SEAI Project RDD/00117 - Project Report

DSSED: Decision Support System for Energy use in Dairy Production

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Executive Summary

The following report provides a comprehensive description of the background, implementation and dissemination of project RDD/00117. This project pertains to the development of an online portal for dairy farmers whereby the users of the portal will receive comprehensive information relating to energy use, electricity costs, carbon emissions, renewable energy and potential on-farm technology investments. With the rapid expansion of the Irish dairy industry resulting from the abolition of European Union milk quotas, the importance of decision support and information for dairy farmers has become extremely important.

The first phase of the project involved monitoring the energy usage of 58 Irish dairy farms, and the subsequent development of a large database pertaining to energy usage on Irish dairy farms. In order to provide a detailed breakdown of energy use, electricity costs and carbon emissions on Irish dairy farms, a wide-ranging statistical analysis was carried out. The results of this analysis are available to farmers as part of the aforementioned portal, with a breakdown of mean energy consumption, cost and carbon emissions presented according to each energy consuming process on Irish dairy farms, as well as monthly trends relative to cow number and milk production. This statistical analysis is constantly updated due to continuous monitoring of 20 Irish dairy farms, with a dynamic information loop in operation between the farms in question and the statistical database.

The second phase of the project involved the development of a dairy farm technology calculator which was included as part of the online portal. This tool provides a means for dairy farmers to input details of their current farm and calculates how investment in renewable and energy efficient technologies will affect their farm from economic, energy and environmental points of view. The technologies which may be analysed are plate coolers, variable speed drives (VSDs), heat recovery systems, solar water heating systems, solar photovoltaic (PV) systems and wind turbines. In addition, the technology calculator may be used as a tool for informing policy relating to incentivising the purchase of these technologies.

It is anticipated that the online portal developed as part of this project will be used extensively in the future to assist farmers in making informed decisions pertaining to dairy farm energy, costs and carbon emissions. It can also be used by state bodies to aid them in policy related decisions.

Introduction

Cork Institute of Technology (CIT), in conjunction with Teagasc completed project objectives as outlined in the CIT project grant RDD/00117. The following report summarises the key outcomes of the project in relation to the original project proposal objectives, a comprehensive explanation of the methods utilised for project completion and an explanation of the functionality of the developed Decision Support System for Energy use in Dairy Production (DSSED).

The Agri-Food sector is Ireland's largest indigenous industry with food and drink exports alone amounting to €12.6 billion in 2017. This represents an increase of 13% over 2016 levels, the 8th consecutive year of export growth. The dairy sector was the strongest performer in 2017, increasing by 19% in 2017 representing a third (€4 billion) of overall export value (Bord Bia, 2017). In particular, butter exports grew 60% to €900m in 2017; however, specialised nutritional powders remain the leading dairy export valued at €1.4bn. The increased production and exportation of Irish dairy products may be attributed to two factors:

1) The abolishment of European Union Milk Quotas in April 2015, thus allowing for the expansion of the Irish dairy industry for the first time in a generation. In preparation, the Irish government identified the potential for a 50% increase in milk production by 2020 over 2007-2009 levels, as outlined in the Food Harvest 2020 report (DAFM, 2010).
2) Ireland's dairy products are recognised internationally as of a significantly high standard due to our primarily pasture-based farming system. With this, the top five markets for Irish dairy products are the UK, China, the Netherlands, Germany and the United States.

The increased dairy herd, milk production and exportation of dairy products comes with its own significant challenges with regard Ireland's 2020 EU targets for renewable energy. Ireland's 2020 targets involve a 20% reduction in greenhouse gas (GHG) emissions over 2005 levels. It is projected that with existing measures in place, Ireland is set to be 4%-6% below the desired target (EPA, 2017). Agricultural activities represent the largest sectoral share, projected to account for 45% of total non-Emission Trading Scheme (non-ETS) GHG emissions in 2020 (EPA, 2017). This is representative of a projected increase in agricultural emissions by 4% to 5% by 2020 over 2015 levels, with an expected dairy cow herd increase of 7% a contributing factor (EPA, 2017). As no immediate solution is available to reducing methane production from dairy cows, increasing the utilisation of renewable energy technologies in dairy production may serve as an appropriate measure to offset the projected increased GHG emissions.

To help optimise the production of milk, some dairy farmers will look to purchasing new technologies such as solar PV, wind turbines and/or VSDs to reduce the cost of production. The implementation of these technologies has the dual impact of:

1) Reducing the required load from the electrical grid.
2) Improving the penetration of renewable energy contributing to overall consumption, thus, improving Ireland's probability of achieving EU targets.

However, such technologies may lead to greater long-term running costs for dairy farmers if not managed and sized correctly. Similarly, the impact of grant aid for these technologies may not be maximised without decision support infrastructure in place. Forecasted cost savings described by technology suppliers cannot be relied upon as these figures are typically calculated for the average dairy farm. For accurate calculations, information regarding details such as, specific dairy farm operations, available grant aid and electricity tariffs is required, as the impact of installing a particular technology may be greatly affected depending upon specific conditions. Without this information (i.e. making decisions based upon averaged/estimated payback periods calculated by the technology supplier), the cost savings of a particular technology may be greatly over-estimated, pro-longing the return on investment (ROI) period for farmers. Currently there exists no government policy or guidelines for best practice in energy management on dairy farms. Thus, this SEAI funded project focused on the development and implementation of a Decision Support System for Energy use in Dairy Production (DSSED) whereby specific farm details may be inputted to:

1) Aid government bodies such as Teagasc and Bord Bia to produce informed dairy production energy utilisation strategies.

2) Advise farm managers on key decisions that determine the energy efficiency and cost effectiveness of the milk production process.
3) Support government bodies such as the SEAI in forming new policy relating to grant aiding for energy efficient and renewable energy technologies.

These measures would ensure that the cost and related GHG emissions associated with the on-farm production of milk remain as low as possible and are essential to ensure the long-term sustainability and growth of Ireland's dairy industry while helping to reduce the agricultural sector's contribution to overall renewable production and GHG emissions, helping Ireland to meet its 2030 renewable energy and 2035 GHG emissions targets. With this, the objectives of this project were to:

1) Integrate existing dairy farm energy usage databases and mathematical models
2) Establish a dynamic information loop between live dairy farms and the DSS
3) Development of the DSSED web app
4) Dissemination of project outcomes

The backend of the DSSED tool was developed and implemented through RStudio (RStudio, 2018a), an open-source, flexible and powerful software foundation for statistical computing and it's Shiny (RStudio, 2018b) package, which allows for the development of interactive web apps from RStudio. The current state-of-art energy prediction model for dairy farms was adapted for utilisation in RStudio. To ensure key model parameters were and will be kept up to date, an autonomous infrastructure was developed whereby energy consumption data is acquired autonomously in 15-minute intervals, pre-processed and added to an existing energy database comprising of 58 Irish dairy farms.

Project Outcomes

The development of the DSSED was categorised into four distinct objectives, each with the following resulting outcomes:

1. Integrate existing dairy farm energy usage databases and mathematical models

The current state of art prediction model for predicting energy on dairy farms in Ireland (the Model for Electricity Consumption on Dairy Farms - MECD) (Upton *et al.*, 2014) was successfully adapted for implementation to the DSSED along with a comprehensive database comprising of sub-metered electrical energy consumption data and related milk production, stock data at annual and monthly time resolutions. Both the database and MECD model are interlinked whereby the database enables the automatic population of MECD parameters based specific on-farm configurations. The incorporated database consists of sub-metered energy consumption data spanning from January 2014 – July 2017, thus it is the largest online database for energy consumption on Irish dairy farms. The regular updating of this database is crucial to maintain up-to date MECD parameters. The MECD model has proved effective in predicting dairy farm related energy consumption and related costs to within 10%.

2. Establish a dynamic information loop between live dairy farms and the DSSED

Remote sensing systems were successfully retro fitted to 20+ commercial farms, which will enable the live updating of the energy usage database to allow the energy model to produce constantly up-to-date policy informing outputs. The remote sensing network sends cumulative consumption data to a receiver on site at Teagasc, Moorepark, Animal & Grassland Research and Innovation Centre, Fermoy where it is transferred to a central database for storage. In turn, this data is transferred to a data manager based in Cork Institute of Technology and run through autonomous pre-processing software to ensure consistent, clean and reliable data uploads. Up to date processed consumption data is then combined with the existing database and uploaded to the DSSED server to: 1) ensure energy usage, cost and CO_2 efficiency indicators remain up to date, and 2) ensure consistent, up-to date and reliable MECD parameters.

3. Development of the DSSED web app

The online DSSED was effectively developed through RStudio (RStudio, 2018a), a flexible and powerful software foundation for statistical computing with website and mobile app development functionality. This DSSED ‘Technology Calculator’ provides an intuitive interface for end users to analyse multiple energy related scenarios, offering farm managers and policy makers key information for making informed decisions regarding technology investments on dairy farms. Concurrently, the DSSED '*Energy Breakdown*' provides a comprehensive dissemination of the full energy database. This offers researcher's key statistics regarding dairy farm infrastructure on a macro level. The Decision Support System for Energy use in Dairy Production (DSSED) tool may be accessed here.

4. Dissemination of project outcomes

Several methods are being employed for the dissemination of the project outcomes:

- **DSSED launch:** The portal will be launched in CIT during national innovation week. Representatives from individual stakeholders and member of the dairy industry are invited. The event will be advertised on national media platforms and through social media.

- **Conferences:** Academic related findings from this project will be presented at national and international conferences over the next year such as Environ 2018 in Ireland and ASABE 2018 in the USA.

- **Journal publications:** Five journal paper have been written that contain information generated as part of this project. They are currently being submitted for peer-review.

- **DSSED demo:** DSSED was demonstrated to a farmer focus group in January 2018 at the Clonakilty agricultural college as a part of Smart Rural. Smart Rural (http://tel.cit.ie/smartrural) is a European project being led by CIT which is researching methods of increasing engagement between farmers and technology, especially new apps for farm management. DSSED received very positive feedback and was showcased to the participating farmer groups.

Project Methods

Work Plan

The successful development of the DSSED required the completion of four primary tasks: 1) data acquisition, 2) the development of the database for dairy farm energy consumption, 3) the

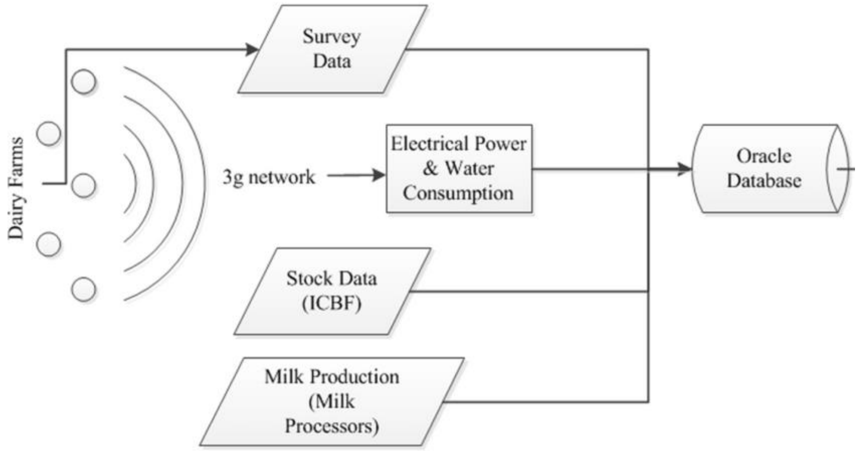


Figure 1: Acquisition of farm resource consumption, survey, stock and milk production data

incorporation of the model for energy consumption on dairy farms (MECD) and 4) the dissemination and explanation of DSSED functionality. Each task is comprehensively explained below.

Data Acquisition

Data were acquired through the automated recording of energy and water consumption through Teagasc, Moorepark (Cork, Ireland), the completion of a once off audit, monthly farmer input sheets, milk processor data and stock data from the Irish Cattle Breeding Federation (ICBF, 2016) of which all data is stored in the central Teagasc Oracle database (Figure 1). In total, 58 Southern Irish pasture based dairy farms were monitored for inclusion in the database. Currently, 20 dairy farms are recording sub-metered energy consumption allowing for the dynamic updating of consumption statistics and model parameters on a continuous basis.

Energy Meters

Installation of autonomous electrical energy metering equipment was carried out during the course of 2008 both through; Energy Monitoring Ireland Ltd, Carrick-on-Shannon, Co. Leitrim and Carlo Gavazzi Automation SpA, Lainate, Italy. Energy analysers of type EM24 DIN were employed to receive electrical pulses from energy and/or water meters. Each of these meters was interconnected by a daisy chain network (RS485 Modbus). This network was connected in tandem with a UR5i Libratum v2 modem where cumulative consumption measurements were sent through a 3g/GPRS network in 15 minute intervals to a receiver on site at Teagasc, Moorepark, Animal & Grassland Research and Innovation Centre, Fermoy. Powersoft data logging and recording software (Carlo

Gavazzi Automation SpA) were employed on-site which recognized each modem and therefore each meter via a virtual VPN. Upon autonomously reaching the Powersoft software, cumulative consumption data for each individual farm was in turn transferred to a database for storage. In turn, this data is transferred to a data manager based in Cork Institute of Technology for pre-processing through a cloud based storage provider.

Figure 2: On-farm electricity and water meters

Milk Production and Stock Data

Milk production records throughout the analysis period were collected (in litres) through liaison with their respective milk processor. Similarly, herd size (total on-farm dry and lactating dairy cows) was attained for each farm through the ICBF (Irish Cattle Breeding Federation). Both data sets were transferred remotely to the Teagasc Oracle database. In turn, this data is transferred to a data manager based in Cork Institute of Technology for pre-processing through a cloud based storage provider.

Farm Audits

Each dairy farmer participated in an on-site audit conducted by a Teagasc based technician throughout the latter half of 2014. An input audit template was created and completed for each dairy farm. Input queries included, but were not limited to: their milk processor name, information relating to on-farm manure storage tanks, detailed information on the milk cooling system (direct expansion or ice bank), the type of water heating system employed (oil or electric), whether a VSD was utilised and the type of on-farm lighting installed (incandescent or Halogen). Upon completion of each survey, details were manually imported to the database on-site at Teagasc, Moorepark.

This information is useful from a statistical point of view whereby energy consumption and related costs can be greatly influenced by the farmer through management practices and equipment choices.

Database for Dairy Farm Energy Consumption

Database Development

A data manager based in Cork Institute of Technology maintains an SQL database, which encompasses energy consumption data, associated milk production and stock data and farm audit data for each of the metered dairy farms. Up to date cumulative energy meter readings and associated milk production and stock figures are autonomously accumulated, processed, and stored with the previously collected data. The SQL database encompasses data at numerous stages from data acquisition to the development of the final database to maintain data transparency. These include: 1) the raw cumulative meter readings (15-minute resolution) for each farm. 2) processed cumulative meter readings (with erroneous/outlier data removed). An autonomous outlier detection algorithm was developed for the detection and removal of erroneous consumption data points caused my meter faults or human error. This pre-processing step is required to ensure a clean and robust database for analysis. 3) monthly consumption figures for each metered process on each farm with mean proportion of energy consumed during day and peak hours. Processed cumulative meter readings were linearly interpolated and consumption readings at the start and end of each month determined for monthly consumption calculations. 4) monthly milk production, stock and farm audit data.

A *Master* file was developed consisting of clean monthly processed data encompassing totalised energy consumption figures, milk production, stock and farm audit data. In some cases, energy consumption and/or total milk cooling related energy consumption must be calculated according to how the meters are installed on farm. I.e. on farm 'A', total energy consumption equals mains energy consumption minus a dwelling reading thus resulting in a totalised dairy farm related energy consumption figure. This master file thus allows statistical data analysis to be carried out with ease on each energy consuming dairy farm process, milk production and stock and related infrastructural equipment, managerial procedures and environmental conditions. An overview of the database for dairy farm energy consumption can be found in Figure 3.

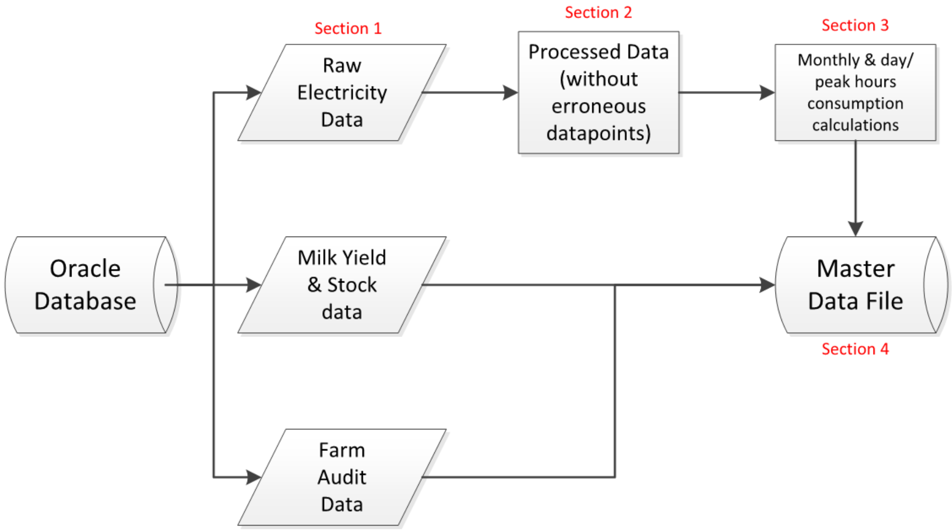


Figure 3: The development and contents of the 'Master' data file. Sections of the universal database are numbered where appropriate.

Energy Breakdown Tab

The development of the *Master* data file allows for the dissemination of energy consumption, cost and related greenhouse gas emissions, as presented in the *Energy Breakdown* tab (No. 1 in Figure 6) of the DSSED tool. This breakdown is further separated into two sub-sections: 1) *Breakdown*, where mean energy consumption (Wh/Lm), *Cost* (cent/Lm) and C*arbon Emissions* (gCO_2/Lm) are calculated and presented according to each energy consumption process on Irish dairy farms. 2) *Monthly Trend*, where consumption, cost and carbon emissions efficiencies per month are calculated for all electricity-consuming processes and presented relative to the number of dairy cows and/or milk production.

The *Breakdown* tab (No. 2 in Figure 6) presents a graphical and numerical breakdown of mean energy consumption, cost and carbon efficiencies (per litre of milk produced) according to each energy consuming process on a dairy farm. Users must first choose an analysis variable (No. 3 in Figure 6). This chosen variable is then be broken down according to each dairy farm process and presented the form of an interactive pie chart (No. 4 in Figure 6). Energy *consumption* is reported in watt-hours (Wh) per litre of milk, energy *costs* are reported in euro cent (cent) per litre of milk while *carbon emissions* are presented in grams of carbon dioxide per litre of milk. Calculated values are available for each farming process by scrolling over the pie chart. The pie chart is available for download above the image. When *Cost* is selected, users may analyse varying day and night rate electricity tariffs. A day rate electricity cost of 18c/kWh and night rate cost of 9c/kWh is set by default, in line with a from a standard Irish electricity provider (ESB, 2014). Day-time hours are fixed at 9am - 12 midnight. When *Carbon Emissions* is selected, users may analyse varying carbon intensity levels and the impact on gCO2/Lm. A Carbon intensity level equalling 468 gCO2/kWh is set as default in line with Ireland's carbon intensity level in 2015 (SEAI, 2016). A table (No.4 in Figure 6) is also presented containing numerical data related to efficiencies for each dairy farm process. This table varies according to input cost and carbon emissions parameters. This breakdown is shown in Table 1 using default input parameters mentioned.

