Journal of Dairy Research (2018) **85** 366–374. © *Hannah Dairy Research Foundation 2018*
doi:10.1017/S0022029918000614

DairyWater: striving for sustainability within the dairy processing industry in the Republic of Ireland

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Received 19 October 2017; accepted for publication 15 July 2018

This Review describes the objectives and methodology of the DairyWater project as it aims to aid the Irish dairy processing industry in achieving sustainability as it expands. With the abolition of European milk quotas in March 2015, the Republic of Ireland saw a surge in milk production. The DairyWater project was established in anticipation of this expansion of the Irish dairy sector in order to develop innovative solutions for the efficient management of water consumption, wastewater treatment and the resulting energy use within the country's dairy processing industry. Therefore, the project can be divided into three main thematic areas: dairy wastewater treatment technologies and microbial analysis, water re-use and rainwater harvesting and environmental assessment. In order to ensure the project remains as relevant as possible to the industry, a project advisory board containing key industry stakeholders has been established. To date, a number of large scale studies, using data obtained directly from the Irish dairy industry, have been performed. Additionally, pilot-scale wastewater treatment (intermittently aerated sequencing batch reactor) and tertiary treatment (flow-through pulsed ultraviolet system) technologies have been demonstrated within the project. Further details on selected aspects of the project are discussed in greater detail in the subsequent cluster of research communications.

Keywords: Dairy processing, Ireland, sustainability, tertiary treatment, wastewater treatment.

Ireland has a long tradition of dairy farming and the production of dairy products for international markets, primarily butter and cheese. Today, Ireland is one of Europe's largest producers of cow's milk and a globally recognised producer of dairy products and ingredients. Over the last two decades, Ireland has become one of the world's leading producers of infant nutritional products with the presence in Ireland of a number of leading infant nutrition companies and accounts for 15% of the global supply of infant formula (Barry, 2012).

In 2016, there were approximately 1·295 million dairy cows on over 17 000 dairy farms in the Republic of Ireland, which produced 6654 million litres of milk with a fat content of 4·1% and a protein content 3·45% (CSO, 2017). Unlike most of Ireland's competitors, the vast majority of cows in Irish dairy herds are fed on grass; for up to 300 d a year this is fresh pasture grazing, while, for the remainder of the year, the main source of fodder is grass silage. However, since milk production is essentially grass-based, it is very seasonal with a milk production ratio of 7 to 1, when comparing May to January (IFA, 2012). Irish milk is produced mainly by three cattle breeds; British Friesian, Holstein Friesian and Jersey. In 2016, an additional 813 million litres of milk was imported from Northern Ireland into Irish dairies, bringing the total amount of milk processed in the Republic of Ireland to 7467 million litres (CSO, 2017).

Currently, dairy ingredients and products comprise almost 30% of the Irish food and drink export market. In 2013, dairy ingredients and products surpassed €3 billion for the first time, making it Ireland's largest indigenous

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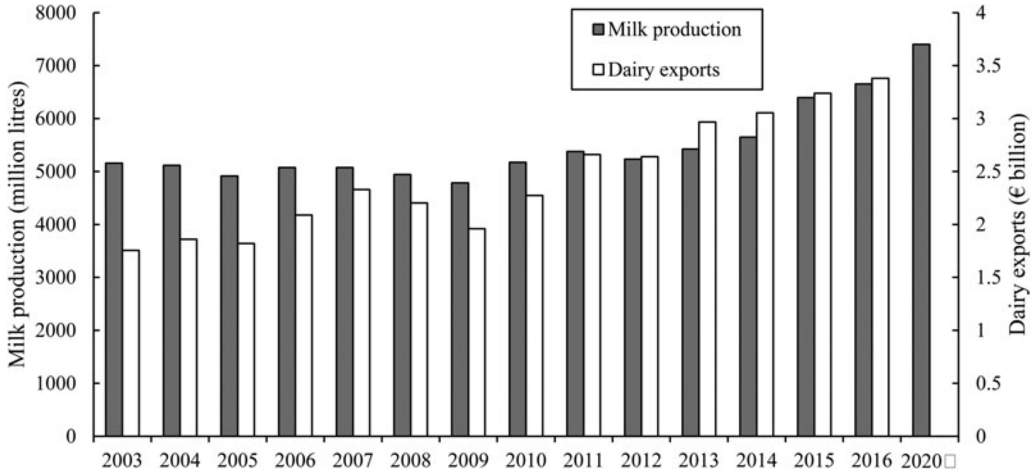

