXPHE returned as the most profitable investment scenario on all 3 farms. The combination of higher electricity consumption and the flat tariff made the IB and IBPHE scenarios unattractive on a TDNI and ROI basis. The TDNI figures for all farms were lower on the flat tariff, indicating that dairy farms should operate on a DN tariff whenever possible.

A final point that may influence a farmer's decision to choose an IB cooling system is their ability to be configured to cool milk below 4°C very quickly. This may produce milk quality benefits (i.e., reduced total bacteria count) for the farmer. This would be especially relevant where direct collection of milk is practiced (i.e., where milk is pumped directly to the

milk collection tanker), where long storage times on farms are a reality (i.e., >3 d). Total bacterial count is one of the primary indicators of quality in raw milk. Microbial contamination of milk can occur from several sources, such as infection within the cow udder, bacteria on the exterior of the udder, bacteria within components of the milking machine, and improper sanitization of the bulk storage tank (Murphy and Boor, 2001). It is important to prevent further growth of bacteria once it has reached the bulk tank, as some microbes are thermotolerant and can survive pasteurization. Most bacteria stop multiplying below 7.2°C; however, during the cooling period, microflora multiply, especially fast-growing psychrotrophic bacteria that are produced in refrigerated bulk tanks (Gennari and Dragotto, 1992; Ternström et al., 1993). Psychrotrophic bacteria continue growing in population until the milk temperature drops below 4°C. Bacteria levels in raw milk not only affect value added products, such as cheese, but also pasteurized milk for direct consumption (Barbano et al., 2006). Raw milk needs to be cooled as fast as possible to ensure maximum product quality, mixing of cooled milk with quantities of warmer milk must also be avoided, if possible, to ensure the blend temperature does not exceed 4°C. The effect of this rapid cooling effect on total bacteria count, however, is difficult to quantify and is not included in our analysis.

Heating Systems. The solar scenario failed to produce an increase in TDNI on any of the farms on either the DN tariff or the flat tariff, despite the reduction in total annual electricity consumption of the large farm by 18%. The ROI for this scenario was negative, and even when the reduced technology costs and increased electricity costs sensitivity analysis was considered the ROI was -12%. The large farm used over 7,800 kWh per annum for water-heating purposes (Table 1), the solar scenario contributed to a decrease in TDNI of \$5,759 or 0.9%. This suggests that solar water heaters should not be considered as an investment option in the context of the farms described in our study.

Milking Systems. The VSD scenario failed to produce an increase in TDNI on any of the farms on either the DN tariff or the flat tariff, and even when the reduced technology costs and increased electricity costs sensitivity analysis on the large farm was considered the ROI was -7%. The large farm used over 5,700 kWh per annum for providing vacuum for the milking system (Table 1), the VSD scenario contributed to a decrease in TDNI of \$2,595 or 0.4%. This suggests that VSD systems should only be considered for the farms studied in our analysis when technology costs reduce dramatically.

Effect of Farm Size

The simulated electricity consumption of the small farm (40.8 Wh/L) was lower than those of the medium (50.5 Wh/L) and large farms (42.2 Wh/L). The electricity costs were lower also for the small farm (\$0.0072/L) than for the medium (\$0.0085/L) and large farms (\$0.0075/L); note that the farm sizes are not evenly graduated. The metrics of watt hour per liter and dollars per liter are sensitive to herd milk yield. In Ireland, land area is the limiting factor on most farms, and therefore milk production per hectare was used as the most important comparison metric. Using this metric, the large farm produced 7,037 L/ha, the medium farm produced 7,414 L/ha, and the small farm produced 5,318 L/ha.

The water-heating costs per liter of milk increased rapidly with farm size. The medium and large farms used automatic wash systems, which are factory set to carry out 1 hot wash cycle per day for labor saving purposes. Whereas smaller farms are more likely to hot wash the milking units manually on alternate days with the washing of the milk storage tank (milk is typically collected every other day in Ireland). Moreover, larger dairy farms in Ireland often experience increased business risk and cash-flow deficits as a result of capital expenditure on livestock and winter facilities (McDonald et al., 2013). As a result, it is common to find low-cost wintering facilities on larger farms (i.e., wintering pads instead of cubicle sheds) which do not use electricity powered automatic scrapers, in the case of the large farm in our study. It is expected that herd size will expand after the abolition of the European Union milk quotas. This will effect of the type of infrastructure that will be needed to carry out the milk-harvesting operation efficiently. We expect that although herd size will expand, the conclusions of our study will remain relevant, as we tested the ROI figures for small, medium, and large farms.

CONCLUSIONS

An investment appraisal methodology analyzing the interaction of capital investment and energy consumption of a range of technologies across 3 farm sizes, under 2 different electricity-pricing structures was described in this study. Of the 6 investment scenarios considered, the DXPHI returned the highest farm profitability and ROI across all 3 farm sizes and both electricity-pricing scenarios. When the DN tariff was considered, the IB scenario offered profitability gains over the base scenario, even though the electricity consumption of the IB scenario was higher and the ROI was lower than

the hurdle rate. To reduce the initial capital investment and improve the ROI of the IB, however, a grant aid framework is required. Likewise, farmers seeking to shift the milk-cooling electricity consumption away from milking times for operational reasons may accept the lower ROI of the IB system. The flat tariff resulted in decreases in TDNI of about 2% on all 3 farm sizes and resulted in decreases in the TDNI of all IB and IBPHE scenarios. The solar and VSD scenarios failed to produce an increase in farm profitability on any of the farms on either the DN tariff or the flat tariff, even when the technology costs were reduced by 40% through a grant aid.

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