Table 1 – Mean energy consumption, cost and carbon emission efficiencies for each dairy farm energy consuming process using default input parameters

Process		Wh/Lm		cent/Lm		gCO2/Lm	
Total Consumption		41.1		0.6		19.3	
Milk Cooling		11.9		0.18		5.58	
	DX		12.7		0.19		5.9
	DX_{GW}		10.5		0.15		4.9
	DX_{ICW}		15.0		0.16		7.0
	IB		19.7		0.24		9.2
	IB_{GW}		13		0.14		6.2
Milk Harvesting		7.6		0.12		3.6	
	No VSD		7.7		0.11		3.6
	VSD		5.2		0.08		2.4
Water Heating		8.0		0.1		3.8	
Lights		1.9		0.02		0.9	
Compressor		0.8		0.01		0.4	
Effluent Pump		0.4		0.01		0.2	
Wash Pump		1.0		0.01		0.4	
Scrappers		2.3		0.01		1.1	
Other		7.2		0.14		3.3	

Milk cooling and milk harvesting energy consumption, costs and CO_2 emissions are further segregated according to milk cooling system and whether a variable speed drive (VSD) is utilised. DX = direct expansion bulk tank. DX_{GW} = DX bulk tank with milk pre-cooling with ground water through a plate cooler. DX_{ICW} = DX bulk tank with milk pre-cooling with ice cold water through a plate cooler. IB = Ice bank milk bulk tank. IB_{GW} = IB bulk tank with milk pre-cooling with ground water through a plate cooler. VSD = variable speed drive.

As mentioned, the energy database, spanning January 2014 to July 2017 is the largest database for dairy farm energy consumption in Ireland. Thus, performance indicators presented in table 1 may be considered the most accurate figures for Irish dairy farm energy consumption, cost and carbon emissions currently available. A previous version of this database was utilised by Shine et al., (2017), where a thorough statistical analysis was carried out. However, this research was limited to analysing consumption and cost data from Jan 2014 – May 2016. Although not currently available from the DSSED tool, a breakdown of milk cooling and milk harvesting related energy consumption is also presented in table 1. Milk cooling related energy consumption is broken down according to the type of milk cooling system and/or milk pre-cooling system employed. This shows that the direct expansion bulk tank with pre-cooling through ground water is the most energy efficient milk cooling system consuming 10.5 Wh/Lm. However, the ice bank bulk tank with pre-cooling through ground water is the most cost efficient milk cooling system requiring 0.14 cent/Lm due to the ability to take advantage of low cost electricity during night time hours. Similarly, milk harvesting is separated according to whether a VSD is utilised for harvesting milk whereby employing a VSD saves on average 32% of milk harvesting related energy consumption equating to 0.03 cent/Lm.

The DSSED database shows that in total, 41.1 Wh are consumed per litre of milk produced, equating to 0.60 cent/Lm and emitting 19.2 grams of CO_2/Lm. These values are in a similar range with (although may be considered more accurate due to larger timeframe) the 39.8 Wh/Lm and 0.55 cent/Lm efficiency indicators calculated by Shine et al., (2017). Energy consumption, cost and CO_2 emissions are further broken down according to the following dairy farm processes: milk cooling, milk harvesting, water heating, lighting, energy for powering air compressors, pumping of effluent water, wash water pumping, scrappers and other miscellaneous, unmonitored processed throughout the farm. The proportion of total energy consumption, cost and CO_2 related to each process can be found in Figure 4 below. These charts were downloaded from the DSSED tool by placing the cursor on the image and clicking the ‘camera’ symbol that appears above the chart. The DSSED displays interactive pie charts whereby specific energy consumption, cost or CO_2 efficiencies for a particular

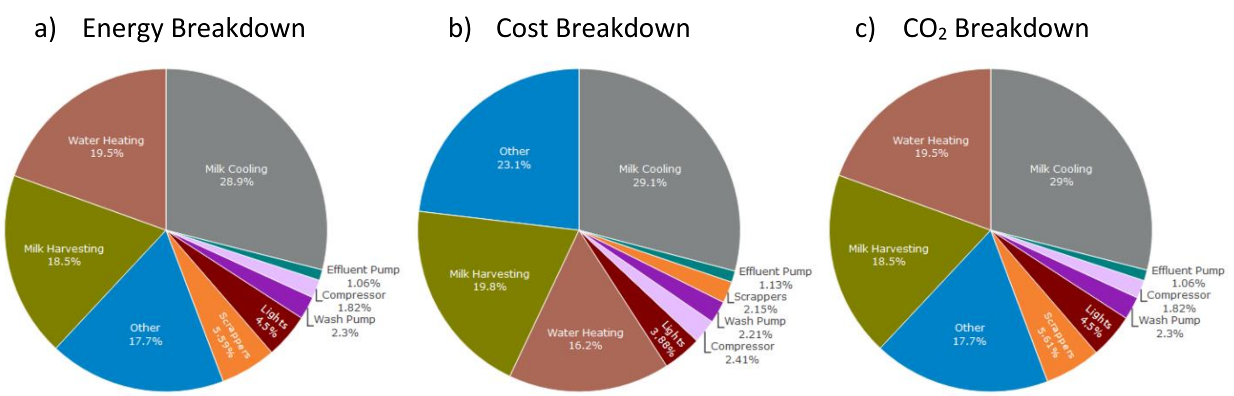


Figure 4: Pie charts presenting energy consumption (a), cost (b) and CO_2 emissions (c) breakdowns (downloaded from DSSED tool using default input parameters)

process appears when floated over with the cursor.

The percentage breakdowns of energy, cost and CO_2 present similar data, as shown in Figure 4. In particular, Figure 4a and Figure 4c, showing the breakdown of energy and CO_2, respectively, show near identical data breakdowns due to the only difference in data being the carbon intensity figure. Thus, any differences in figures can be attributed to data rounding. However, differences between percentage breakdowns shown in Figure 4a and Figure 4c, showing the breakdown of energy and cost, respectively, can be quite prevalent as cost is calculated using a day and night pricing structure and thus is dependent upon the average daily usage trend of each energy consuming process. For example, heating hot water of washing of parlour equipment etc. is responsible for 19.5% of total energy consumption. However, this equates to only 16.2% of total energy related costs. This is due farms employing timers on their water heating systems to allow for the heating of water during night time hours (12 midnight – 9am). This allows farmers make use of lower electricity costs (while having minimal impact on their usage of hot water), thus reducing the proportion of total costs attributed to water heating.

Monthly Trend

The *Monthly Trend* tab (No. 2 in Figure 7 presents a graphical breakdown of mean energy consumption, cost or carbon efficiencies per month according for each energy consuming process. This graphical breakdown is in the form of an interactive stacked bar chart where specific values are shown when highlighted with the cursor. As with the *Energy Breakdown* tab, users must first chosen an analysis variable. In the instance presented in Figure 7, *Carbon Emissions* is selected with the default carbon intensity level of 468 kg CO2/kWh (No. 3 in Figure 7). Carbon emissions (or energy consumption or cost) per month may be presented relative to either the number of on farm dairy cows or milk production. This option in available by selecting either or from the drop down list (No. 4 in Figure 7). The stacked bar chart is displayed (No. 5 in Figure 7) according to the chosen analysis variable and "*relative to"* variable.

A stacked bar chart displaying energy consumption per cow per month is presented in Figure 5a. For each month, energy consumption per cow is divided amongst each energy consuming process. A distinct trend can be seen in this chart. That is, both milk cooling and milk harvesting energy related consumption follows the milk lactation curve associated with Ireland's predominant Spring caving system. I.e. peak milk production (and consequently milk cooling and harvesting related energy consumption) occurs around May before gradually reducing month by month. Ireland's milking cycle predominantly lasts 300 days which is then follows by a 'dry' period where no milking occurs, occurring around the January – February months. This is the case for most dairy farms, thus, January and February are the two months with the least energy consumption. However, some dairy farms will milk all year round resulting in small magnitudes of energy being consumed overall, as shown in Figure 5a.

A stacked bar chart showing energy consumption per litre of milk produced per month is displayed in Figure 5b. As mentioned, little milk is produced during both January and December, however, energy is still consumed for parlour washing, water heating, lighting etc. Thus, this results in a large energy consumption to milk production ratio that can be seen in the Jan, Feb, Nov and Dec months in Figure 5b.

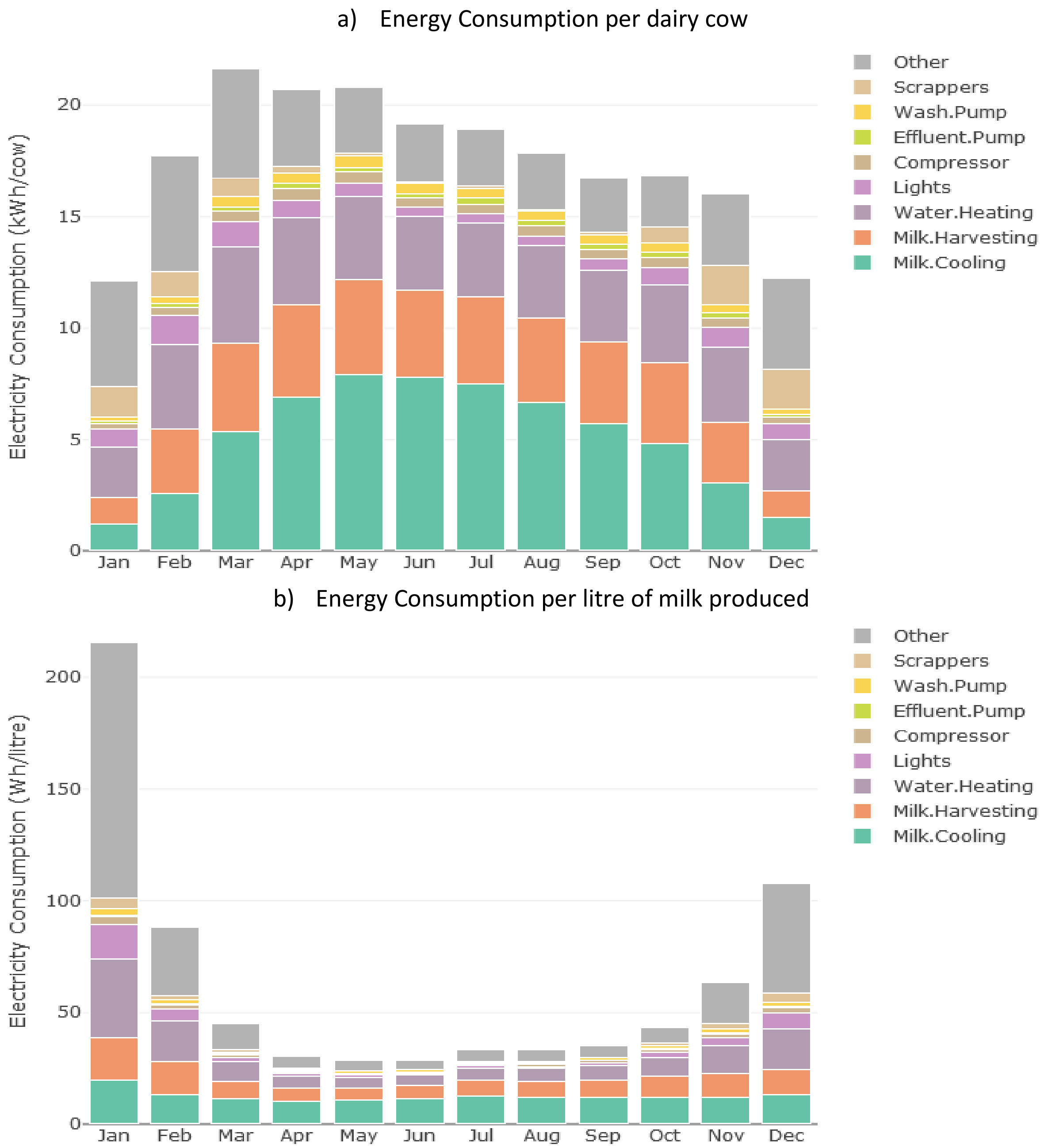
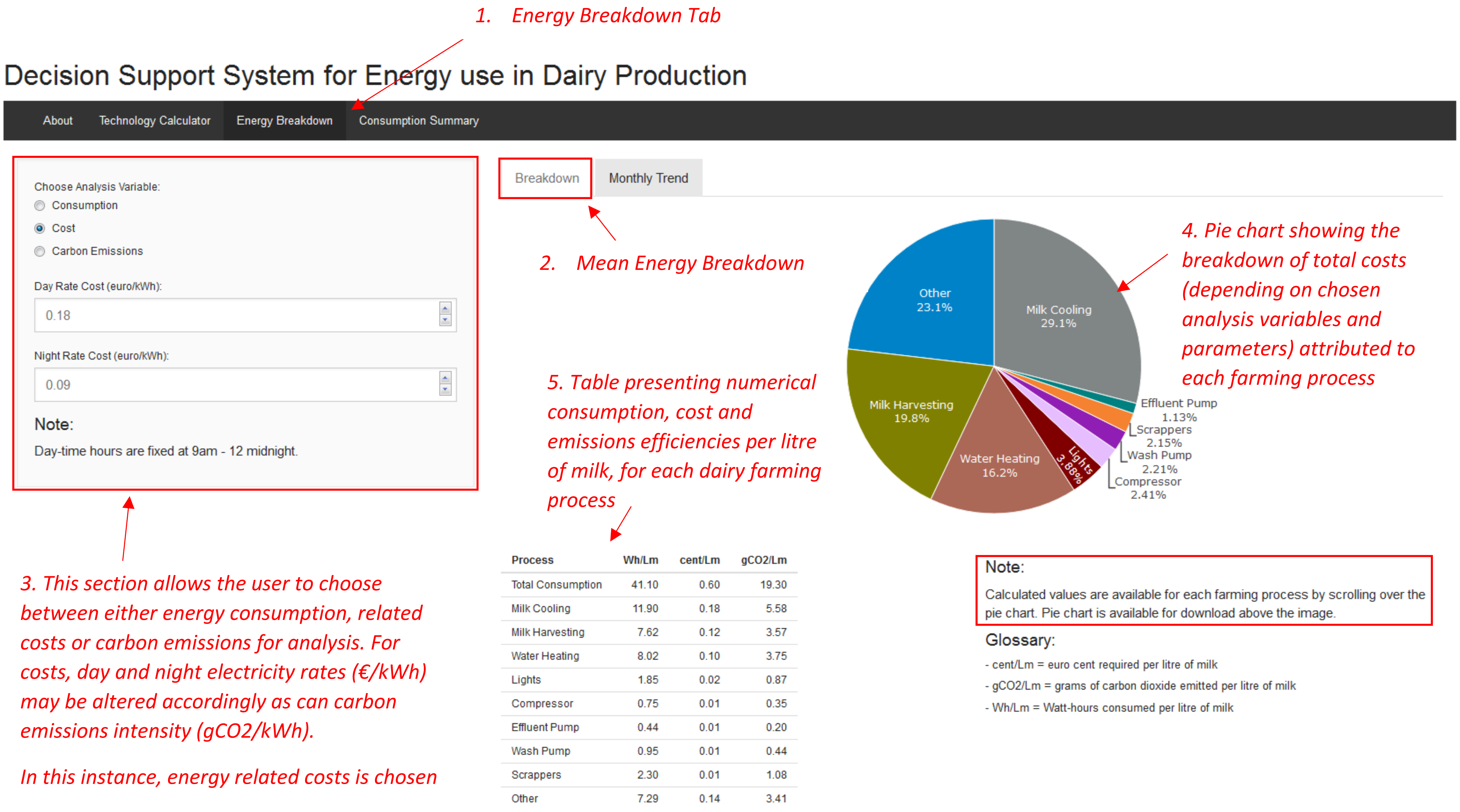


Figure 5: Mean monthly energy consumption per dairy cow (a) and per litre of milk produced (b) for each energy consuming process



Process	Wh/Lm	cent/Lm	gCO2/Lm
Total Consumption	41.10	0.60	19.30
Milk Cooling	11.90	0.18	5.58
Milk Harvesting	7.62	0.12	3.57
Water Heating	8.02	0.10	3.75
Lights	1.85	0.02	0.87
Compressor	0.75	0.01	0.35
Effluent Pump	0.44	0.01	0.20
Wash Pump	0.95	0.01	0.44
Scrappers	2.30	0.01	1.08
Other	7.29	0.14	3.41

Figure 6: Screenshot and description of the 'Energy Breakdown', breakdown tab of the DSSED tool

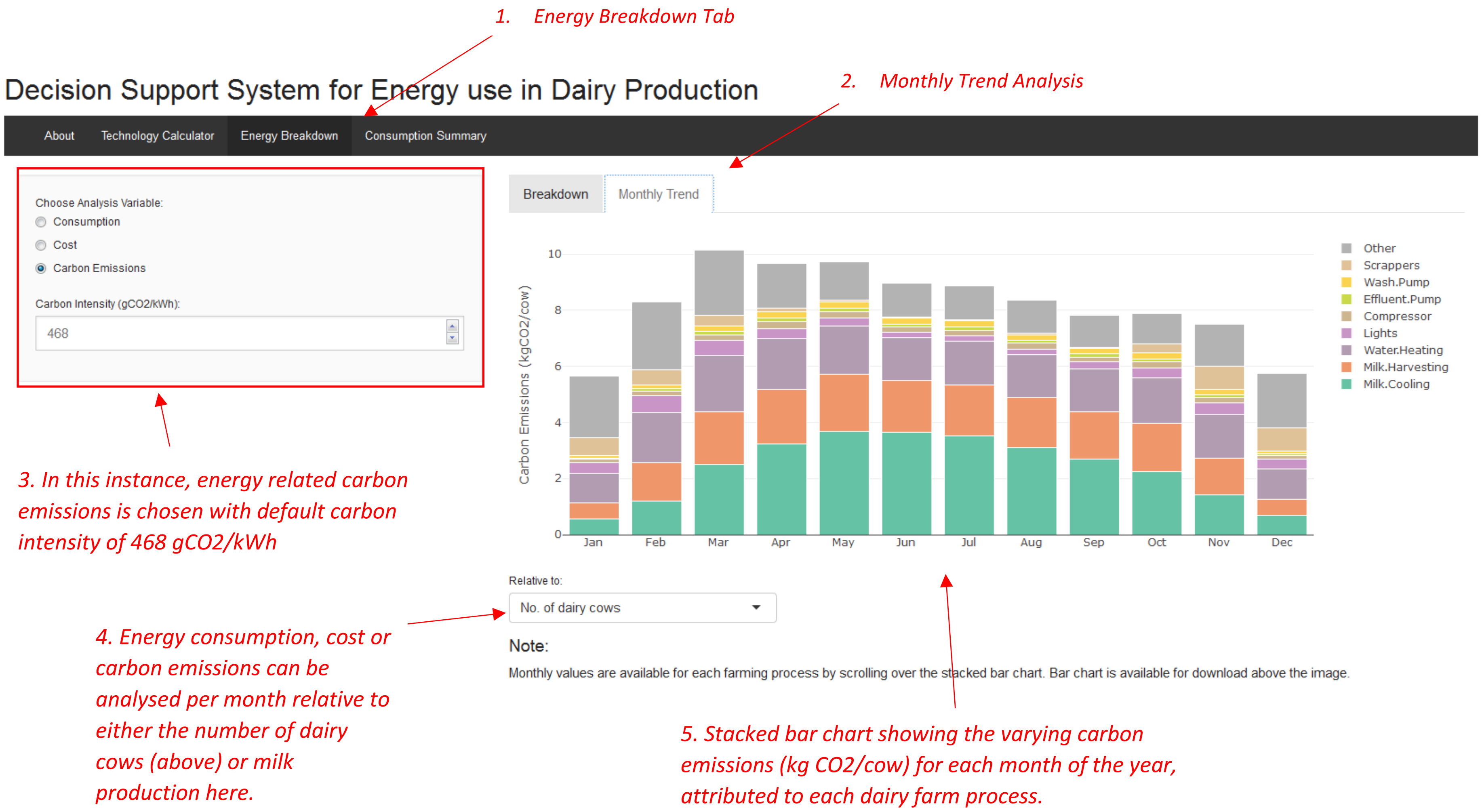


Figure 7: Screenshot and description of the 'Energy Breakdown', Monthly Trend tab of the DSSED tool