Fig. 1. Domestic milk production in the Republic of Ireland between 200 and 2016 and included the projected volume ([a]) for 2020; data obtained from CSO (2017) and NMA (2017).

industry that reached €3·4 billion in 2016 (NMA, 2017), which can be seen in Fig. 1. The increasing value of Irish dairy produce is also evident from this graphic, as Irish dairy processors move towards high value dairy products and ingredients. Traditionally individual dairy processing factories would have produced either cheese and whey products or butter and powder products (Geraghty, 2011). However, with the growth and development of the industry, certain dairy processing factories now specialise in the production of powders, cheeses or whey products. Approximately 7% of Ireland's milk is used for liquid milk consumption with the remainder (93%) manufactured into a variety of products, including butter, cheese, milk powder, whey and proteins (NMA, 2017).

At present, the Republic of Ireland is on the brink of a new era for the dairy industry as European milk quotas, which restricted milk production since 1984, were abolished in March 2015. As a result, milk production is expected to increase by 50% by 2020, based on the reference years 2007 to 2009 (Farrelly et al. 2014). Since their abolition, an immediate increase in milk production has been instigated, which is evident from Fig. 1.

This increase in the volume of milk being processed, together with stringent measures on emissions from the industry and growing commercial drive for operational efficiencies is driving the need for innovative technological and operational solutions within the dairy processing industry. In this context DairyWater, a multi-stakeholder research project, is developing innovative solutions for the efficient management of water consumption, wastewater treatment and the resulting energy use within the country's dairy processing industry. This project has the potential to position Ireland at the forefront of European, or indeed international, research in this sector as it strives to make the Irish dairy processing industry more efficient and environmentally sustainable by reducing carbon footprints, energy and water use. This will, in turn, lead to greater potential for exports, increased international competitiveness for Irish products and stimulate job creation.

This paper outlines the project aims and technologies that are being explored in the DairyWater project. Much of the data presented in this paper has been compiled through direct contact with the Irish dairy processing industry, due to the lack of published data available. However, although the presented study is based on the Irish dairy industry, it has relevance internationally as processing technologies are similar to those employed in other developed countries, in particular those European countries whose milk production was previously restricted by the milk quotas. The study would be particularly comparable to other countries with pasture based milk production, such as New Zealand, the United Kingdom, Galicia in Spain and Michigan in the United States of America. The overarching aim of the project is to aid the Irish dairy processing industry in becoming more sustainable. In order to achieve this the project intends to efficiently and effectively treat wastewater effluent from dairy processing factories using a range of innovative biological, nanomaterial-based and disinfection technologies. In parallel, the efficient use of water (and resulting energy costs) within the factories is also being explored. Additionally, a study on the environmental impact of the Irish dairy industry, along with an assessment of the contribution water and wastewater treatment at the dairy processing factory make to this, is performed. Selected aspects of the project have been discussed in greater detail as a cluster of research communications, which are entitled:

- Efficient treatment of dairy processing wastewater in a laboratory scale Intermittently Aerated Sequencing Batch Reactor (IASBR) (Leonard et al. 2018a)
- Efficient treatment of dairy processing wastewater in a pilot scale Intermittently Aerated Sequencing Batch Reactor (IASBR) (Leonard et al. 2018b)

- Dominance of the genus *Polaromonas* in the microbial ecology of an Intermittently Aerated Sequencing Batch Reactor (IASBR) treating dairy processing wastewater under varying aeration rates (Gil-Pulido et al. 2018)
- Potential of using synthesised nano-zeolite for ammonium and phosphate immobilisation in dairy wastewater (Gao et al. 2018)
- Microbiological characterisation and impact of suspended solids on pathogen removal from wastewaters in dairy processing factories (Fitzhenry et al. 2018)
- What is the environmental impact of the dairy processing industry in the Republic of Ireland? (Finnegan et al. 2018)

The main aim of the DairyWater project is to aid the Irish dairy processing industry in becoming more sustainable. In order to ensure that the research remains relevant to the Irish dairy processing industry throughout the project, the research team worked closely with leading industry stakeholders and a project advisory board is in place, which included leading members of the dairy processing industry and government funded bodies. Due to the fact that there is very little detailed information available in the published literature, it was essential for the industry partners to provide data, host site visits and facilitate pilot-scale activities, during the project; thus enabling potential commercial benefits of this research to be realised. The project can be divided into the following main research areas, which are discussed in the remainder of this section:

- water consumption and dairy wastewater characterisation;
- dairy wastewater treatment technologies and microbial analysis;
- water re-use and rainwater harvesting; and
- environmental assessment.

