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Technology Options in a Dairy Plant: Assessing Whole-System Eco-Efficiency

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Abstract

Industries are increasingly looking beyond their own fences to optimise their supply and delivery chains. Increasing industrial production costs for resources and costs to comply with stringent legislation have led many industries to look for more cost effective solutions. Establishing collaboration with water and energy utilities and other industries in the neighbourhood of the industrial production site is one option being analysed.

This paper presents how eco-efficiency analysis - at a system level going beyond the fences of an industrial production site - can calculate economic value and environmental impacts in such wider systems. The paper presents how the analysis can lead to the identification of eco-efficient solutions at a system level as well as at the level of each actor in the system.

The eco-efficiency analyses are based on the ISO standard ISO 14045. The water use system analysis comprises a dairy plant producing milk powder located in a production site in Holstebro, Denmark. The dairy uses water in its utility operation and in the dairy processes for purposes like cleaning (Cleaning in Place, CIP), rinse processes and standardization of products.

In the eco-efficiency analysis a water value chain is modelled in five stages: water supply, dairy production, wastewater treatment, energy production (biogas) and transport. The eco-efficiency analysis thus has another focus than a Water Footprint analysis, which also includes water use for feed production, water used at farm level and in some cases also includes the water use at retail and consumer level. The eco-efficiency study focus not only on water efficiency but also on and how energy saving technology options linked to water use could upgrade the whole-system eco-efficiency.

The identification of the environmentally weak stages as being emissions of climate gasses resulting from energy use and water resource enables the selection of alternative actions, which could upgrade the whole value chain and improve the overall eco-efficiency. Four innovative technologies in the dairy production stage and one in the wastewater treatment stage are examined and three alternative technology scenarios combining these technologies are formulated. All scenarios focus on resource efficiency, while one also focuses on reducing the emissions to water.

The eco-efficiency assessments showed that advanced oxidation and UV light treatment of the water stream separated from the milk stream had the highest eco-efficiency corresponding to an increase of 130% compared to the baseline for the freshwater resource depletion indicator. Anaerobic pretreatment of the dairy wastewater in the dairy plant had the highest eco-efficiency showing an increase of 10% as compared to the baseline for the climate gas indicator. For all other technologies and combinations of technologies the increases were significantly smaller.

The eco-efficiency assessment results provided a basis for workshops with the actors in the value chain to discuss how to anticipate distributional effects. The analysis of the economic performance clearly showed that the dairy plant had the highest economic performance due to the high value of their product and that investments in new technologies increased the economic performance even more. This was mainly caused by savings on costs for water supply and wastewater treatment services, which left the water utility with a reduced economic performance.

Keywords: Eco-efficiency, Water-use systems, Dairy industry, Resource efficiency, Pollution prevention.

1. Introduction

Eco-efficiency assessments and Life Cycle Assessments have gained increasing acceptance also in the dairy industry over the last decades (Moll and Gee, 1999; OECD, 2009; WBSCD, 2000). The UNEP Working Group for Cleaner Production in the Food Industry has developed a guidance manual for the dairy processing industry for eco-efficiency as a management tool to help dairies save money and decrease environmental impacts (UNEP, 2004).

A recent review of the status of water utilization, energy utilization and wastewater discharge provides both an overview of state of the art of technologies and management systems to improve the eco-efficiency of the dairy processing industry (Rad & Lewis, 2014). The dairy industry sector has also developed its own guideline for LCA assessment (IDF, 2005). Treatment of dairy waste water is possible both with physical chemical treatment (Martin-Rilo et al 2015) and biological treatment processes (UNEP, 2004). Djekic et al, 2014 found that the environmental impacts of dairy rely on the energy fuel profile, water optimization and waste water management practices.

The LCA analysis shows that 99% of the water footprint is in the primary production stage at farm level. However, the review of status of water and energy use (Rad & Lewis, 2014) shows that there is still a potential to increase the efficiency of the water and energy use and reduce wastewater emissions. Not least the potential to use water coming into the dairy with milk (about 87% of the milk is water) may replace the use of water with drinking water quality used in many dairies in Europe. This potential is largest in milk powder and cheese producing dairies as the dairy processes already comprise separation processes which separate milk components from water still containing low concentrations of milk components (often called milk or cow water). As food safety cannot be compromised, there are some limitations to the amount of water which can be reused or recirculated-however, there has been a clear trend over the recent years that dairies use a higher percentage of water coming into the dairy with the milk.