Technology Calculator

Overview

In order to develop a tool which allowed farmers to decide whether to invest in certain renewable and energy efficient technologies, previously published and developed models were used to create the DSSED Technology calculator (TC). The TC enables the user to enter details pertaining to a farm, including herd size, morning milking time, evening milking time, number of milking units, type of milk cooling system, type of water heating system, hot wash frequency, milk collection interval, whether the farm has a plate cooler, and the electricity tariff used. The user may then select from six different renewable and energy efficient technologies, with the user subsequently entering the size and cost of the technology as well as the level of grant aid associated with the technology and the rate of inflation. Information is then displayed relating to the payback period, CO_2 emissions, energy savings, renewable energy penetration and day/night time electricity use associated with the selected technology on the user's chosen farm. The six renewable and energy efficient technologies which may be chosen by the user, along with a brief explanation of each technology, are as follows:

- **Plate cooler –** Reduces milk cooling energy use by cooling milk using cold water in a plate heat exchanger, prior to the milk entering the main cooling system. The plate cooler is not an option in the TC if it has already been selected as part of the farm details entered by the user.
- **Variable speed drives –** This technology controls the speed of the milking machine vacuum pump motor in order to maintain the desired vacuum level for milking. VSDs can greatly reduce milking machine energy use.
- **Heat recovery –** These systems are installed in order to recycle the heat extracted from milk during cooling to preheat water for sanitation, thus reducing the energy used in water heating while also increasing the coefficient of performance of the milk cooling system.
- **Solar water heating –** This renewable technology uses solar irradiance to heat a fluid as it is passed through solar panels. The fluid is then transferred from the panels through a coil in a water tank, transferring heat to the water before being passed through the solar panels once more.

- **Solar PV –** These renewable systems use solar irradiance to produce electricity. This electricity may then be used on the farm as required, or exported to the grid if not needed.
- **Wind turbines –** This renewable technology converts wind power to electricity. This electricity may then be used on the farm as required, or exported to the grid if not needed.

To create the TC, models to determine dairy farm electricity use, electricity costs and carbon emissions were required, as well as models to represent the use of the six technologies. These models are described below.

Model for electricity consumption on dairy farms

The model for electricity consumption on dairy farms (MECD), developed by Upton et al. (2014), was used to simulate the electricity consumption, related costs and CO_2 emissions on dairy farms under the headings of milk cooling, water heating, milking machine, water pumping, lighting and winter housing. Inputs to the MECD included details pertaining to the equipment on the farm such as milk cooling system, water heating system and milking machine. Information relating to the farm's herd such as number of cows and milk yield were also required, as well as specifics concerning the management of the farm including the milking times and frequency of on-farm milk collection.

The outputs of the MECD included electricity consumption associated with milk cooling, water heating, milking machine, water pumping and winter housing. The electricity consumed by each system was outputted in a 12 x 24 matrix structure to simulate a representative day for each month of the year i.e. 12 months x 24 hours. The total electricity consumption of the farm could then be calculated by adding the various matrices for each electricity consuming system. This total electricity consumption (in a 12 x 24 structure) was then multiplied by an electricity tariff matrix, also in a 12 x 24 structure, representing hourly and monthly electricity price changes depending on the electricity tariff selected. Hence the total annual electricity costs of the farm in question could be determined.

Regarding electricity related CO_2 emissions on dairy farms, for the TC a dynamic CO_2 emission factor was used to simulate the CO_2 emissions associated with the farm's electricity consumption. The CO_2 emission intensity of electricity use in Ireland for the year 2016 was downloaded from the Eirgrid website (Eirgrid, 2017). This data was then used as an input to the MECD in a 12 x 24 structure as above, with the CO_2 intensity matrix being multiplied by the total electricity consumption matrix to provide a CO_2 emissions matrix from which the total farm CO_2 emissions could be calculated.

In order to assess the feasibility of technology investments on dairy farms, a previously published dairy farm ROI model was used (Upton et al., 2015). This model used average farm financial performance data and variable and fixed cost data from the Teagasc Eprofit Monitor (Teagasc, 2017), as well as revenue from sales of both milk and livestock, with a base milk price set to 33 cents per litre. Farm variable costs were also included, such as feed, fertilizer, veterinary bills, contractors and electricity. The electricity costs were calculated using the MECD as described above. Fixed costs included hired labour, machinery, car/phone expenses and depreciation. All costs in the analysis were inflated by a certain amount (percentage) per annum. The financial performance of the farm before and after the addition of technologies, taking into account the capital costs of the technology in question, was then compared to assess the payback of these technologies. Further information on the modelling strategy can be found in Upton et al. (2015). One difference between the ROI model used by Upton et al. (2015) and the model used for the TC was as follows: for the TC it was assumed that there was no borrowing of capital expenditure from financial institutions.

Models for renewable and energy efficient technologies

Plate cooler

For analysis of plate coolers in the TC, it was assumed that the milk is cooled to 15°C before entering the milk cooling system (Upton et al., 2015). It was also assumed that the water to milk ratio in the plate cooler was 2:1, with a pumping cost of €0.10 per square metre of water pumped through the plate cooler. As the use of a plate cooler may be simulated using the MECD, the development of a separate model was not required. The figures for precooling temperature, water to milk ratio and water pumping cost were used in the MECD and ROI models for the TC in order to analyse the potential payback of plate coolers on dairy farms.

Variable Speed Drives

For analysis of VSD systems, it was assumed that they contributed 60% of the farm's milking machine electricity use, in line with the figure used in Upton et al. (2015). As the use of VSDs may be simulated using the MECD, the development of a separate model was not required. The figure for VSD contribution was used in the MECD and ROI models for the TC in order to analyse the potential payback of VSD systems on dairy farms.

Heat recovery

To simulate the contribution of heat recovery systems to dairy farm water heating electricity use, experiments were carried out at Teagasc Moorepark in 2016 whereby waste heat from a Direct Expansion milk cooling tank was recycled using a SWEP B15nx30 heat exchanger to heat water in a 500 litre tank. The equipment used for these experiments is shown in Figure 8. A mechanistic model was developed which used coefficients empirically derived from a series of experiments on the heat recovery system. The developed model used hourly starting water and milk temperatures, as well as compressor power and the coefficient of performance of the milk cooling system, to predict the quantity of heat transferred to the water tank on an hourly basis. For analysis of heat recovery systems in the TC, the annual contribution of heat recovery systems to dairy farm water heating electricity use was determined using this model. The calculated contribution was then used in conjunction with the MECD and ROI models for the TC to analyse the potential payback of heat recovery systems on dairy farms.

Figure 8: Equipment for heat recovery experiments. Clockwise from top left: 500L water tank heated using heat from Direct Expansion (DX) cooling tank; Heat exchanger to transfer waste heat to water; Temperature sensor control for DX tank; DX tank.

Solar water heating

To simulate the contribution of solar water heating systems to dairy farm water heating electricity use, experiments were carried out at Teagasc Moorepark in 2016 using a MPTEC FK-21 solar water heater and accompanying 500 litre water tank. The equipment used for these experiments is shown in Figure 9. A mechanistic model was developed which used coefficients empirically derived from a series of experiments on the solar water heating system. The model developed used hourly irradiance, wind speed and ambient temperature values, as well as the hourly starting temperature of the water tank, to predict the quantity of energy transferred from the solar water heating system to the water tank on an hourly basis. For analysis of solar water heating systems in the TC, a full year of irradiance, wind speed and ambient temperature data measured using the weather station at Cork Institute of Technology in 2016 was used to simulate the contribution of solar water heating systems to dairy farm water heating electricity use. The calculated contribution was then used in conjunction with the MECD and ROI models for the TC to analyse the potential payback of solar water heating systems on dairy farms.

Figure 9: Equipment used for solar water heating experiments, clockwise from top left: Solar panel array; Pyranometer to measure irradiance; Water tank to which heat was transferred; Anemometer to measure wind speed.

Solar PV

For simulation of solar PV system power output, the model previously described in Breen et al. (2015) was used. This involved the use of a well-known mechanistic PV simulation model, whereby the power output of a PV system could be determined based on the irradiance and ambient temperature. For analysis of PV systems in the TC, a full year of irradiance and ambient temperature data measured using the weather station at Cork Institute of Technology in 2016 was used to simulate the output power of PV systems. This output power was then formatted to a 12 x 24 matrix and used in conjunction with the MECD and ROI models for the TC to analyse the potential payback of PV systems on dairy farms. If excess electricity was produced by the PV system, this electricity was exported to the grid with a certain monetary amount being earned per kilowatt hour of electricity exported. In addition, to assess the potential of PV systems for use in a residential home adjacent to the dairy farm, standard load profiles for residential electricity customers in Ireland were downloaded from RMDS (2018). The electricity consumption of the residential home was then formatted to a 12 x 24 matrix and added to the total farm electricity consumption calculated by MECD, and used with the PV system model to assess the feasibility of PV systems on dairy farms.

Figure 10: PV system at Cork Institute of Technology on which PV model was validated.

Wind turbines

For simulation of wind turbine power output, wind turbine power curve modelling was used. This involved the fitting of a polynomial curve to data provided by the wind turbine manufacturer, whereby the power output of the turbine could then be determined based on wind speeds. For more details on this method please refer to Breen et al. (2015). The turbine used in the aforementioned paper is located at Cork Institute of Technology and is shown in Figure 11. For analysis of wind turbines in the TC, a full year of wind speed data measured using the weather station at Cork Institute of Technology in 2016 was used to simulate the output power of wind turbines. This was then formatted to a 12 x 24 matrix and used in conjunction with the MECD and ROI models for the TC in order to analyse the potential payback of wind turbines on dairy farms. If excess electricity was produced by the wind turbine, this electricity was exported to the grid with a certain monetary amount being earned per kilowatt hour of electricity exported. Furthermore, to assess the potential of wind turbines for use in a residential home adjacent to the dairy farm, standard load profiles for Irish residential electricity customers were used in the same way as described for PV systems above.

Figure 11: 10kW turbine at Cork Institute of Technology.

Functionality
The flow of information through the TC is illustrated in Figure 12.

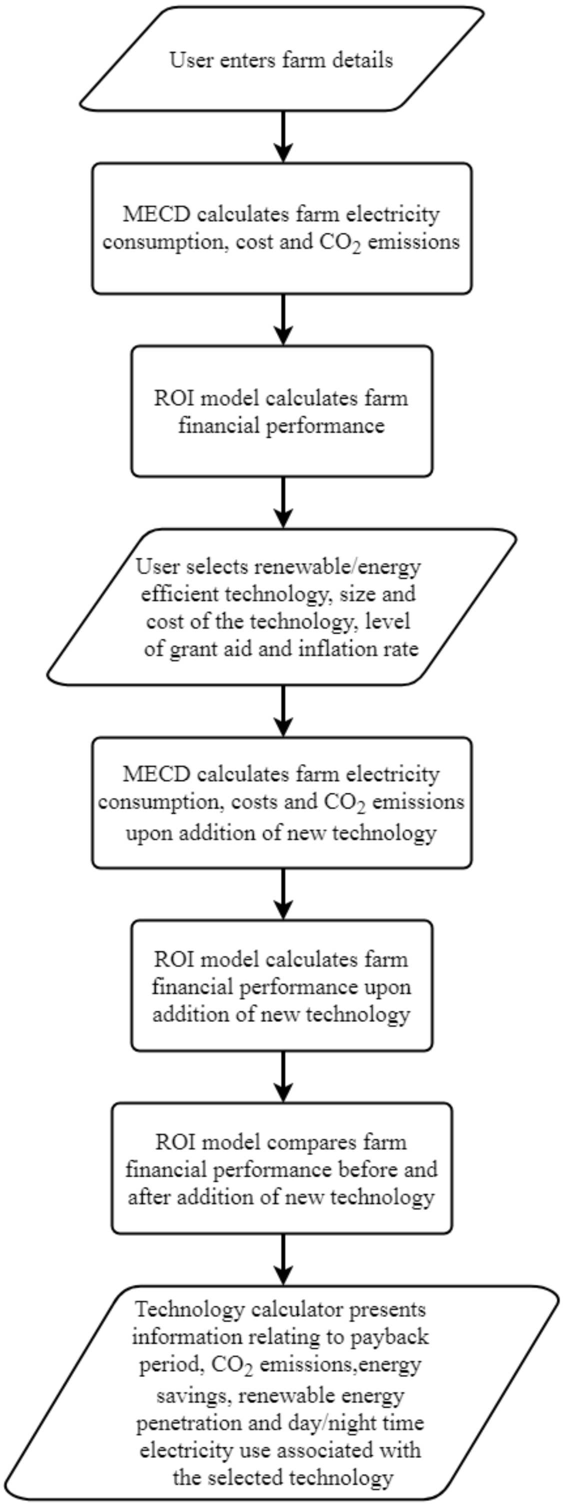


Figure 12: Flow of information through Technology Calculator.

For detailed instructions on how to use the TC, please see Appendix A.

It should be noted that, when using the TC, no parameters pertaining to the renewable/energy efficient technology are fixed. This functionality was included so that the user would not be constrained to one scenario for each technology. For example some users may get higher quotes for certain technologies than others, depending on their location and supplier. Furthermore, factors such as level of grant aid and feed in tariff may be altered to determine what level of these is required to make investments in certain technologies worthwhile. This should be of great interest to policy makers looking to incentivise the purchase of renewable technologies to enable Ireland to reach its renewable targets.

Once the TC has been run once, it is possible for users to change both the farm details and the selected technology investment as many times as they wish. For example, a user may want to determine which of the six technology investments best suits their farm either economically or environmentally. Similarly, a user may wish to find out by how much their herd size should be increased to make investment in a certain technology feasible, or whether altering their milking times or electricity tariff will make an investment more or less worthwhile. The TC was designed to be as comprehensive as possible in helping farmers make important decisions pertaining to technology investments.

Demonstration of DSSED Tool

In order to show how the DSSED may be used, the TC was used to create six hypothetical scenarios involving various renewable and energy efficient technologies, as well as different dairy farm sizes, configurations, grant aids, feed in tariffs and inflation rates. This demonstrates how the TC may be used for future exploratory analysis, both for farmer decision support as well as informing policy. The following six scenarios are purely hypothetical and are based on random farm configurations, these scenarios are for demonstrative purposes only and are not design to be used as feasibility indicators.

Scenario 1. Plate cooler

The farm setup for this scenario was as follows (Figure 13):

- 100 cow herd size
- Milking times of 8:00 and 18:00
- 11 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- No plate cooler
- Day night electricity tariff with a daytime price of €0.18 per kWh and a night time price of €0.09 per kWh

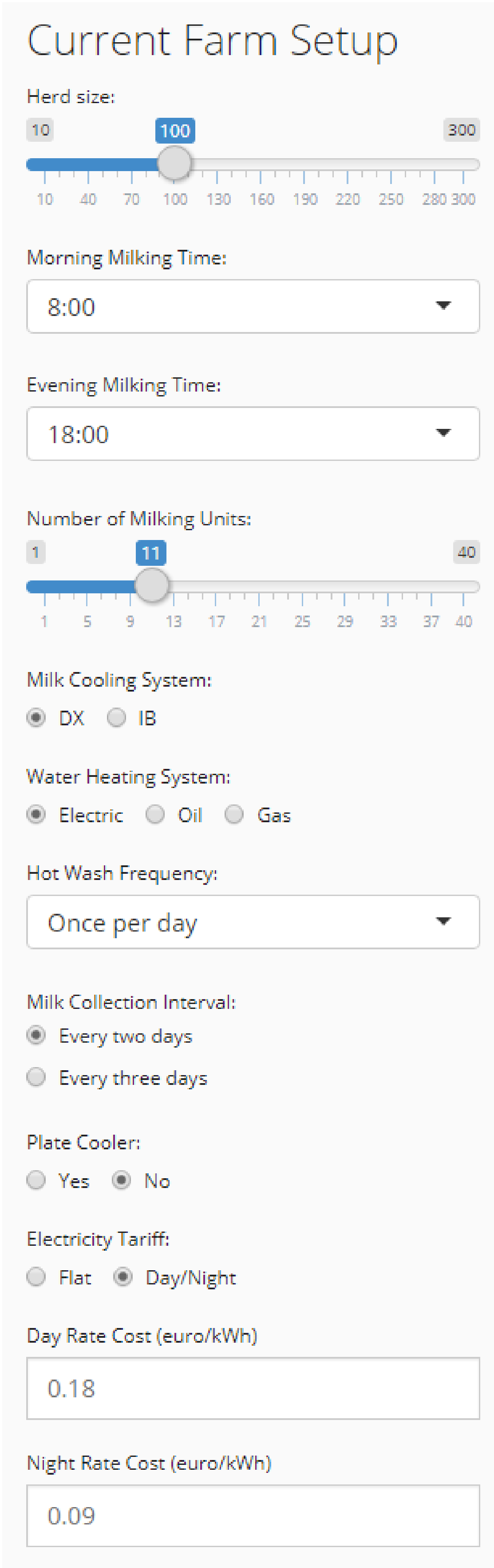


Figure 13: Dairy farm setup for Scenario 1

The on-farm technology selection for Scenario 1 was as follows (Figure 14):

- Selected technology: Plate cooler
- Investment cost of €2,300
- No grant aid
- Inflation rate of 2%