Water consumption and dairy wastewater characterisation

Initially, in order to gain a greater insight into the Irish dairy processing industry, a series of site visits, which included site data surveys and sampling of water and wastewater streams, took place. The feedback from these visits and surveys further reinforced the need to a reduction in water consumption at the factories and for more efficient and environmentally friendly solutions for wastewater treatment. Grab samples were used to investigate the water and wastewater streams within the dairy processing factories, which were taken during site visits due to time and resource constraints. The results of part of the survey, relating to the on-site water consumption and a breakdown of water usage, is given in Table 1 for 5 Irish dairy processing factories. Overall, the largest consumer of water on-site is related to cleaning, where a summary of the main water users within a dairy processing factory is shown graphically in Fig. 3. The wastewater produced, as a result of its high nutrient and microbial quantities, needs to be treated to reduce its environmental impact (such as eutrophication) on receiving waters. Therefore, a nutrient and microbial analysis was performed on samples of this wastewater to give an indication of the typical concentrations of key nutrients, where the results are given in Table 2. However, it can be seen in Table 2 that these nutrients vary greatly from site-to-site and, based on discussions with site personnel, can vary greatly throughout the day at a single site. For example, in this analysis, ammonium nitrogen, ortho-phosphate and coliforms vary between 0·9–184·2 mg/l, 5–102 mg/l and 3– 450 000 CFU/ml, respectively. The details relating to the operation of the facility and the results of the site data surveys were used as direct inputs in order to perform the environmental assessment of the Irish dairy processing industry.

Dairy wastewater treatment technologies and microbial analysis

One of the most central aspects of the project is to investigate the potential for the intermittently aerated sequencing batch reactor (IASBR) technology as solution for treating dairy wastewater. This technology has been selected as it previously showed potential for treating high strength wastewater and the resources of the project only allow for the complete investigation of one wastewater treatment technology, although the research team acknowledges that there may be other suitable solutions. Its viability within the Irish dairy industry, along with the development of an operating procedure for the IASBR technology to allow it to perform efficiently when treating dairy wastewaters, is investigated during the project. This technology has a distinct advantage over current systems as it is a biological wastewater treatment system in which wastewater is completely mixed with the microorganisms in the system for the duration of the react phase in order to remove nutrients and treat the wastewater. Previously, the IASBR technology has been applied in the treatment of municipal wastewater (Henry et al. 2013), high strength slaughterhouse wastewater (Henry, 2014; Pan et al. 2014) and, at laboratory-scale, dairy wastewater (Tarpey, 2016). Since wastewaters with high biodegradability are suitable for treatment by biological processes (Pan et al. 2014), the IASBR system has the potential to treat dairy wastewater efficiently. Additionally, the technology has been shown, if managed correctly, to be superior in certain industries in the removal of nitrogen and phosphorus than the more traditionally used sequencing batch reactor technology for the treatment of the wastewater (Pan et al. 2013; Henry, 2014).

In order to develop the technology, experimental procedures at both laboratory-scale and pilot-scale IASBR systems will be investigated. Nutrients which are commonly known to be responsible for eutrophication, primarily nitrogen and phosphorus, (Pan et al. 2013) will be removed and their removal efficiencies will be monitored, as well as the operating cost and energy demand. This will aid in determining the most efficient and effective solution when compared technologies currently employed in the Irish dairy processing industry. The initial step of the project was to

Table 1. Results from a survey of 5 Irish dairy processing factories relating to water consumption, including a breakdown in water usage within the factory

	Site 1		Site 2		Site 4	Site 5		Site 6
Products processed	Fluid milk	Cream	Milk powder	Butter	Milk powder	Milk powder	Butter	Infant formula
Milk processed (million litres)	50		206		80	587		125
Total water consumption (m^3)	58 000		155 000		82 000	500 000		438 000
Water consumption (litre per litre milk)	1·16		0·75		1·03	0·85		3·5
CIP	56%	1·7%	33%	10%	75%	53%	7%	15%
Boilers & flushing	3%	0·1%			25%	13%	2%	2%
Cooling						22%	3%	
Intake	14%	0·5%						
Separators				4%				
Butter factory				8%				
Deaerator				8%				
Dryers			14%					24%
Evaporators			14%					
Tanker wash			7%	2%				
WWTP	7%	0·2%						
Other	17%	0·5%						59%

Legend: clean-in-place system (CIP); wastewater treatment plant (WWTP).