The review also shows that the main efforts to increase eco-efficiency has been on measures internally in the dairy processing industry, while there has been limited focus on the potential of the dairy processing industry to find solutions with other actors in the water value chain (from water supply to dairy - to wastewater treatment plant and biogas production) (Rad & Lewis, 2014; UNEP, 2004).

2. Methods and Research Focus

2.1 Goal Definition

The goal of the developed methodology is an integrated assessment of the eco-efficiency of a water service and water-use system. The methodology comprises a number of consecutive steps following the LCA procedure (Ecowater, 2014; JRC 2010 and 2011). The water use system is represented as a network of unit processes. Each process corresponds to an activity, through which materials (water, raw materials, energy and other supplementary resources) are converted into products while releasing emissions to the environment (air, land, water) or into the system’s water flow.

2.2 Economic Performance

The assessment of the environmental performance is based on a life-cycle oriented approach using midpoint impact categories. Based on the flows entering and leaving every process in the system, the significance of potential environmental impacts is evaluated. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterisation factors.

An inventory of flows entering and leaving every process in the system is created and based on that, the significance of potential environmental impacts is evaluated. The results of the inventory, expressed as elementary flows, are assigned to impact categories according to the contribution of the resource/emission to different environmental problems, using standard characterisation factors. The environmental impact for impact category c is expressed as a score (ES_c) in a unit common to all contributions within the category. It can be easily calculated using the flows from the inventory analysis and the characterisation factors, as

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follows:

$$ES_c = \sum_r cf_{r,c} \times f_r + \sum_e cf_{e,c} \times f_e \quad (1)$$

Where $cf_{r,c}$ is the characterisation factor of resource r for the impact category c, $cf_{e,c}$ the characterisation factor of emission e for the impact category c (both retrieved from LCA databases), and f_r, f_e the elementary flows of resource r and emission e, respectively.

2.3 Economic Performance

The economic performance of the system is calculated by using the Total Value Added (TVA) to the product due to water use, expressed in monetary units per period and per functional unit for the year 2012. The total economic value from water use is calculated by subtracting the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage from the total value of the products (Jasch, 2009).

It is estimated as:

$$TVA = EVU + VP_{BP} - TFC_{WS} - TFC_{WW} - FC \quad (2)$$

Where EVU is the total economic value from water use, VP_{BP} the income generated from any by-products of the system, TFC_{WS} the total financial cost related to water supply provision for rendering water suitable for the specific use, TFC_{WW} the total financial cost related to wastewater treatment and FC the annual equivalent future cash flow generated by the introduction of new technologies in the system. The total economic value from water use can be calculated by subtracting the expenses for all the non-water inputs as well as the costs related to emissions in the water use stage from the total value of the products.

2.4 Eco-Efficiency Indicators and Assessment

The Eco-Efficiency Indicators (EEI) of the water use systems are defined as ratios of the economic performance (total value added, TVA) to the environmental performance (environmental impacts) of the system. There is one eco-efficiency indicator for each environmental impact category c:

$$EEI_C = \frac{TVA}{ES_C} \quad (3)$$

3. Results and Discussion

3.1 Actors and System Boundary Definition

The studied system is divided into a foreground and a background sub-system. The foreground system contains the water supply, the water use chain (the dairy), the wastewater treatment plant, the biogas plant and transport of milk and by-products. These stages enclose the relevant actors involved in the system and the interactions among them. The actors of the system, directly as well as indirectly involved, are the following:

- The Water Utility "Vestforsyning A/S" operating both the water supply and the wastewater treatment system
- The dairy plant "HOCO" being part of Arla Foods in Denmark
- The biogas plant "Maarberg Biorefinery"
- Private companies transporting milk, milk powder and other milk ingredients under contract with the dairy.

The background system consists of the production processes of the supplementary resources (electricity and natural gas), raw materials and chemicals. However, only the electricity and natural gas production processes are taken into consideration for the eco-efficiency assessment, as data on chemical uses have not been made available for the study.