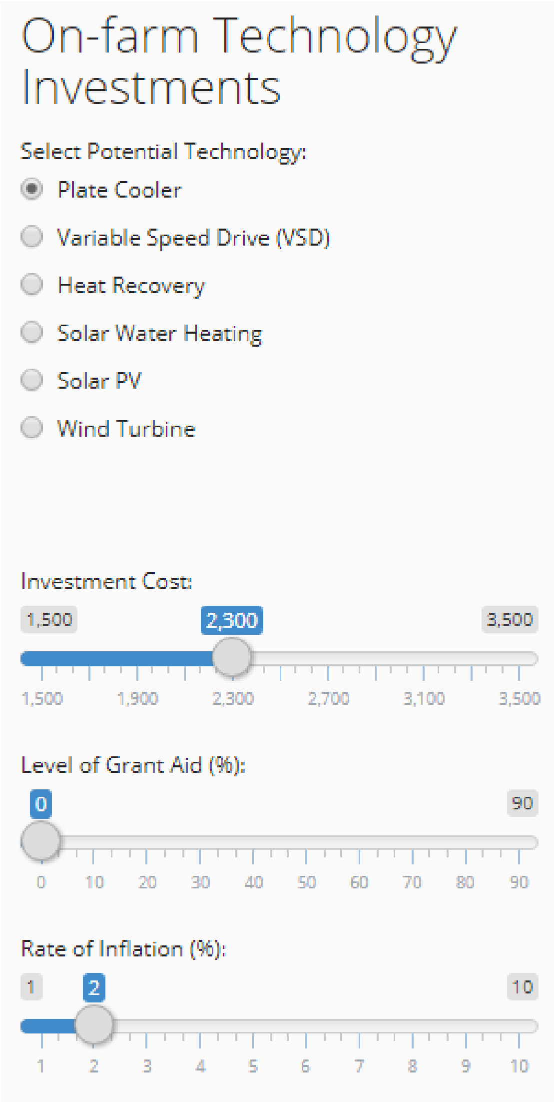


Figure 14: On-farm technology setup for Scenario 1

The results for Scenario 1 were as follows:

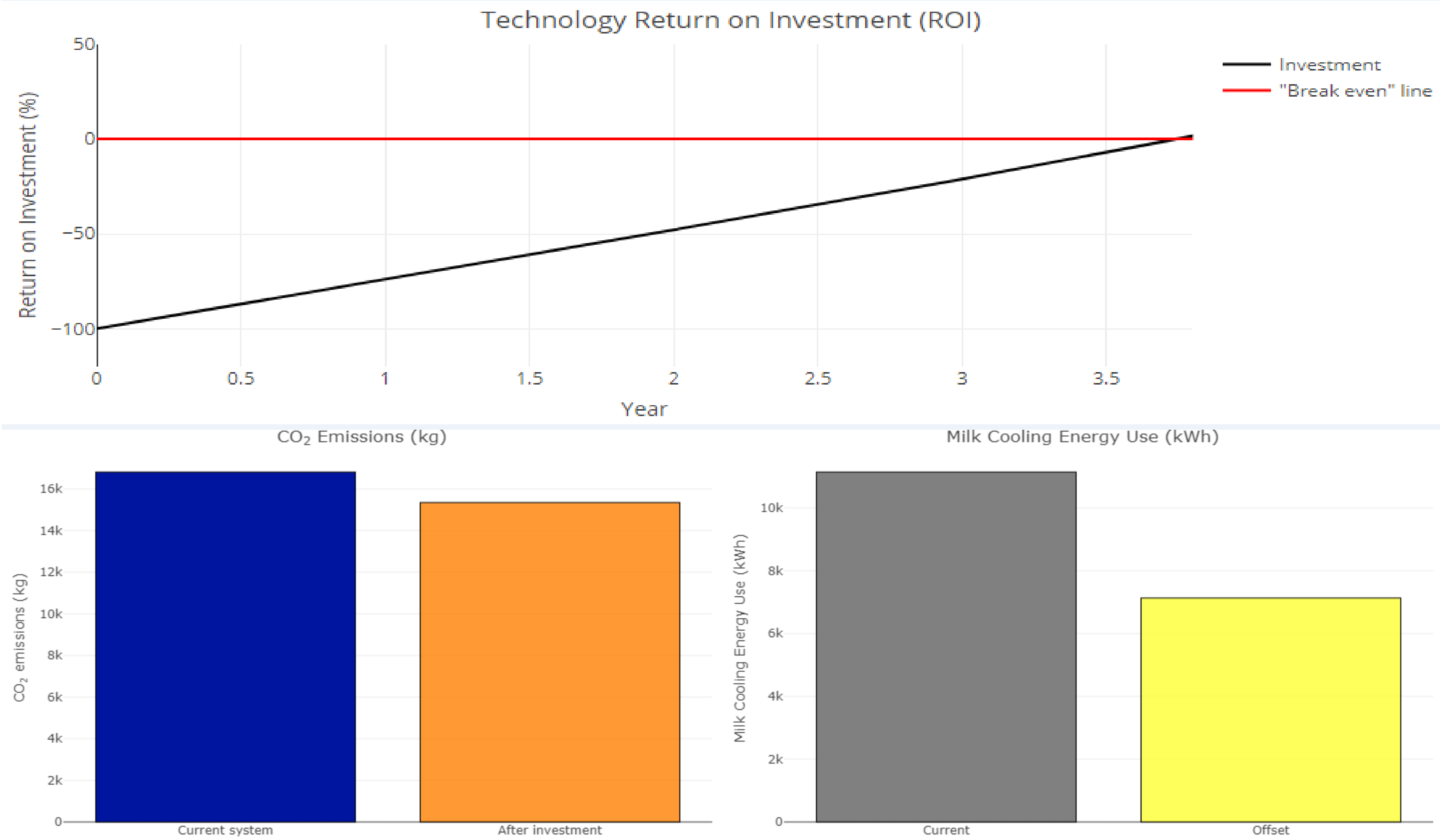
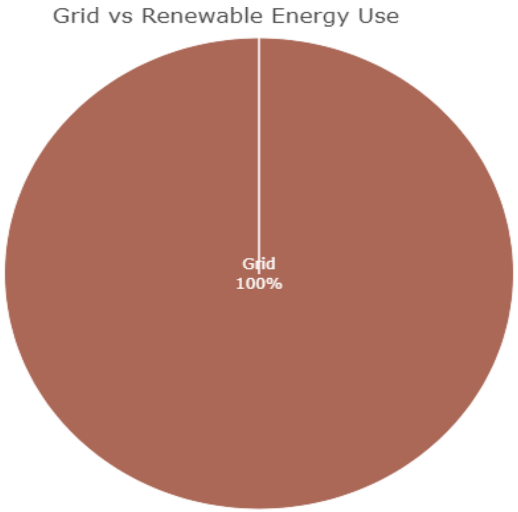


Figure 15: Scenario 1 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart



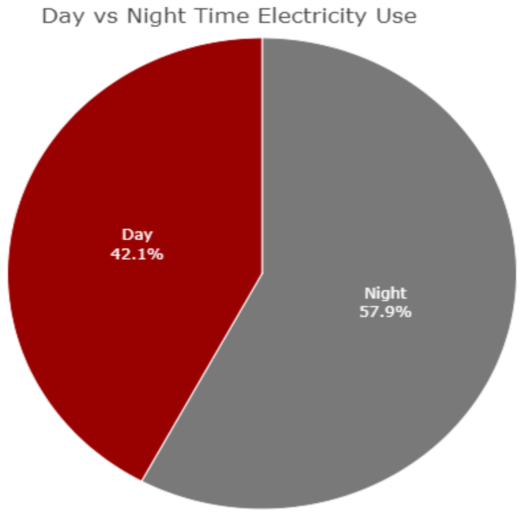


Figure 16: Scenario 1 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As shown in Figures 15 and 16, the addition of a plate cooler under the conditions describes saves 63,289 kg of CO_2 over the technology's lifetime, offsets approximately 64% of the farms milk cooling energy use, uses 100% energy from the grid, uses 42.1% daytime and 57.9% night time electricity, and pays back in 3.8 years. These results indicate that investment in a plate cooler under these conditions is very worthwhile.

Scenario 2. VSD

The farm setup for this scenario was as follows (Figure 17):

- 110 cow herd size
- Milking times of 7:00 and 17:00
- 12 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- Farm uses a plate cooler
- Flat electricity tariff with a price of €0.18 per kWh

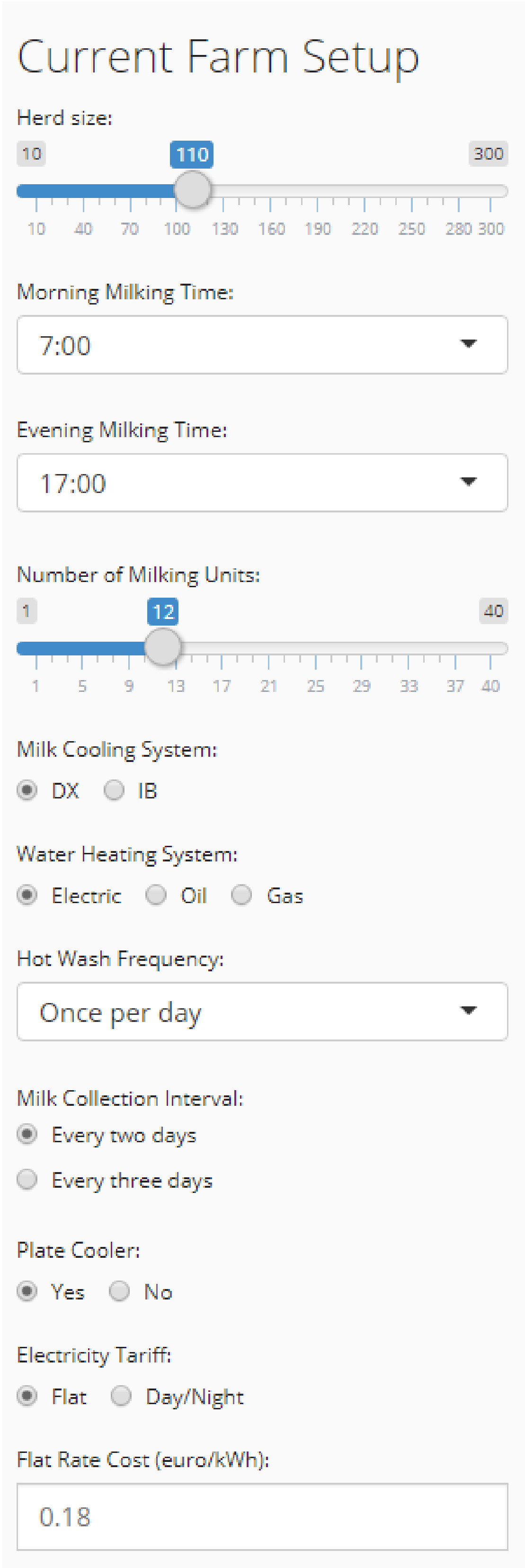


Figure 17: Dairy farm setup for Scenario 2

The on-farm technology selection for Scenario 2 was as follows (Figure 18):

- Selected technology: VSD
- Investment cost of €3,000
- 50% grant aid in line with the VSD pilot grant scheme carried out by the SEAI and Teagasc in 2017
- Inflation rate of 2%

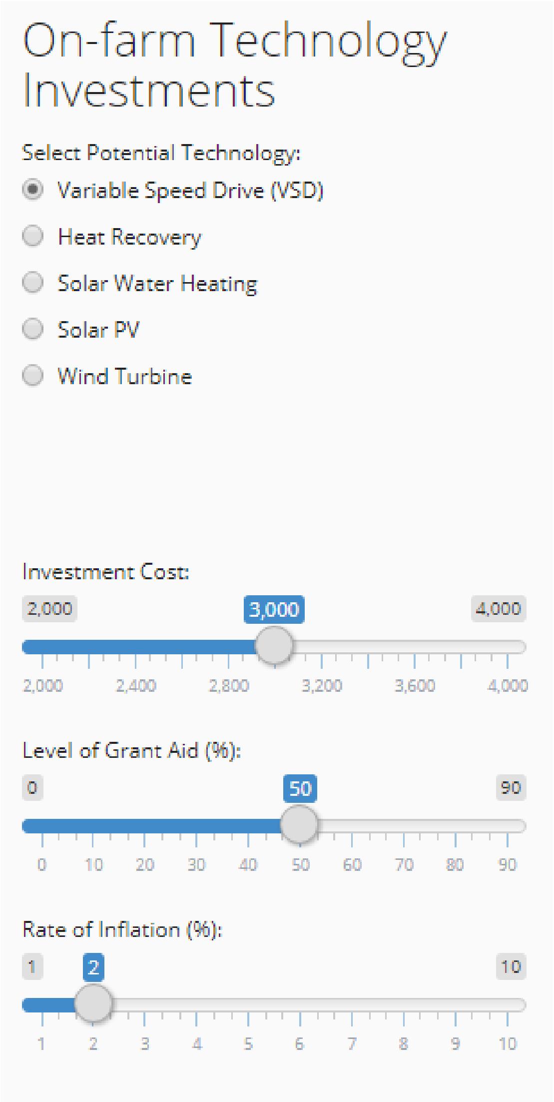


Figure 18: On-farm technology setup for Scenario 2

The results for Scenario 2 were as follows:

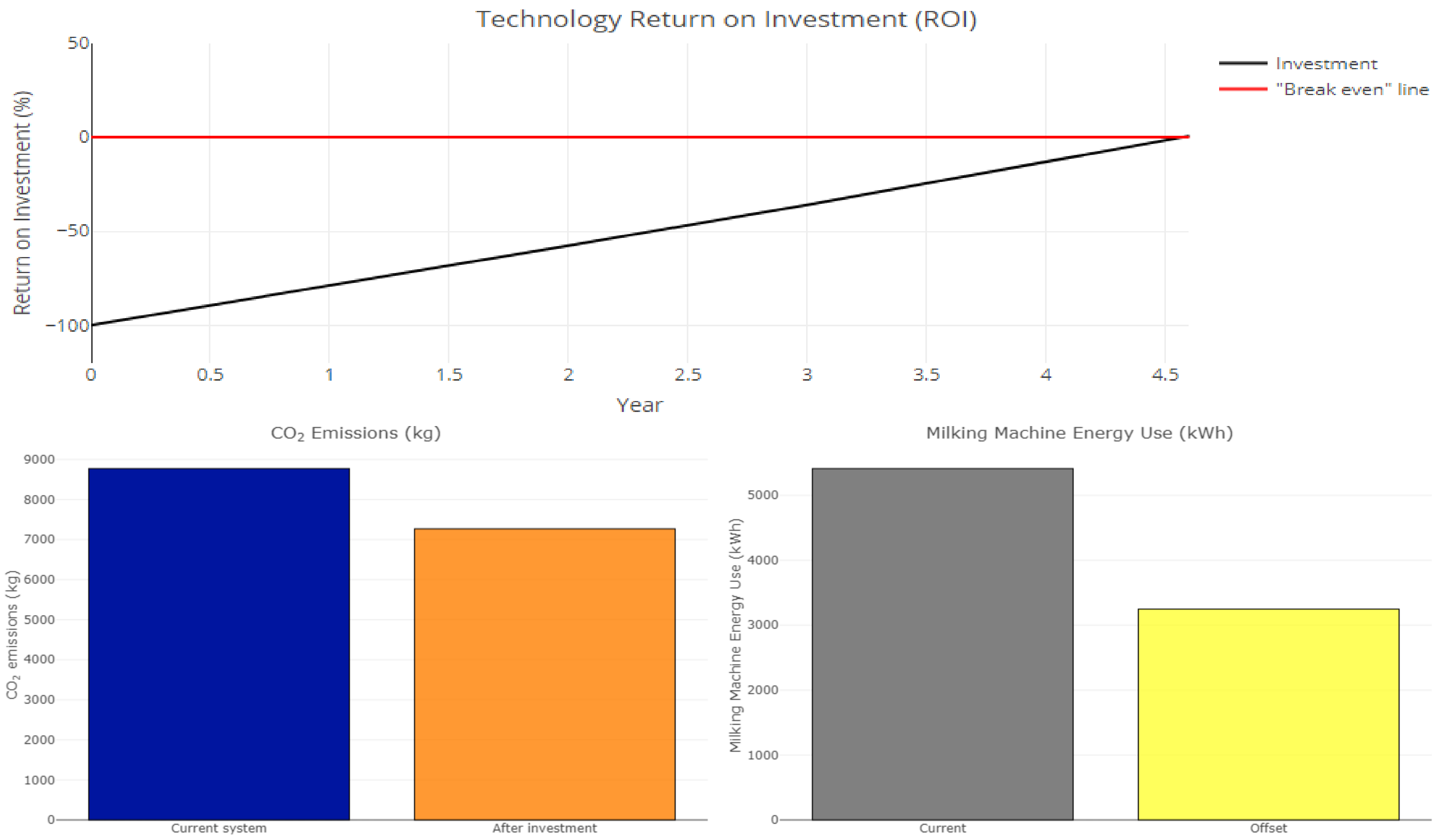
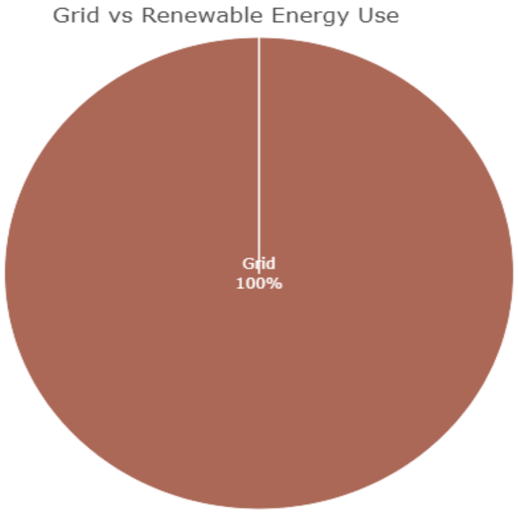


Figure 19: Scenario 2 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart



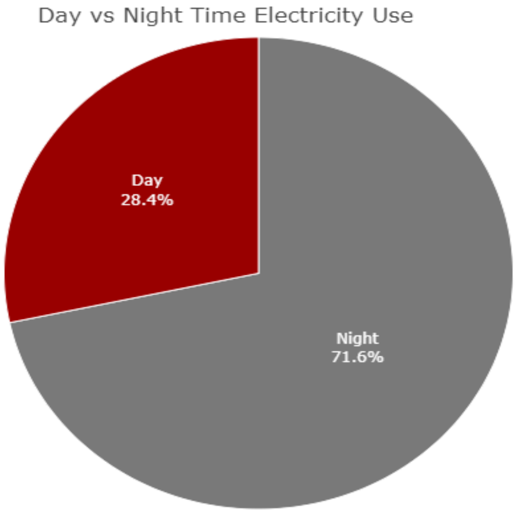


Figure 20: Scenario 2 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As show in Figures 19 and 20, the addition of a VSD under the conditions describes saves 30,100 kg of CO_2 over the technology's lifetime, offsets 60% of the farm's milking machine energy use, uses 100% energy from the grid, uses 28.4% daytime and 71.6% night time electricity, and pays back in 4.6 years. These results indicate that investment in a VSD under these conditions is very worthwhile.