Table 2. Results from a nutrient and microbial analysis of samples of wastewater (prior to on-site wastewater treatment) at 6 Irish dairy processing factories

	pH	TSS	COD	BOD_5	NH_4	Nitrite	PO_4	Coliforms	*E. coli*
	–	(mg/l)						(CFU/ml)	
Site 1	N/A	2370	9770	4900	7·8	0·144	5·3	$1·00 \times 10^2$	$8·35 \times 10^1$
Site 2	N/A	750	1430	N/A	0·9	4·5	5·0	N/A	N/A
Site 5	9·8	915	3310	3300	184·2	0·1	8·1	$4·50 \times 10^4$	$0·00 \times 10^0$
Site 7	5	490	3270	1900	20·1	0·065	31·7	$1·35 \times 10^5$	$2·55 \times 10^1$
Site 8	6·3	311	1210	1200	6·1	0·0	6·6	$4·50 \times 10^5$	$5·63 \times 10^2$
Site 9	N/A	205	1171	375	1	0	102	$3·00 \times 10^0$	$0·00 \times 10^0$

Legend: ammonium nitrogen (NH_4); 5-day biochemical oxygen demand (BOD_5); chemical oxygen demand (COD); colony-forming unit (CFU); *Escherichia coli* (*E. coli*); ortho-phosphate (PO_4); test not performed (N/A); total suspended solids (TSS).

replicate the technology in a laboratory setting (using a laboratory-scale system containing three 8 l cylindrical units, which is shown in Fig. 2, to gain a greater understanding of the technology and to create parameters from which a pilot-scale system could be designed. This laboratory-scale system not only proved the validity of the technology for the treatment of dairy wastewater, but also determined initial operating parameters for the pilot-scale IASBR system. The pilot-scale IASBR system has been designed and installed on-site at the wastewater treatment plant of an Irish dairy processing factory and has a working volume of 3000 l, which is shown in Fig. 2. The system is supplied with wastewater from the processing factory and is monitored daily using an on-site automated refrigerated sampler. These samples are tested weekly in order to monitor the performance of the system. This pilot-scale system gives a greater insight into the performance of the IASBR technology at a near commercial-scale.

In order to gain a greater understanding about the performance of the IASBR technology, the bacterial communities underpinning nutrient removal efficiencies arising from the laboratory-scale and pilot-scale systems have been profiled. Microorganisms are they key contributors in biological wastewater treatment processes and the knowledge of bacterial community structures contributes to the development of strategies for process optimisation (Daims et al. 2006). Therefore, during this research, next generation sequencing (NGS) methods will be applied to IASBR biomass samples. Sample collection is intended to provide representation of varying operational parameters at laboratory-scale (e.g. aeration rates), pilot-scale (e.g. cycle length) and varying influent compositions (e.g. synthetic *vs.* industrial influent). NGS outputs were subjected to comprehensive *in silico* analyses to determine microbial community structures and to facilitate correlations between relative microbial abundance and reactor performance (Zhang et al. 2012; Weissbrodt

Fig. 2. Experimental systems used as part of the DairyWater project. Clockwise (from top left): laboratory-scale intermittently aerated sequencing batch reactor (IASBR) system; laboratory-scale pulsed ultra violet (PUV) system; low pressure ultra violet (LPUV) system; pilot-scale IASBR system.

et al. 2014). In silico metabolic profiling of the bacterial community was also performed to predict the abundance of functional gene families and to identify potential, key contributors to nutrient bioremediation (Ahmed et al. 2017). In an effort to corroborate the modelled outputs with respect to NGS determined dominant groups and metabolic functionalities, spatial distribution analyses was also performed. Fluorescence in situ Hybridisation (FISH) and quantitative polymerase chain reaction (qPCR) will be used for the enumeration of specific targeted microbial groups of interest and their spatial organisation within the representative biomass samples (Nielsen et al. 2009; van Loosdrecht et al. 2016). This study seeks to address the knowledge gap which exists in relation to the microbial community structures underpinning IASBR application. Such knowledge is critical to the optimisation of the IASBR technology, where a reliance on key microbiota can be demonstrated. While the target application of this project is the dairy processing sector, the findings have potential significance in the treatment of other agri-industrial wastewaters.