The system analysed is presented in figure 1:

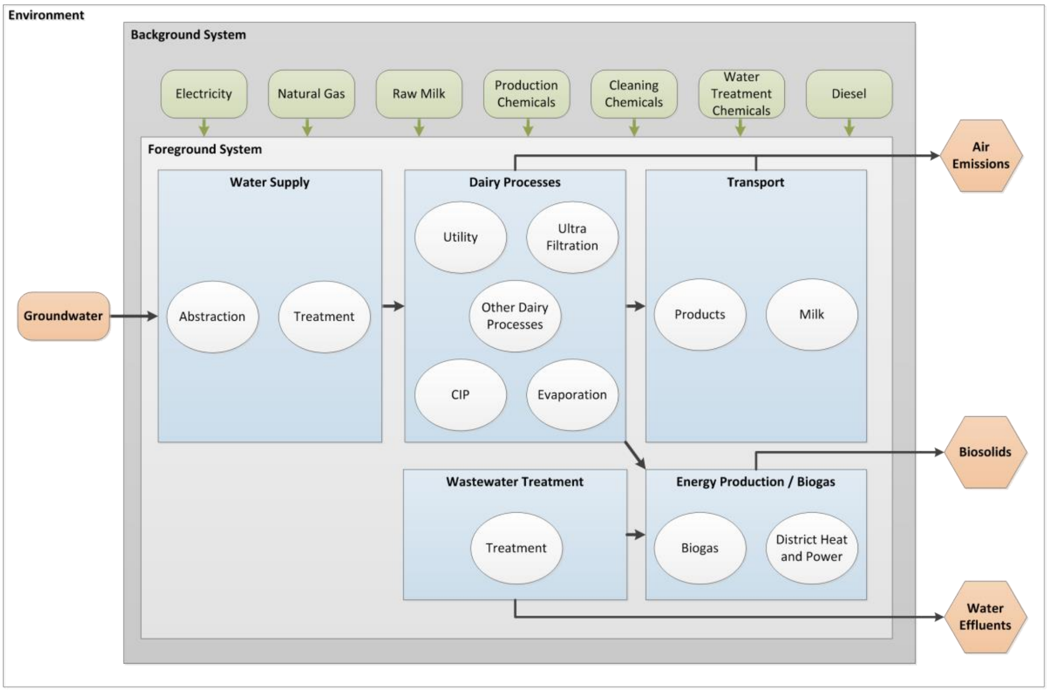

Figure 1. System boundaries and actors

3.2 Eco-efficiency Assessment

3.2.1 Environmental Assessment

The dairy had an output of 17.165 ton milk powder in 2012. For the dairy processes it is estimated that in 2012 1 kg of milk powder required 31 litre of groundwater, 2.560 kWh of electricity and energy from natural gas equivalent to 7676 kWh. The input of raw milk in 2012 was 524.236 ton giving a groundwater intake to milk ratio of about 1 liter per kg of raw milk. This is below the average 1.5 litre of water per kg of raw milk reported for milk powder production (Weeks, 2010).

In the calculations of the baseline scenario it has been taken into account that the wastewater treatment plant as well as the biogas plant also receives inputs from other wastewater and sludge and bio solid sources. The resource uses and emissions and value added therefore only refer to the amounts from the dairy plant.

The impacts from the use of freshwater are neglected by most LCA studies and databases and as a result, there is no standardised environmental midpoint indicator for the freshwater resource depletion (JRC, European Commission, 2010). However, since water consumption is an important component of the studied system, freshwater depletion is taken into consideration. Milà i Canals et al. have proposed a methodology measuring freshwater depletion which suggests the Freshwater Ecosystem Impact (FEI) indicator. FEI relates current freshwater use to the available freshwater resources and is defined as:

$$FEI = f_{w,abs} \times WTA \quad (4)$$

Where $f_{w,abs}$ is the flow of freshwater abstracted and WTA is the water withdrawal to availability ratio (Mila i Canals et al, 2009). In the area in Jutland where the dairy is located and abstracts its wastewater the water withdrawal to availability ratio is estimated to be 25%.

The environmental performance of the dairy system is assessed through eight environmental midpoint indicators, representative for the specific system and relevant to the dairy industry. The background processes that are taken into account for the assessment of the environmental impacts are electricity and natural gas production, as it was not possible to collect data for the other background processes. The characterisation factors included in the CML-IA database are used for the calculation of the environmental impacts of the foreground system, while the factors for the background system are obtained from the EcoInvent database, using the CML 2001 Method (JRC, 2011).

The environmental assessment of the baseline scenario is summarized in Table 1. This table presents the normalized values of environmental indicators per kg of milk powder produced for the entire system and the contribution of the foreground and the background system separately. The most significant environmental foreground problems are freshwater depletion and climate change impact. The freshwater use in the background (the water used in agriculture to produce the milk) is not included in the figures in Table 1. If included, the background would account for more than 99% and the Freshwater Resource Depletion would increase by a factor of 64 to 0,5 m^3/kg of milk powder produced.