Scenario 3. Heat Recovery

The farm setup for this scenario was as follows (Figure 21):

- 210 cow herd size
- Milking times of 7:00 and 17:00
- 24 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- No plate cooler
- Day night electricity tariff with a daytime price of €0.18 per kWh and a night time price of €0.09 per kWh

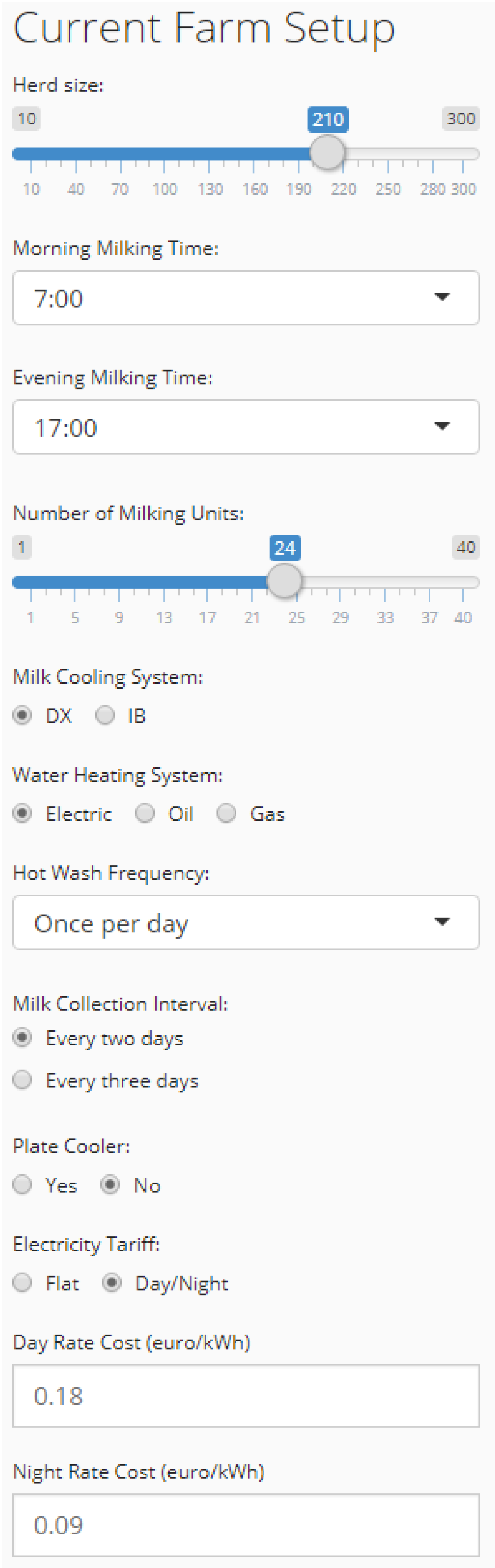


Figure 21: Dairy farm setup for Scenario 3

The on-farm technology selection for Scenario 3 was as follows (Figure 22):

- Selected technology: Heat recovery
- Investment cost of €6,000
- 40% grant aid based on the current Targeted Agricultural Modernisation Scheme II (DAFM, 2017)
- Inflation rate of 2%

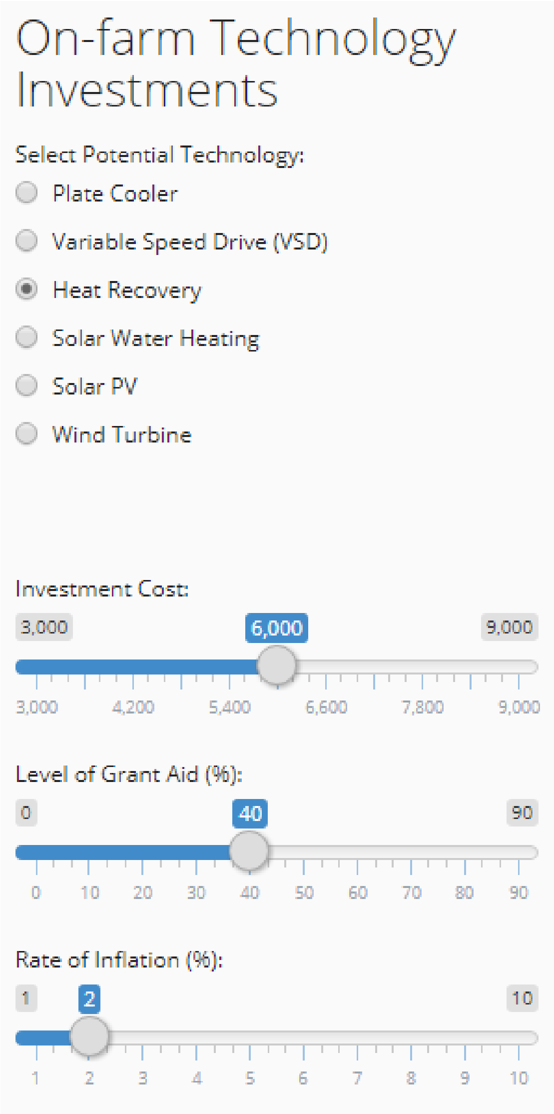


Figure 22: On-farm technology setup for Scenario 3

The results for Scenario 3 were as follows:

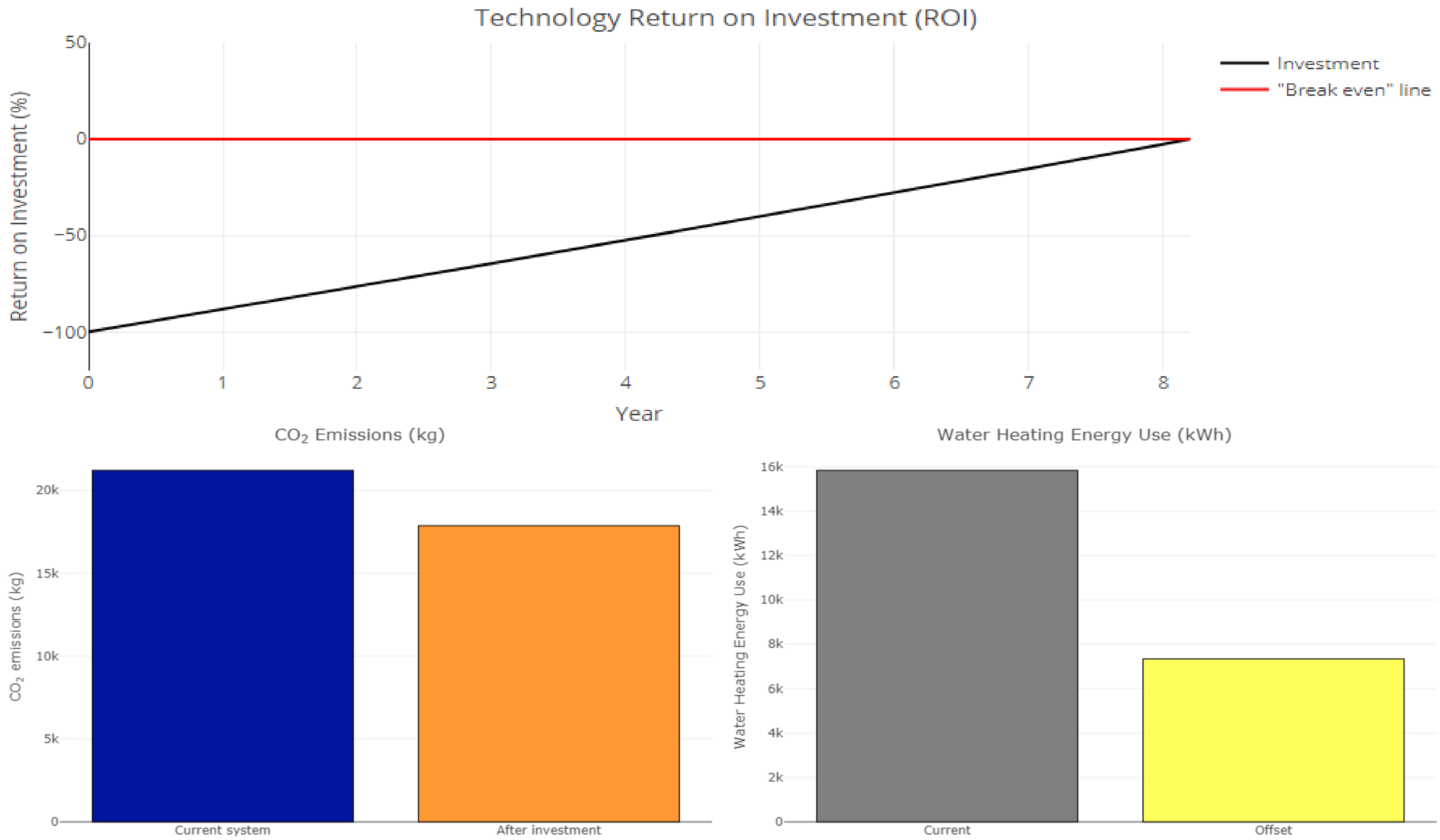
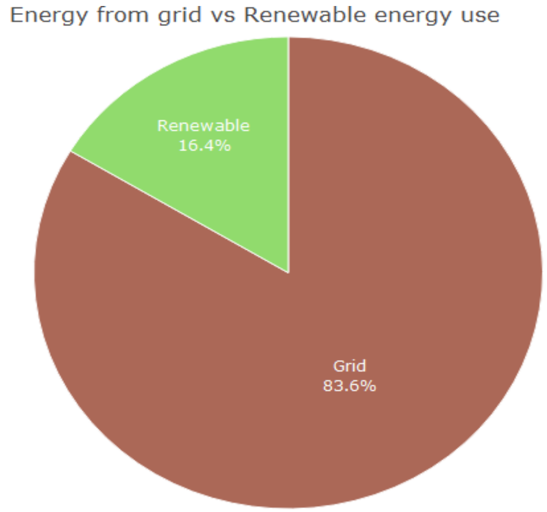


Figure 23: Scenario 3 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart



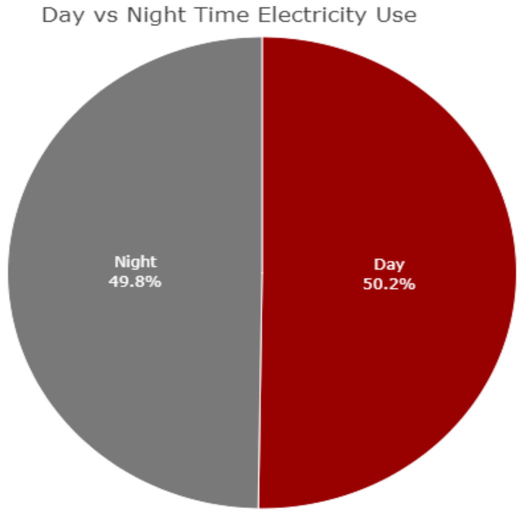


Figure 24: Scenario 3 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As shown in Figures 23 and 24, the addition of a heat recovery system under the conditions describes saves 66,878 kg of CO_2 over the technology's lifetime, offsets approximately 46% of the farm's water heating energy use, uses 16.4% renewable energy and 83.6% energy from the grid, uses 50.2% daytime and 49.8% night time electricity, and pays back in 8.2 years. These results indicate that investment in a heat recovery system under these conditions is somewhat worthwhile.

Scenario 4. Solar Water Heating

The farm setup for this scenario was as follows (Figure 25):

- 150 cow herd size
- Milking times of 7:00 and 17:00
- 18 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- No plate cooler
- Flat electricity tariff with a price of €0.18 per kWh

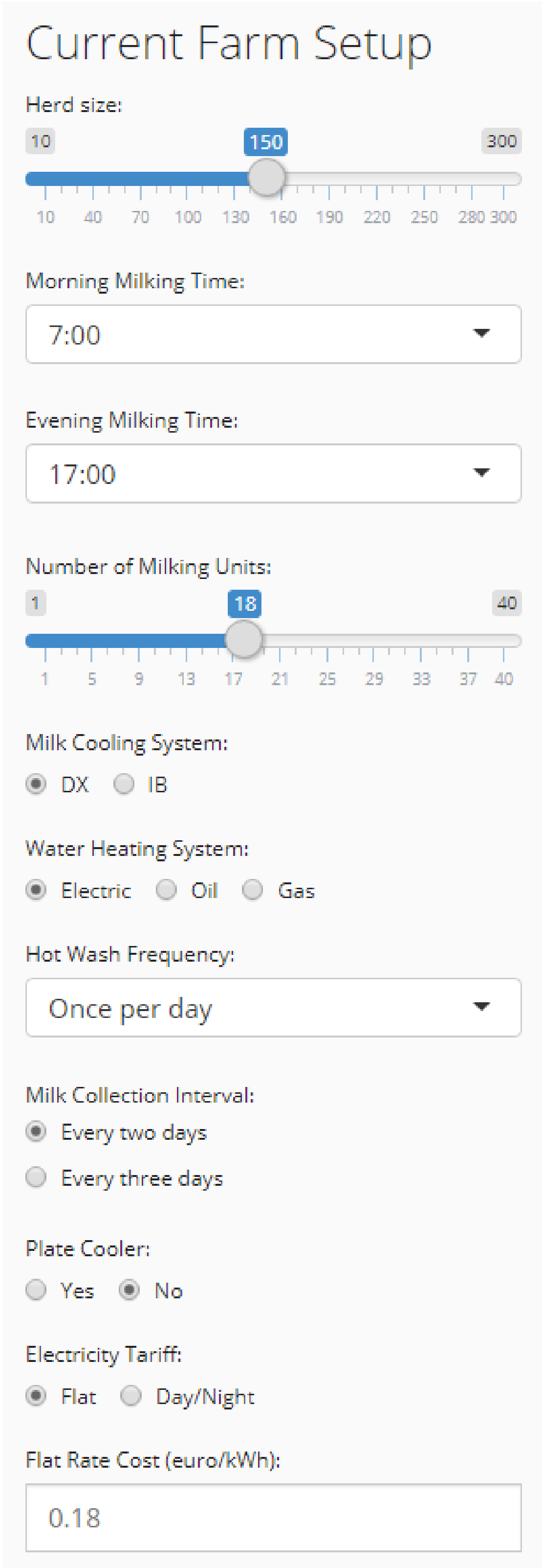


Figure 25: Dairy farm setup for Scenario 4

The on-farm technology selection for Scenario 4 was as follows (Figure 26):

- Selected technology: Solar water heating
- Solar water heater size of $10m^2$
- Investment cost of €10,000
- 50% grant aid on the technology
- Inflation rate of 2%

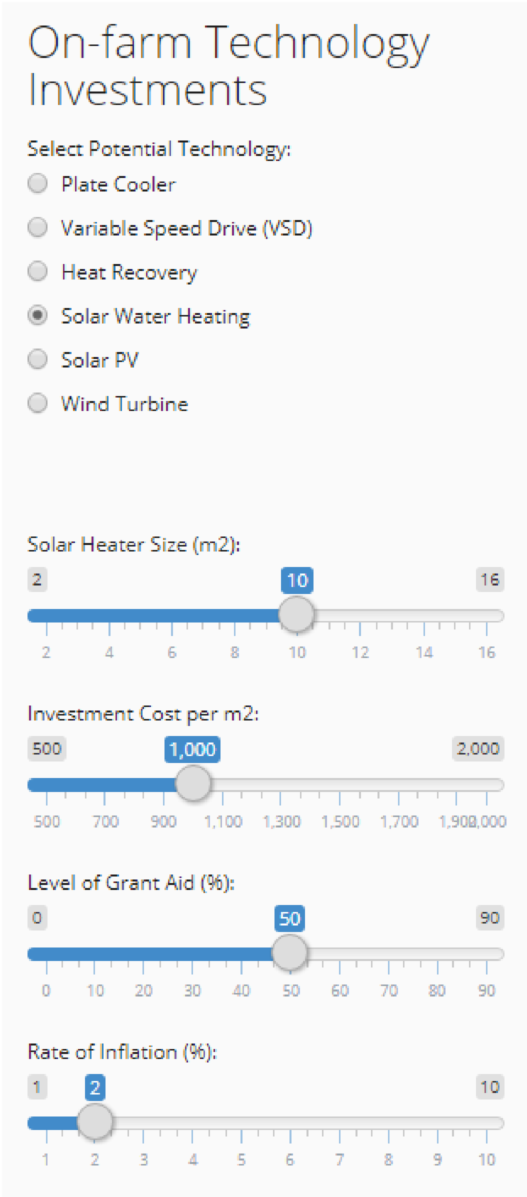


Figure 26: On-farm technology setup for Scenario 4

The results for Scenario 4 were as follows:

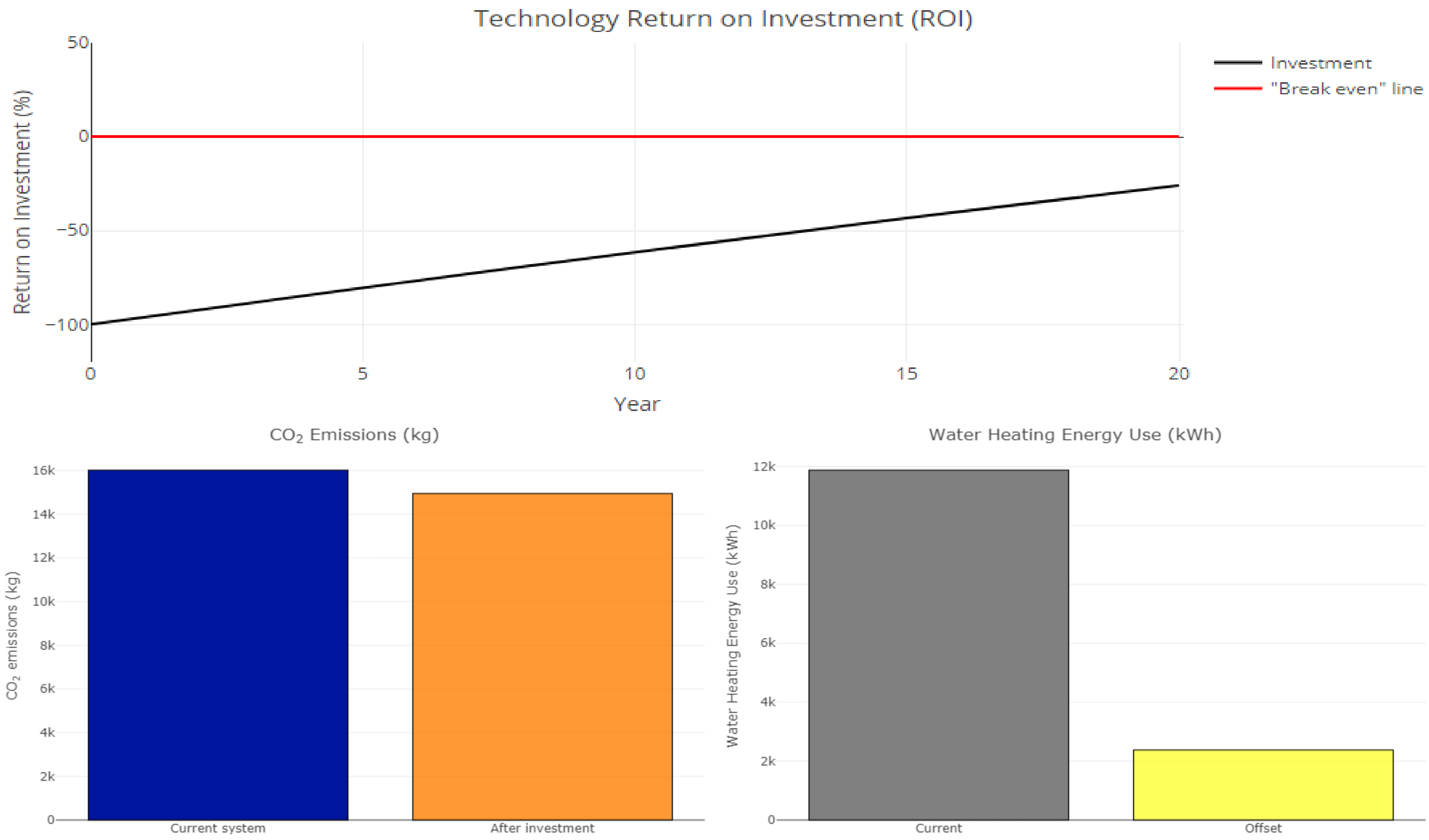
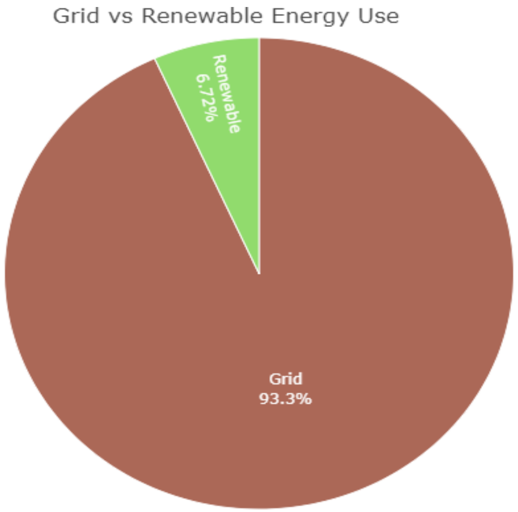