The use of nanomaterials to improve the efficiency of wastewater treatment processes in this sector has not previously been well explored. Therefore, a selection of nanomaterials have been tested in order to seek an appropriate one for simultaneous removal and recovery of nitrogen, phosphorus and other contaminants for the treatment of dairy wastewater. The nanomaterials tested in the study include nano-zeolite, surface modified nano-zeolite, carbon nanotubes and activated charcoal (Camblor et al. 1998). The physicochemical characteristics of nano-zeolite, such as high mechanical and chemical resistance and its high surface area, have formed the basis for its widespread use in catalysis, separation, and ion-exchange (Song et al. 2005). In this study, the feasibility of using coal fly ash to synthesise nano-zeolite was studied, along with the nitrogen and phosphorus adsorption efficiencies of the nano-zeolite. In addition, surface modifications were conducted by adhering Cu, Mg, Fe, Zn, Ca ions and Hexadecyltrimethylammonium (HDTMA) onto the surface of nano-zeolite in order to change the surface properties and enhance the contaminants removal efficiency.

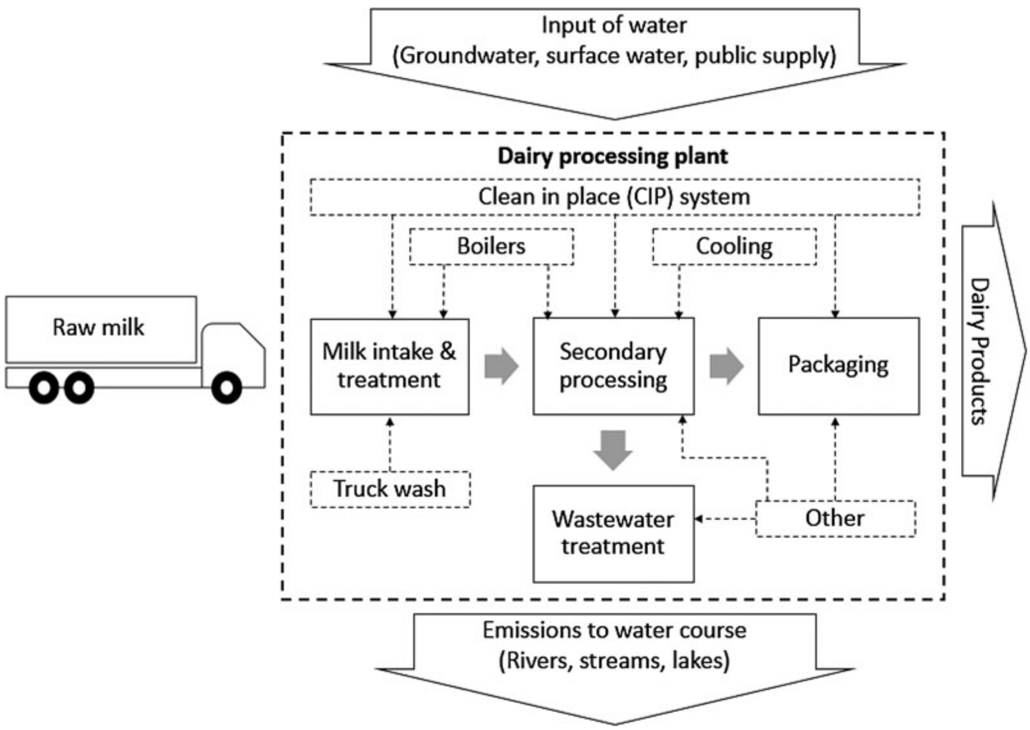

Fig. 3. Schematic summarising processing within a dairy processing factory and the main water users within the manufacture of dairy products.

Comparative batch experiments were conducted to study the effect of sorption time, pH values and dosage of nanomaterials on the contaminant removal efficiency. Additionally, in order to minimise the operation cost, the regeneration of nanomaterials after use has been considered. A microbial fuel cell (MFC) has been chosen instead of typical acid/alkaline wash, as MFCs possess the ability of generating electricity from organic matter using exoelectrogenic bacteria during wastewater treatment (Logan, 2008). The possibility of regenerating the nanomaterials and energy recovered by using MFCs will be examined further in this research.