Table 1. Contribution of the foreground and the background systems in the overall environmental impact for the baseline scenario

Midpoint Impact Category	Environmental Performance Indicator per kg of milk powder produced	Foreground Contribu-tion	Background Contribu-tion
Climate change	58 kg CO_{2eq}/ kg	45	55
Freshwater Resource Depletion	0,008 m^3/kg	100	0
Eutrophication	1,7 kg $PO_4{}^{3}{}_{-,eq}$/kg	0,3	99,7
Human toxicity	0,06 kg $1,4DCB_{,eq}$/kg	14	86

Acidification	0.56 kg $SO_2^-{}_{,eq}$/kg	0,8	99,2
Aquatic Ecotoxicity	0,002 kg 1,4DCB$_{,eq}$/kg	0	100
Terrestrial Ecotoxicity	0,003 kg 1,4DCB$_{,eq}$/kg	0	100
Photochemical Ozone Formation	0.0005 kg $C_2H_{4,eq}$/ kg	35	65

3.2.2 Value Assessment

In the dairy case the service price is used for TFC_{WS} and TFC_{WW}.

Calculated value assessment of the value chain per actor is shown in Table 2. The total net economic output is 30.201.664 € - equivalent to 1.7 € per kg of milk powder produced. As this figure refers to the specific value chain it cannot be compared with other dairy plants.

Table 2. Economic evaluation of the value chain

Actor	Annual O&M costs (€/yr)	Gross income (€/yr)	Revenues from services €/yr)	Net economic output €/yr)
Water supply operator	52.731	0	953.300	882.569
Dairy industry	213.154.418	249.642.370	-9.668.941	26.819.011
WWT operator	294.049	0	2.428.019	2.133.970
Biogas plant	19.618	102.627	0	83.008
Transport companies	6.022.515	0	6.305.620	283.105

The net economic output of the value chain is completely dominated by the dairy industry and the value of the milk powder produced. For the dairy the main cost is the raw milk and the net economic output is highly influenced by this price.

3.2.3 Eco-Efficiency Assessment

Table 3 presents the results of the baseline eco-efficiency assessment for the overall system. It is confirmed that the major environmental impacts of the studied system (including both foreground and background) are eutrophication, acidification, human toxicity, climate change and freshwater resource depletion which are characterised by the lowest eco-efficiency indicator value and thus the worst performance. Focussing only on the foreground, climate change and freshwater resource depletion had the lowest eco-efficiency value and thus the lowest performance.

Table 3. Baseline eco-efficiency assessment

Midpoint Impact Category	Unit	Total for the value chain
Climate change	€/kgCO_{2eq}	0,030
Freshwater Resource Depletion	€/m^3	203
Eutrophication	€/kg$PO_4^{3}{}_{-,eq}$	0.99
Human toxicity	€/kg1,4DCB$_{,eq}$	28,5

Acidification	€/kgSO^{2-}$_{,eq}$	3,14
Aquatic Ecotoxicity	€/kg1,4DCB$_{,eq}$	737
Terrestrial Ecotoxicity	€/kg1,4DCB$_{,eq}$	630
Photochemical Ozone Formation	€/kg $C_2H_{4,eq}$	3271

3.3 Value Chain Upgrading

With the focus on the foreground technologies that could upgrade eco-efficiency, focus should be on reduction of climate change and freshwater resource depletion.

Thus, three main objectives were set for the upgrading of the studied system: (a) increase of resource efficiency, focusing on freshwater and energy optimisation; (b) energy pollution prevention and c) circular technologies, where the water in the milk is treated to enable an increased reuse. After discussing with the directly involved actors in the system and reviewing the relevant literature, four alternative technologies were selected for potential implementation in the dairy, one in the wastewater treatment plant and one for transport of milk, by-products and waste products. The result of the eco-efficiency assessment of these 6 technologies compared to the baseline (Table 3) is shown in Table 4.