Figure 27: Scenario 4 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart



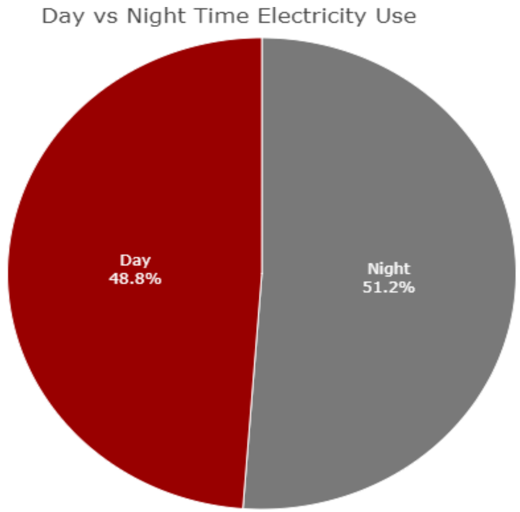


Figure 28: Scenario 4 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As show in Figures 27 and 28, the addition of a solar water heating system under the conditions described saves 21,455 kg of CO_2 over the technology's lifetime, offsets approximately 20% of the farm's water heating energy use, uses 6.7% renewable energy and 93.3% energy from the grid, uses 48.8% daytime and 51.2% night time electricity, and does not pay back within 20 years. These results indicate that investment in a solar water heating system under these conditions is not worthwhile.

Scenario 5. Solar PV

The farm setup for this scenario was as follows (Figure 29):

- 130 cow herd size
- Milking times of 8:00 and 18:00
- 16 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- No plate cooler
- Flat electricity tariff with a price of €0.18 per kWh

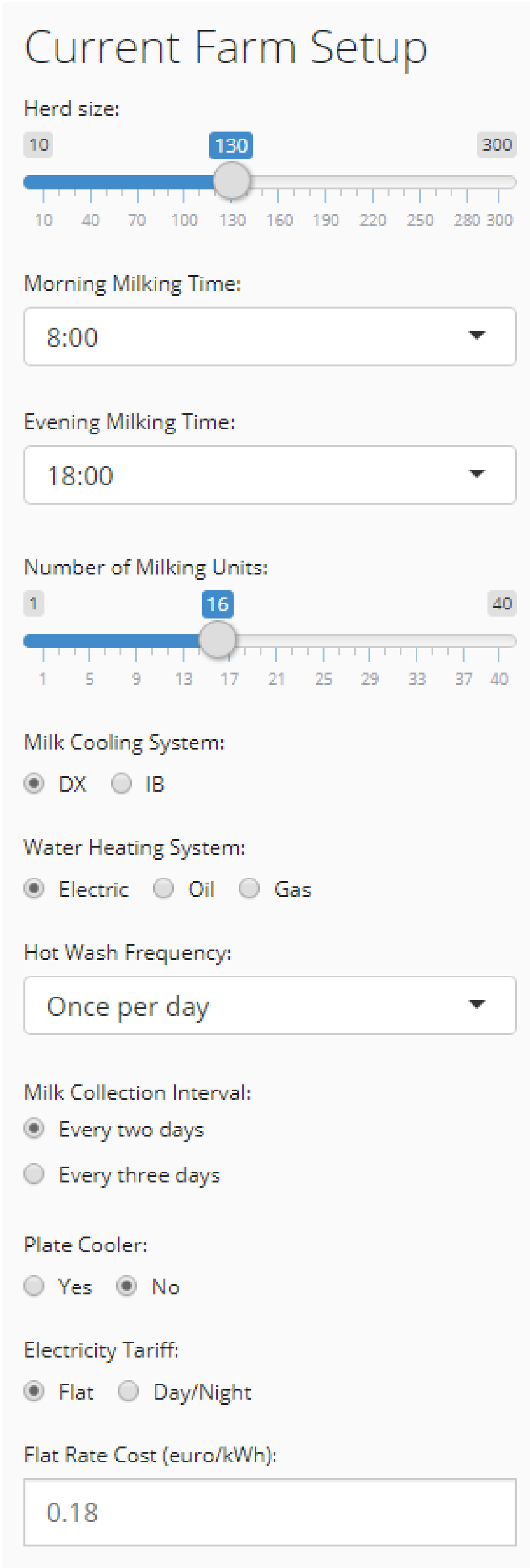


Figure 29: Dairy farm setup for Scenario 5

The on-farm technology selection for Scenario 5 was as follows (Figure 30):

- Selected technology: Solar PV
- Solar PV size of 5 kWp
- Investment cost of €5,500
- 40% grant aid on the technology in line with the pilot grant scheme for Solar PV recently announced by the Irish Minister for Communications, Climate Action and the Environment, Denis Naughten
- Inflation rate of 2%
- No feed in tariff as there is none currently available in Ireland
- The Solar PV system also contributes to the electricity demand of a residential home adjacent to the dairy farm, which has an annual electricity demand of 5,500kWh

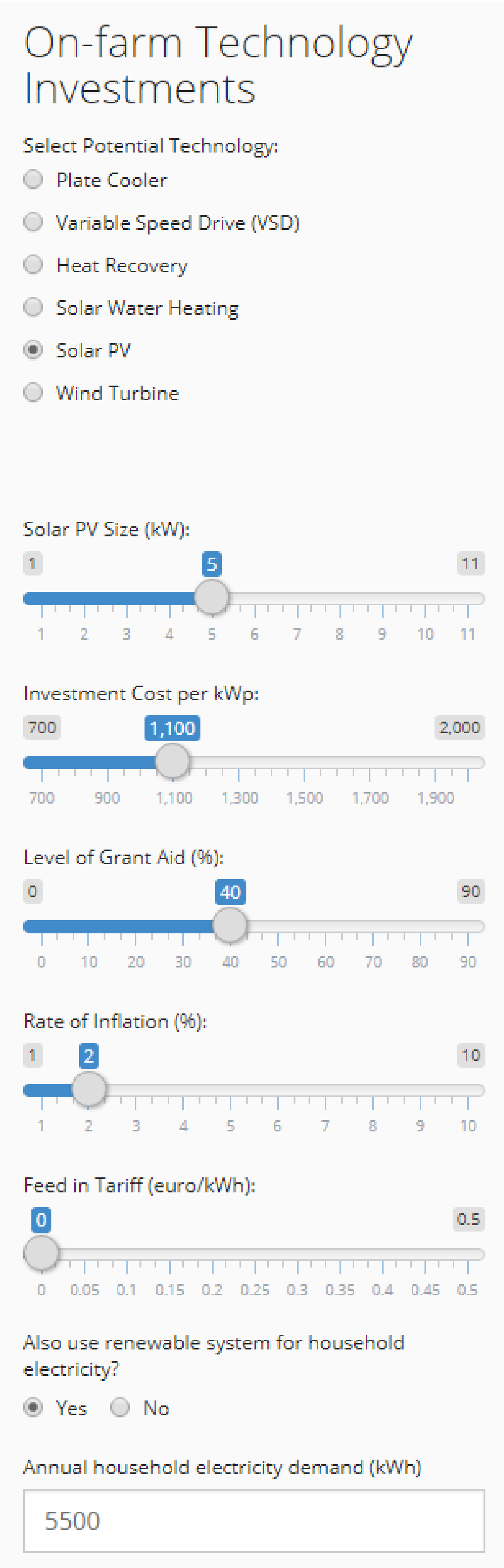


Figure 30: On-farm technology setup for Scenario 5

The results for Scenario 5 were as follows:

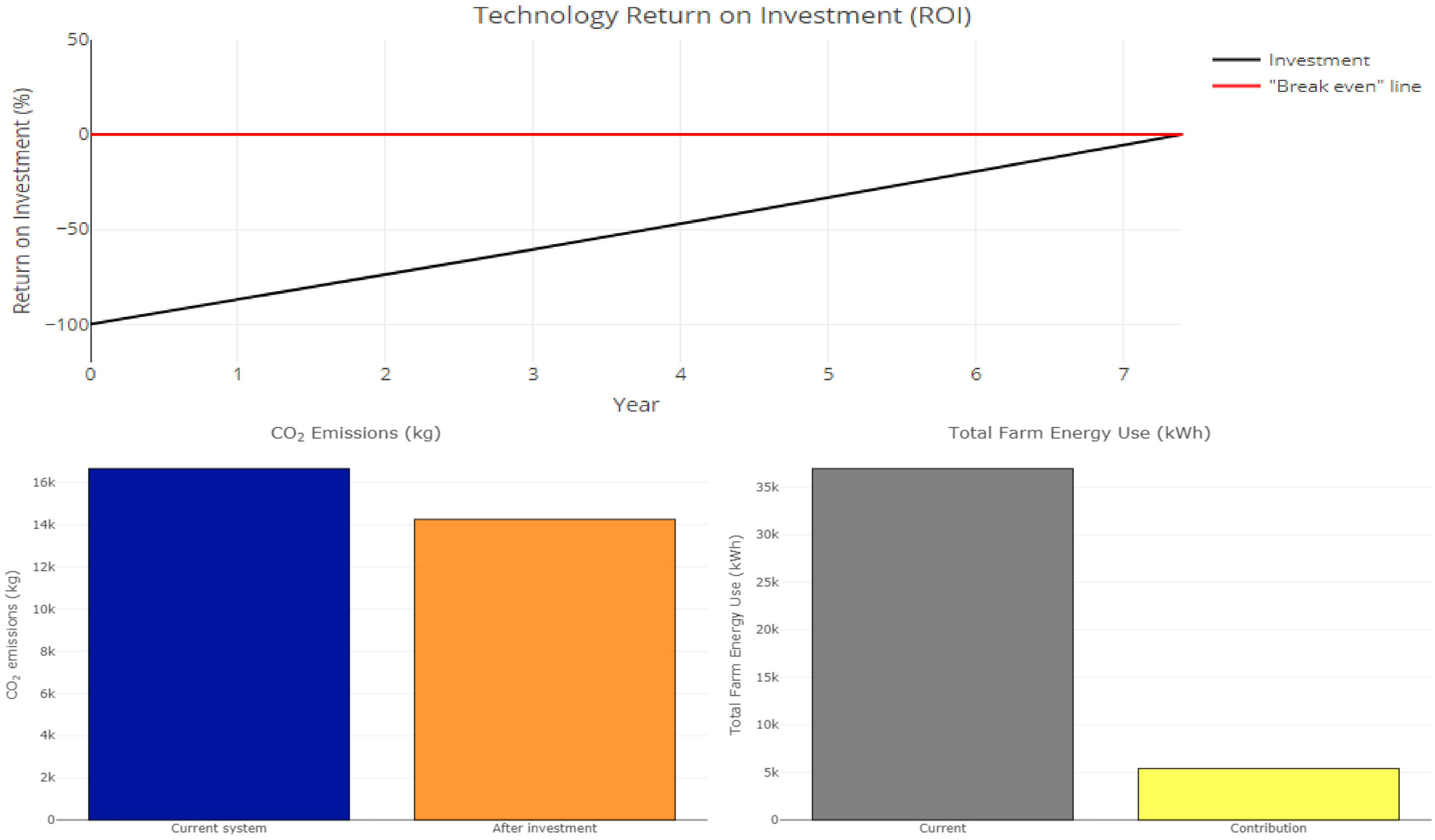
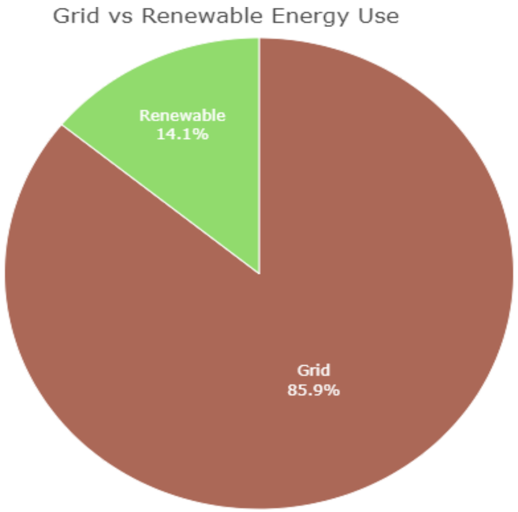


Figure 31: Scenario 5 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart



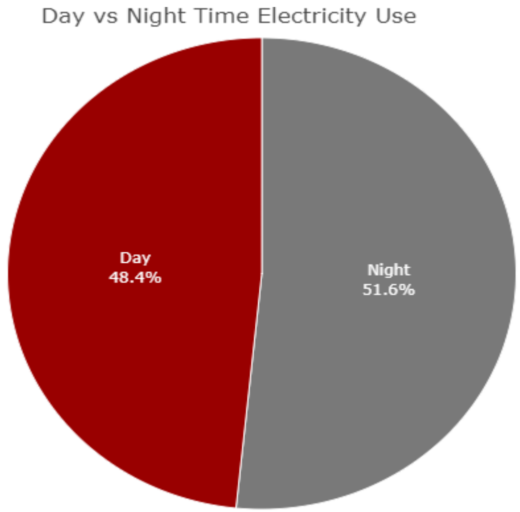


Figure 32: Scenario 5 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As show in Figures 31 and 32, the addition of a solar PV system under the conditions described saves 48,124 kg of CO_2 over its lifetime, offsets approximately 15% of the farm's total energy use, uses 14.1% renewable energy and 85.9% energy from the grid, uses 48.4% daytime and 51.6% night time electricity, and pays back within 7.4 years. These results indicate that investment in a solar PV system under these conditions is worthwhile.

Scenario 6. Wind turbine

The farm setup for this scenario was as follows (Figure 33):

- 210 cow herd size
- Milking times of 7:00 and 17:00
- 24 milking units
- DX milk cooling system
- Electric water heating system
- Hot wash frequency of once per day
- Every two day milk collection
- Farm uses a plate cooler
- Day night electricity tariff with a daytime price of €0.18 per kWh and a night time price of €0.09 per kWh

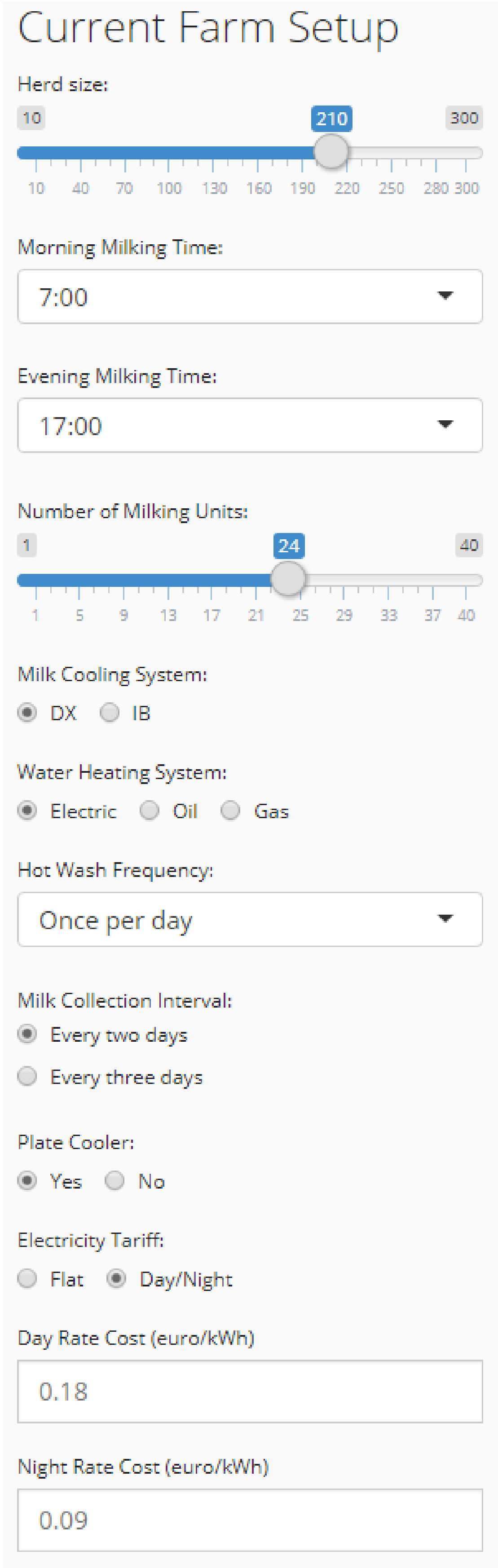


Figure 33: Dairy farm setup for Scenario 6

The on-farm technology selection for Scenario 6 was as follows (Figure 34):

- Selected technology: Wind turbine
- Wind turbine size of 10kWp
- Investment cost of €30,000
- 50% grant aid on the technology
- Inflation rate of 2%
- Feed in tariff of €0.18 per kWh exported to the grid
- The wind turbine also contributes to the electricity demand of a residential home adjacent to the dairy farm, which has an annual electricity demand of 5,500kWh