Water reuse and rainwater harvesting

Given the significant quantities of water consumed by the Irish dairy processing industry, the reuse of wastewater within the sector may be necessary for economic, regulatory and sustainability purposes (Geraghty, 2011). A key barrier to water reuse within this sector (and indeed other industries) is the implementation of pathogen removal. This study compares a flow-through pulsed ultraviolet (PUV) system (Barrett et al. 2016) and a continuous low-pressure UV (LPUV) system, which are both shown in Fig. 2, as potential technologies for (i) tertiary wastewater treatment plant effluent disinfection and (ii) disinfection systems to restore dairy wastewater to reusable levels for certain dairy processing factory practices. The two systems were compared in terms of energy usage and bacterial UV dose response and the impact of dairy wastewater parameters, primarily suspended solids (SS), on the system, along with the inactivation efficiency of *E. coli*.

Preliminary work included a nationwide dairy processing factory site survey followed by the microbiological characterisation of water/wastewater streams. The sample streams tested included cooling waters, condensate water and wastewater treatment plant (WWTP) influent and effluent. Feedback from this survey analysis indicated low levels of water reuse practices at dairy processing factories however the introduction of microbiological effluent discharge standards is likely in the near future. The key findings from the microbiological characterisation included the detection of faecal indicators in 11 out of the 12 samples collected including all three WWTP effluent samples. Pathogenic bacteria typically associated with the dairy industry were also detected; *Listeria monocytogenes* was present in all samples at two sites, while *Campylobacter* spp. was also present in cooling waters and wastewater treatment plant effluent at one of the sites. *Bacillus pumilus* and *Bacillus subtilis* endospores have been investigated as they are noted to exhibit increased resistance to LPUV in comparison to vegetative cells (WRF, 2010; Boczek et al. 2016).

From the results, inert suspended solids do not appear to inhibit PUV or LPUV efficiency at high SS concentrations (30 mg/l and above) while organic particles impacted on the PUV and to a lesser extent on LPUV efficiency. A PUV dose of approximately 2000 mJ/cm^2 was required for a 2

https://doi.org/10.1017/S0022029918000614 Published online by Cambridge University Press

log inactivation of *B. pumilus* endospores while a LPUV dose of 30 mJ/cm^2 was required for a 5 log inactivation. The effect of agar supplement manganese sulphate ($MnSO_4$) on the enhanced UV resistance of endospores has also been analysed. Cultivation agar supplemented with $MnSO_4$ appears to increase the UV resistance of *Bacillus* spp. endospores when exposed to both PUV and LPUV. Preliminary investigations into the energy efficiency of both systems indicated that the LPUV system exhibits a higher efficiency of converting electrical energy to UV energy in comparison to the PUV system. The photoreactivation potential of dairy pathogens post PUV and LPUV flow-through disinfection is to be investigated, along with 'on-site' dairy wastewater been incorporated into UV disinfection trials to evaluate the potential of UV treatment for low-level water reuse at dairy processing factories.

As dairy production increases, so too will the vast volumes of water required for dairy product output, which currently stands at 2·5 m^3/m^3 of milk processed (Geraghty, 2011). Legislation regarding the discharge limitations of dairy wastewater effluent is becoming increasingly stringent along with initiatives to conserve and reuse water within the industry. Thus, alongside the potential for reusing treated wastewaters, there is significant potential to harvest and use rainwater. A key consideration for the industry in implementing rainwater harvesting is the potential for a positive and benefit to cost ratio and a relatively short pay-back time. Given the relatively low costs of water in Ireland (in some cases where water is withdrawn from private sources there may not be any charge associated with water use) this project focused on the development of design tools that would enable the industry determine the viability of implementing rainwater harvesting at a number of case-study sites. The toolkit also includes a life cycle assessment module which modelled expected life cycle emissions from the construction and operation/maintenance of the rainwater harvesting system. The tool was trialled, based on case-study data from a number of dairy facilities in Ireland. In general it was shown that given current water tariffs, the costs of deploying rainwater harvesting at each site and the potential end-uses for rainwater such systems might not at this time be economically viable.