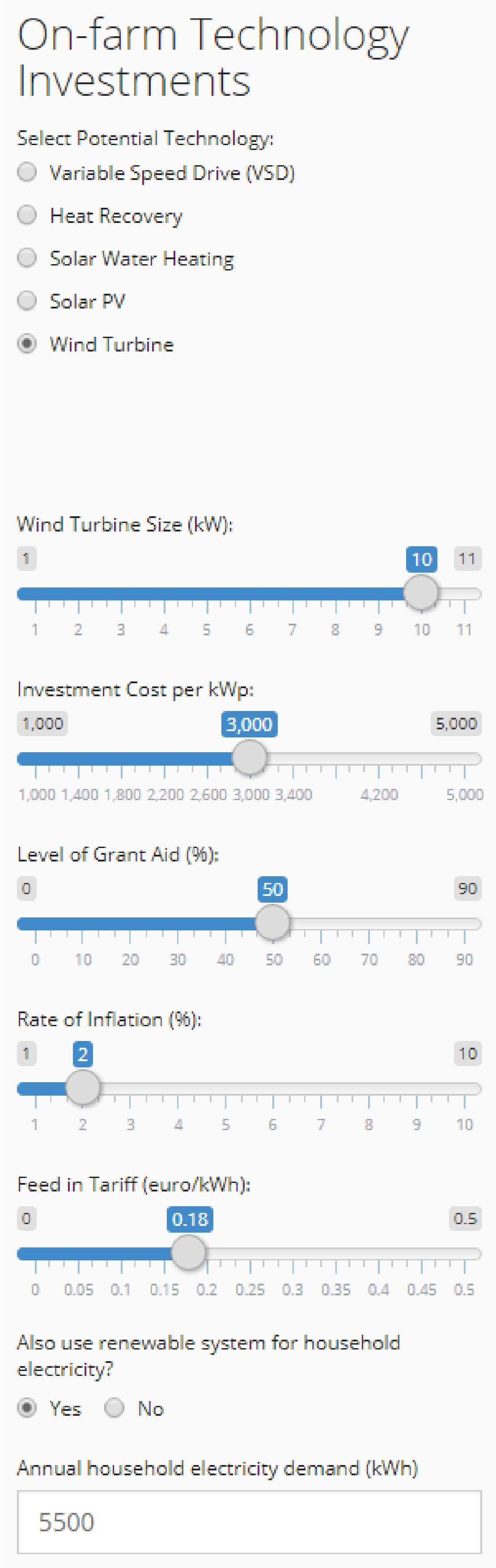


Figure 34: On-farm technology setup for Scenario 6

The results for Scenario 6 were as follows:

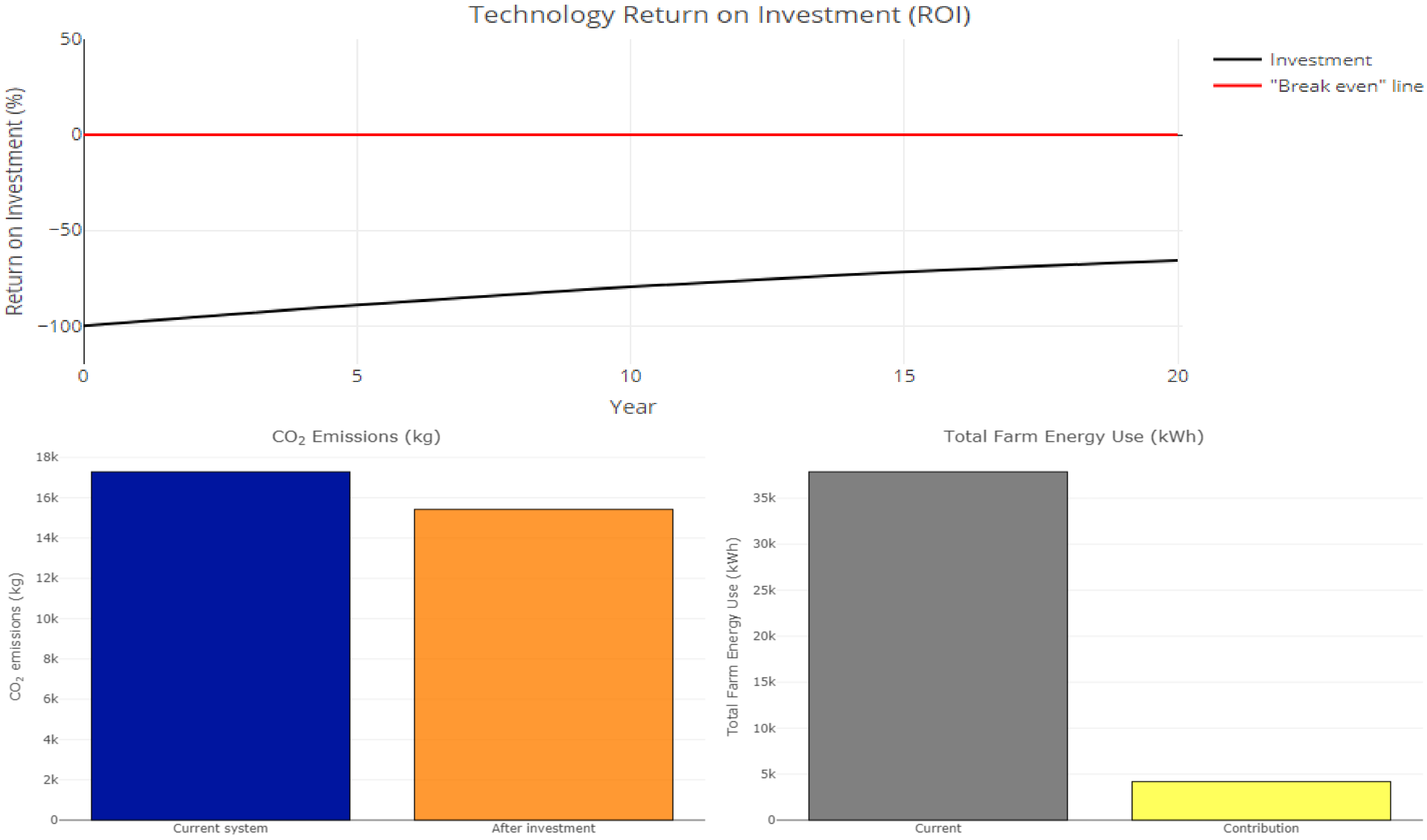


Figure 35: Scenario 6 results - clockwise from top: Technology Return on Investment (ROI) graph; Energy use bar chart; CO_2 emissions bar chart

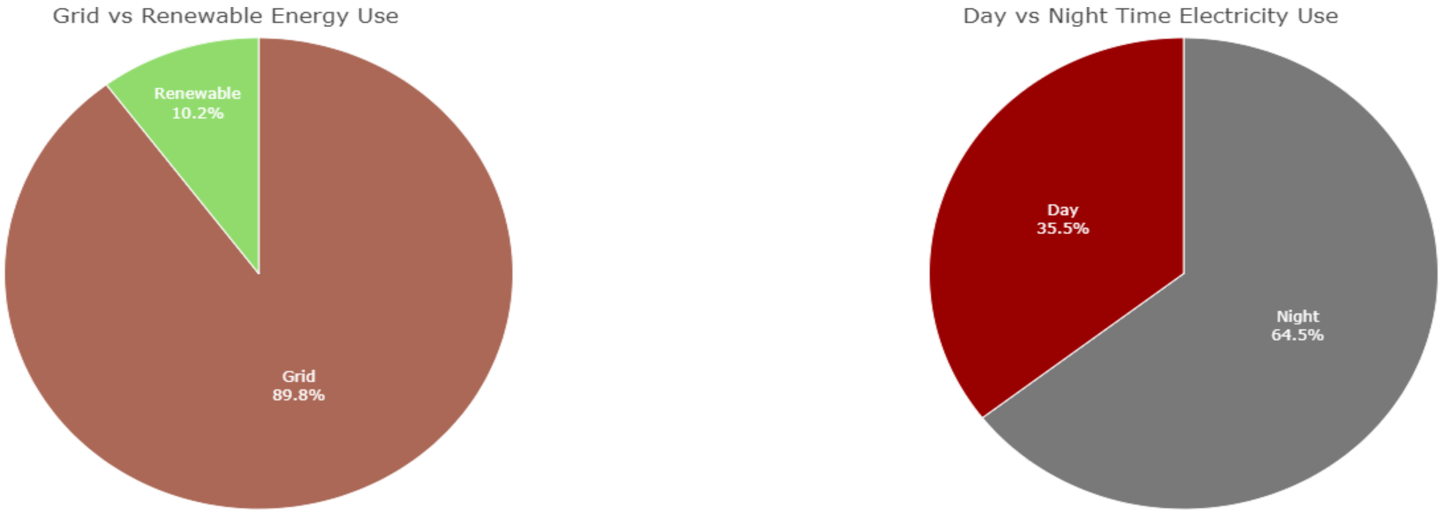


Figure 36: Scenario 6 results - left to right: Grid vs Renewable Energy Use pie chart; Day vs Night Time Electricity Use pie chart

As show in Figures 35 and 36, the addition of a wind turbine system under the conditions described saves 37,312 kg of CO_2 over its lifetime, offsets approximately 11% of the farm's total energy use, uses 10.2% renewable energy and 89.8% energy from the grid, uses 35.5% daytime and 64.5% night time electricity, and does not pay back within 20 years. These results indicate that investment in a wind turbine under these conditions is not worthwhile.

Summary

This report detailed the methods by which the Decision Support System for Energy use in Dairy Production (DSSED) was developed. Both the statistical database and the technology calculator in DSSED are anticipated to be extremely useful to dairy farmers looking to expand their farms post quota, as well as those looking to invest in renewable and energy efficient technologies. It is anticipated that the DSSED will be widely used in the future to aid farmers in making informed decisions. The information provided by DSSED is wide-ranging and will not only provide essential decision support, but also provide useful material for informing policy. Future work will extend the DSSED further by focusing on the optimisation of dairy farm infrastructure investments, whereby the optimum combination of dairy farm equipment, management practices, energy technology and electricity tariff will be found for a user-defined farm size, in terms of payback, CO_2 emissions and renewable energy penetration. Optimising dairy farm infrastructure investments is important since slight changes in equipment setup and management practices can greatly affect the farm, both economically and environmentally. The optimisation of dairy farm infrastructure on a large number of farms could hypothetically save millions for the Irish dairy industry, and has the potential to considerably reduce CO_2 emissions. These saving can be dynamically quantified by DSSED on a macro-level, therefore the annual changes in nation dairy energy consumption, renewable energy production and GHG emissions can be profiled and monitored.

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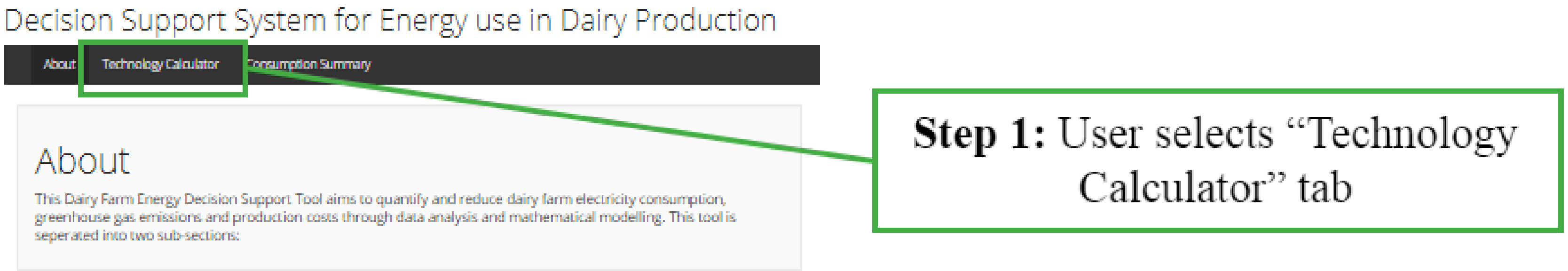
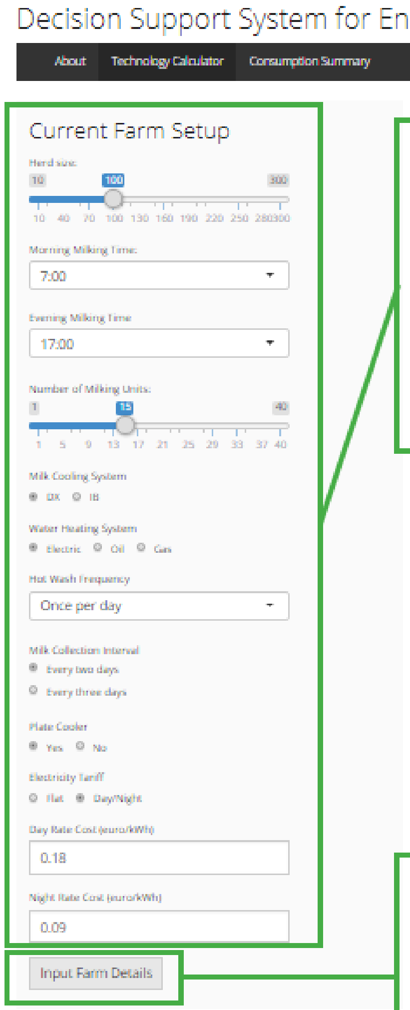
Appendix A

Instructions for using the Decision Support System for Energy use in Dairy Production (DSSED) Technology Calculator

Part 1: Select Technology Calculator from the DSSED homepage



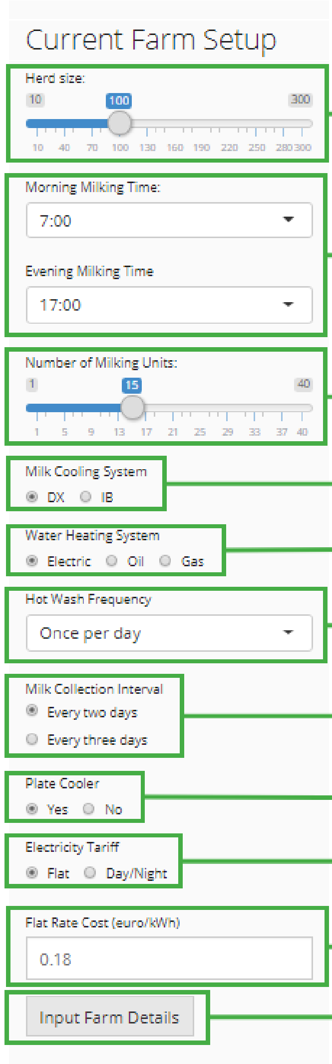
Part 2: Input farm details - Overview



Step 1: User enters details relating to their farm or a particular farm setup which is of interest to them. See overleaf for a detailed description of the possible inputs involved in dairy farm selection.

Step 2: User presses the button indicated to input the farm configuration which they have entered to enable this information to populate the Technology Calculator.

Part 2: Input farm details – Description



Step 1: User enters the herd size of the farm which they wish to analyze.

Step 2: User enters the morning and evening milking times of the farm.

Step 3: User enters the number of milking units on the farm.

Step 4: User selects the milk cooling system of the farm. "DX" = Direct expansion, "IB" = Ice bank.

Step 5: User selects the method by which water is heated on the farm.

Step 6: User selects the frequency at which the milking machine is washed.

Step 7: User selects the frequency at which milk is collected from the farm.

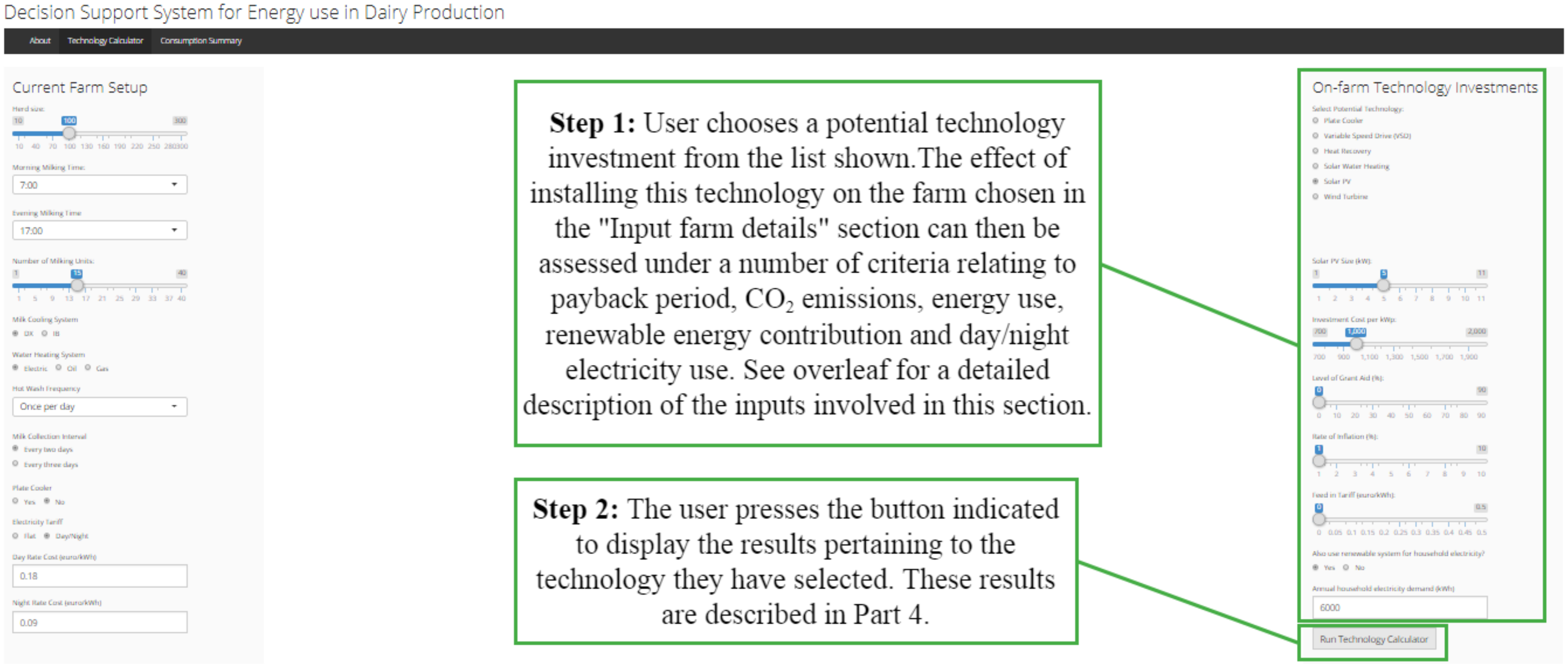
Step 8: User inputs whether a plate cooler is used for milk precooling.

Step 9: User inputs the electricity tariff used by the farm.

Step 10: If "Flat" is selected in Step 9, user inputs the rate per kWh under the flat electricity tariff. If "Day/Night" is selected in Step 9, user inputs the rate per kWh for both day time and night time hours under the day/night tariff.

Step 11: User inputs the details of the farm by clicking the button shown.