Environmental assessment

Since the main aim of the DairyWater project is to help form a more sustainable Irish dairy processing industry, particularly from an environmental point-of-view, it is first necessary to establish a benchmark for the industry. This study will also aid in determining the true impact of water and wastewater treatment technologies on the overall environmental impact associated with the manufacture of dairy products. Therefore, life cycle assessment (LCA) is being used in order to estimate the current environmental impact of the Irish dairy industry. Additionally, LCA will be used to evaluate the environmental impact of the technologies developed during the DairyWater project in order to ensure that they will have a positive impact on the environment. In order to ensure the accuracy of this study, it is structured in accordance with the LCA guidelines of the International Organisation for Standardisation (ISO, 2006) and the LCA methodology for the dairy industry published by the International Dairy Federation (FIL-IDF, 2015).

Initially, a macro-scale LCA of the Irish dairy industry, which assessed the global warming potential associated with the main Irish dairy products, was performed (Finnegan et al. 2017a). The life cycle stages included in this study are raw milk production, raw milk transportation and dairy processing and publically available data, along with national statistics, were used. This study identified the critical processes, inputs and emissions that are necessary in delivering an accurate LCA. The main LCA performed during the study is an environmental LCA of selected dairy products in the Republic of Ireland, which included a number of environmental impact categories. This analysis was performed for a number of dairy products, including milk powder, butter, fluid milk, cream, infant formula, cheese and whey powder. So as to perform this analysis, data was collected from 11 dairy processing factories within the Republic of Ireland for 2013, which process approximately 49% of the total raw milk processed. Due to the availability of data, comprehensive studies relating to the production and manufacture of milk powder and butter have been carried out (Finnegan et al. 2017b, c). From these studies, the environmental impact of these two products have been estimated and the processes (within the dairy processing factories) that are the most significant contributor to the impact have been identified.

Along with performing an assessment of Irish dairy products, both an economic cost–benefit analysis and an environmental assessment (using LCA) of the potential positive impact of novel technologies investigated in this project will be carried out. The results of this analysis will be compared to existing dairy water and wastewater treatment technologies in order to demonstrate how sustainability may be improved.

The technologies being developed in this project have the potential to greatly increase the sustainability of the Irish dairy processing industry, while also returning a financial benefit. For example, the proposed IASBR system is a biological wastewater treatment system and, thus, does not require any chemicals, which is one of the largest expenses when treating wastewater. Additionally, as Ireland's agricultural and agri-food sector continues to grow, it has been suggested that a carbon tax on dairy processors, similar to the carbon tax paid by motorists for their cars and householders for their fuel bills, may be introduced as an incentive to reduce emissions (Melia, 2015).

At current milk processing levels, many dairy processors in Ireland are at the limits of their emissions to water, as set by the Irish environmental protection agency (EPA). As a result of the increase in raw milk production due to the European milk quotas being abolished, processors will be under increased pressures to remain within these limits. Additionally, in 2015, domestic water charges were introduced in the Republic of Ireland for the first time. Even though this didn't affect the Irish dairy processing industry, as groundwater and surface waters are the main source, it may in the future if extraction charges are introduced. Therefore, water reuse, particularly the reuse of wastewater as process water, may be necessary to reduce the water footprint of dairy processing factories and to reduce costs associated with production. The tertiary treatment systems proposed in this project, PUV and LPUV systems, would be vital in exploiting the potential of water reuse together with meeting the requirements of dairy processing factories to comply with strict regulations when emitting treated effluent to rivers and lakes, such as those implemented by the Water Framework Directive (WFD – 2000/60/EC), Surface Waters Regulations (S.I. No. 272 of 2009) and the European Community Shellfish Waters Directive (2006/113/EC).

In conclusion, this article outlines the project aims and technologies that are being explored in the DairyWater project, where the main aim is to aid the Irish dairy processing industry in becoming more sustainable. As Europe moves into a post-quota era, it will be essential for Ireland to improve its sustainability and maintain its 'green' image if it is to remain competitive internationally. Therefore, the DairyWater project has the potential to position Ireland at the forefront of European, or indeed international, research in this sector. The project strives to make the Irish dairy processing industry more efficient and environmentally sustainable, which will lead to greater potential for exports and increased international competitiveness for Irish products, along with stimulating job creation. In addition, the results of the study are suitable to be applied internationally as, although milk production conditions may not be pasture based, processing, and many of the associated environmental impacts and challenges that arise, are generally the same when using modern processing technologies.

The authors would like to acknowledge the funding provided by the Department of Agriculture, Food and the Marine for the DairyWater project (Ref.: 13-F-507); for additional details see http://www.dairywater.ie. Additionally, the DairyWater research team would like to the members of the Irish dairy sector for their cooperation and contributions throughout the research project.

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