Part 3: Input on-farm technology details – Overview



Step 1: User chooses a potential technology investment from the list shown.The effect of installing this technology on the farm chosen in the "Input farm details" section can then be assessed under a number of criteria relating to payback period, CO_2 emissions, energy use, renewable energy contribution and day/night electricity use. See overleaf for a detailed description of the inputs involved in this section.

Step 2: The user presses the button indicated to display the results pertaining to the technology they have selected. These results are described in Part 4.

Part 3: Input on-farm technology details – Description

Step 1: User selects the technology which they wish to analyze for use on the farm selected previously. If the user has already stated that the farm uses a plate cooler, it is not included in the technology options.

Step 2: User inputs the size of the technology selected. This step is only relevant for solar water heating, solar PV and wind turbines.

Step 3: User inputs the investment cost of the technology selected.

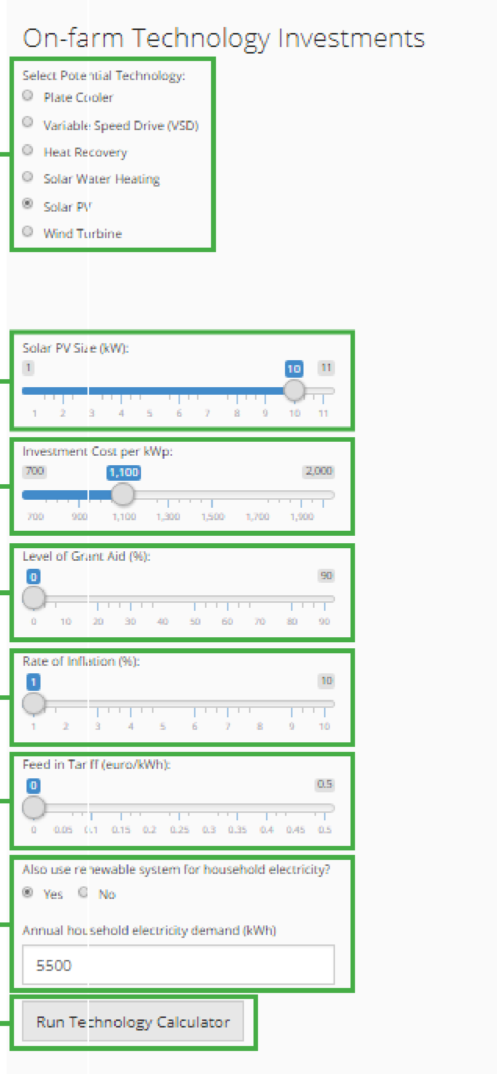
Step 4: User inputs the level of grant aid associated with the selected technology, as a percentage of the technology investment cost.

Step 5: User inputs the yearly inflation rate, to be used in calculating the expected payback period of the selected technology.

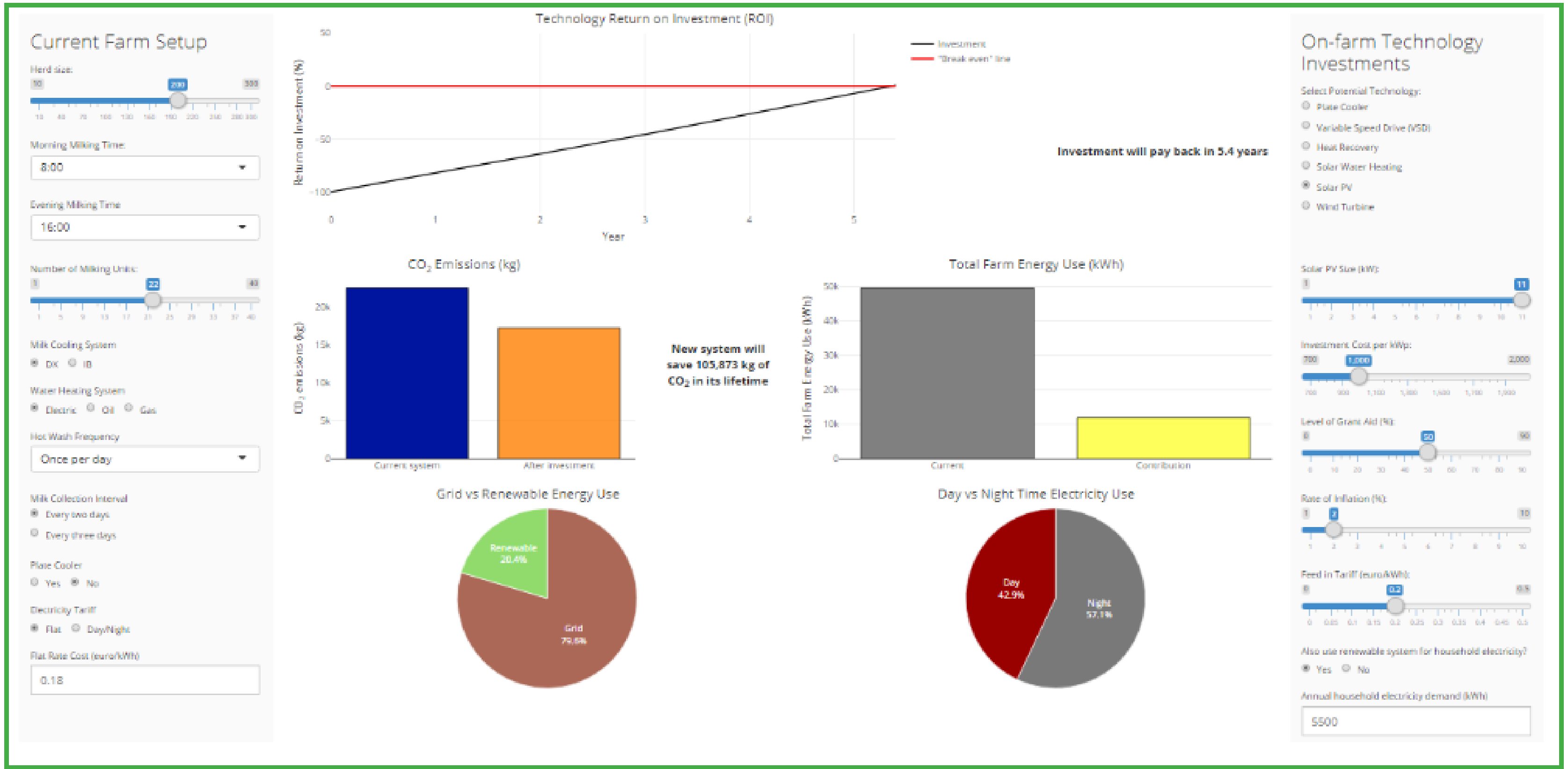
Step 6: If solar PV or wind turbine has been selected, the user inputs the feed in tariff associated with the selected technology.

Step 7: If solar PV or wind turbine has been selected, the user inputs whether the installed system is also used to supply electricity to a residential property. If "Yes" is selected, the user inputs the annual electricity consumption of the residential property.

Step 8: User runs the technology calculator by clicking the button shown.

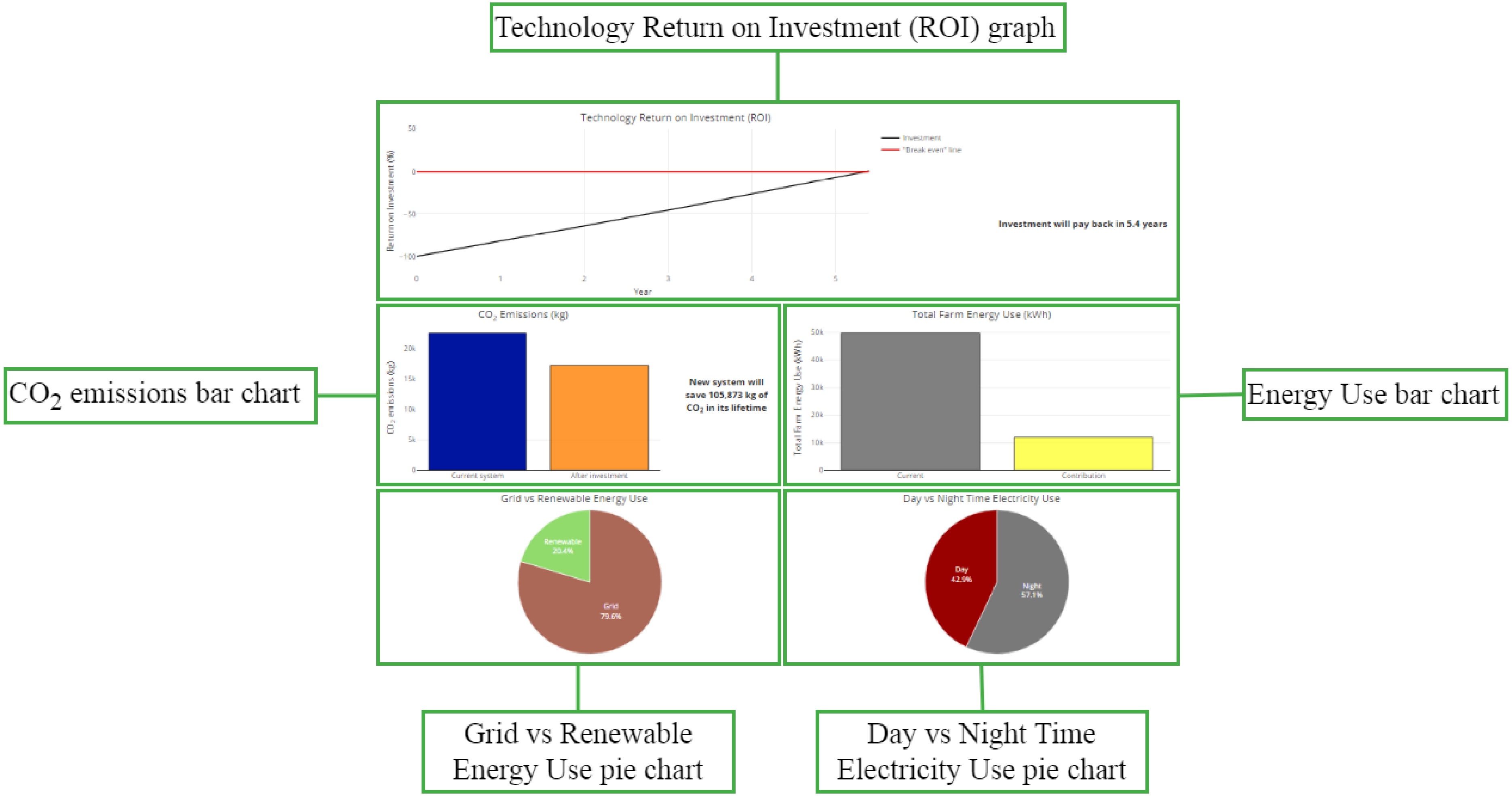


Part 4: Technology Calculator results – Overview

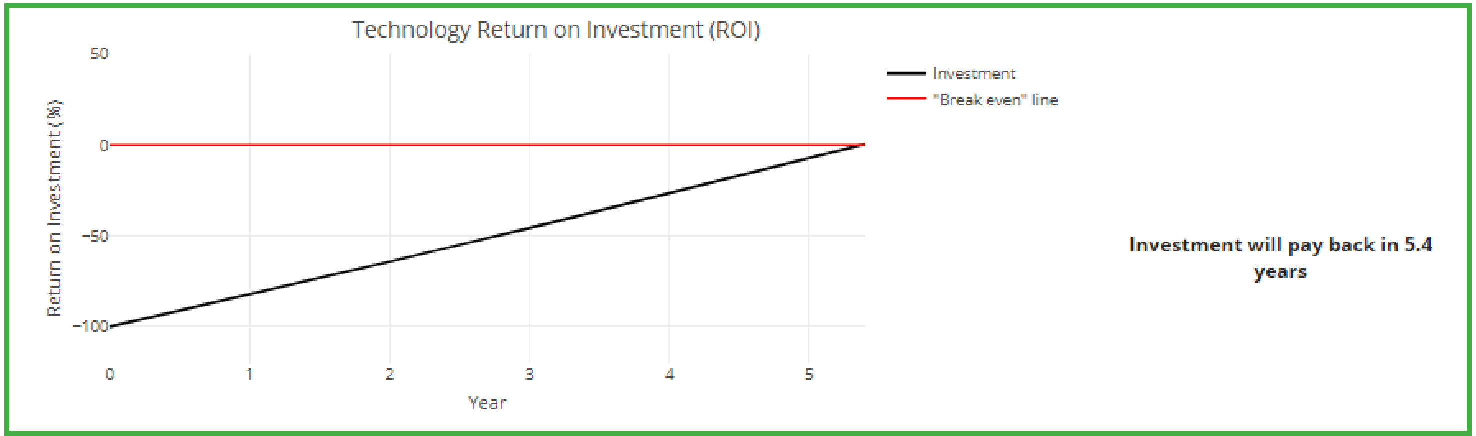


Having entered farm details and on-farm technology details, the results pertaining to payback period, CO_2 emissions, energy use, renewable energy contribution and day/night electricity use are displayed. See subsequent pages for a detailed breakdown of the displayed results.

Part 4: Technology Calculator results – Breakdown

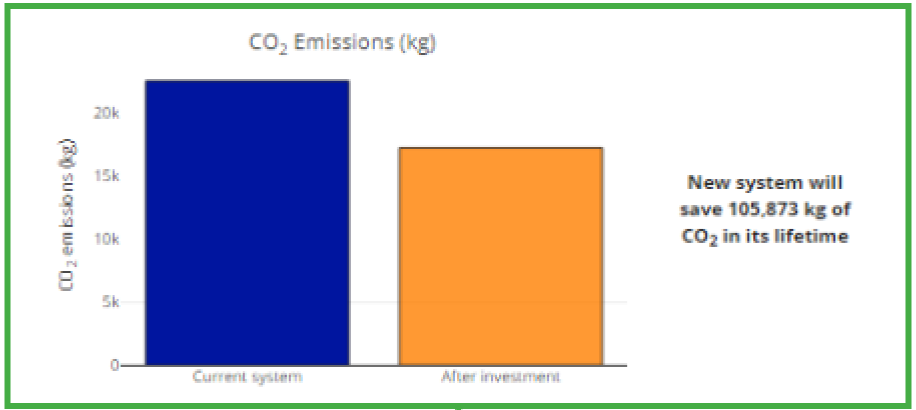


Part 4: Technology Calculator results – Technology Return on Investment (ROI) graph description



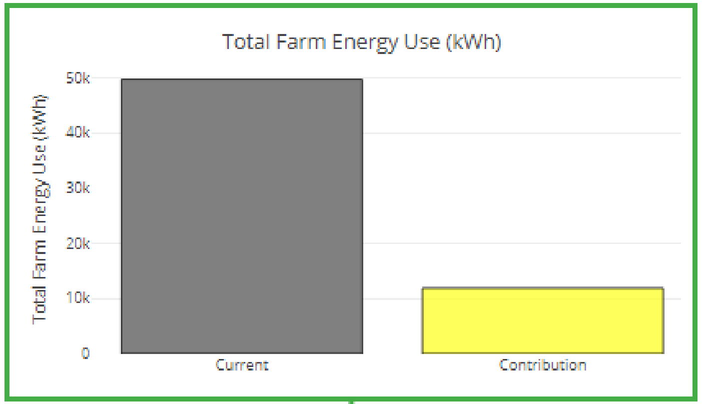
The "Technology Return on Investment (ROI)" graph demonstrates the yearly performance of the selected technology in terms of its ROI. When the technology is first purchased (Year 0), the ROI is -100%, with this figure changing over time to reflect the savings incurred using the selected technology (black coloured line). The technology "pays back" when the ROI reaches 0%, at which point it crosses the "break even" line (red coloured line). The payback time in years is displayed to the right of the graph.

Part 4: Technology Calculator results – CO_2 emissions bar chart description



The CO_2 Emissions bar chart demonstrates the environmental impact which the use of the selected on-farm technology has on the farm. The "Current system" bar illustrates the annual CO_2 emissions of the farm prior to the addition of on-farm technologies, while the "After investment" bar illustrates the annual CO_2 emissions of the farm when an on-farm technology is used. The saving on CO_2 emissions over the lifetime of the selected on-farm technology is displayed to the right of the bar chart.

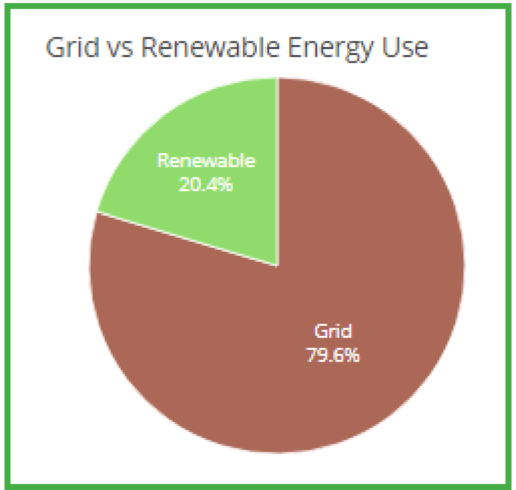
Part 4: Technology Calculator results – Energy use bar chart description



The Energy Use bar chart demonstrates the impact which the selected on-farm technology has on the energy use of the farm. The "Current" bar illustrates the farm's energy use prior to the addition of on-farm technologies. If a plate cooler is selected as the on-farm technology, the milk cooling energy is shown. If VSD is selected, the milking machine energy is shown. If solar water heating or heat recovery are selected, the water heating energy is shown. If solar PV or wind turbine are selected, the overall farm energy is shown.

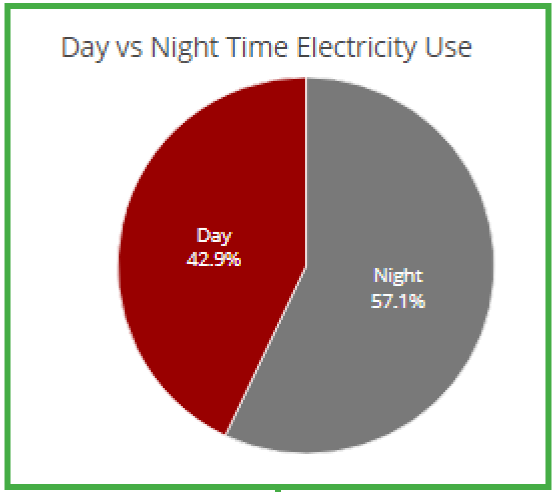
If plate cooler, VSD, solar water heating or heat recovery are selected, the "Offset" bar displays the amount of energy which is provided by the selected technology. If solar PV or wind turbine are selected, the "Contribution" bar displays the amount of energy which is provided by the selected technology, in addition to the amount of energy exported to the grid by the technology.

Part 4: Technology Calculator results – Grid vs Renewable Energy Use pie chart description



The "Grid vs Renewable Energy Use" pie chart shows the breakdown of the total annual kilowatt hours of energy purchased from the grid versus the total annual kilowatt hours of energy provided by renewable systems, after the addition of an on-farm technology.

Part 4: Technology Calculator results – Day vs Night Time Electricity Use pie chart description



The "Day vs Night Time Electricity Use" pie chart shows the breakdown of the total annual electricity use during day time hours versus the total annual electricity use during night time hours, after the addition of an on-farm technology.