Table 4. Summary of eco-efficiencies of individual technologies compared to the baseline eco-efficiency (plus indicates an increase in eco-efficiency)

Midpoint Impact Category	Baseline	An-aerobic digestion	Advan-ced oxidation and UV light treatment	Product and water recove-ry from CIP	Clea-ning and reuse of conden-sate	More effici-ent blowers	Increa-sed loading capacity of trucks
Climate change	0,030 €/kgCO_{2eq}	+21%	+11%	+9%	+8%	+0,3%	+1%
Freshwater Resource Depletion	203 €/m^3	+8%	+131%	+15%	+ 35%	0%	0%
Eutrophi-cation	0,99 €/kg$PO_4^{3}$$_{-,eq}$	+7%	+3%	+7%	+7%	0%	+4%
Human toxicity	28,5 €/kg1,4DCB$_{,eq}$	+9%	-1%	+8%	+7%	+0%	+0,3%
Acidification	3,1 €/kgSO^{2-}$_{,eq}$	+11%	+4%	+8%	+8%	0%	+4%
Aquatic Eco-toxicity	737 €/kg1,4DCB$_{,eq}$	+9%	+1%	+8%	+7%	0%	+1%
Terrestrial Eco-toxicity	630 €/kg1,4DCB$_{,eq}$	+8%	+2%	+8%	+7%	0%	+2%
PhotochemicalOzone Formation	3271 €/kg $C_2H_{4,eq}$	+9%	+3%	+8%	+7%	+1%	+2%

As can be seen, the largest improvements in eco-efficiency indicators are for the climate change and freshwater resource depletion indicators. The advanced oxidation and UV light treatment, anaerobic pre-treatment and the reuse of condensate show the largest improvements in eco-efficiency.

Other technologies like more efficient diffusers in the wastewater treatment plant and increased loading capacity of trucks have almost no impact on the eco-efficiency of the overall system, while it has an impact if only assessing the wastewater treatment and transport stage individually (results not shown).

As a second step in the process of upgrading the value chain, four alternative technology scenarios were assessed. The scenarios combine the most eco-efficient individual technologies with the aim to improve resource efficiency, reduce pollution load and increase the circular economy. Finally, one scenario combines the most water efficient technologies with the aim to analyze how close the dairy can get to closing the water intake through replacement of freshwater with other types of water present in the dairy Table 5.

Table 5. Technology scenarios combining individual technologies

Technology Scenarios	Technologies Included
Increased resource efficiency and pollution prevention	Anaerobic digester
	Advanced oxidation
Increased resource efficiency, pollution prevention and circular economy	Anaerobic digester
	Advanced oxidation
	Product and water recovery
Increased water resource efficiency	Product and water recovery
	Cleaning and reuse of condensate
Towards circular economy and closing the water loop	Advanced oxidation
	Cleaning and reuse of condensate

Table 6 presents the result of the scenario assessment with the result of the baseline. It is assumed that the technologies can be implemented as individual technologies, which adds the effect on environmental and economic performance and eco-efficiency, and that the investment cost and operating cost can be calculated as the sum of the individual technologies.

Table 6. Summary of eco-efficiencies of technology scenarios compared to the baseline eco-efficiency (plus indicates an increased eco-efficiency)

		Anaerobic digestion and	Anaerobic digestion,	Product and water recovery	Cleaning and reuse of

		advanced oxidation	advanced oxidation and product and water recovery	and cleaning and reuse of condensate	condensate and advanced oxidation
Midpoint Impact Category	Base line	Aim to increase resource efficiency and pollution prevention	Aim to increase resource efficiency, pollution prevention and circular economy	Aim to increase water resource efficiency	Aim to move towards circular economy and close the water loop in the dairy
Climate change	0,030 €/kgCO_{2eq}	+12%	+12%	+2%	+11%
Freshwater Resource Depletion	203 €/m^3	+133%	+131%	+47%	+316%
Eutrophication	0,99 €/kgPO_4^{3}-,eq	+3%	+3%	+8%	+4%
Human toxicity	28,5 €/kg1,4DCB,eq	+2%	+1%	+7%	+0,3%
Acidification	3,1 €/kgSO^{2-},eq	+4%	+4%	+8%	+4%
Aquatic Eco-toxicity	737 €/kg1,4DCB,eq	+2%	+1%	+7%	+1%
Terrestrial Eco-toxicity	630 €/kg1,4DCB,eq	+3%	+2%	+7%	+2%
Photochemical Ozone Formation	3271 €/kg $C_2H_{4,eq}$	+4%	+3%	+7%	+2%

The implementation of advanced oxidation combined with cleaning and reuse of condensate showed the highest improvements of eco-efficiency for the impact category freshwater resources depletion and climate change and also for the other efficiency indicators at the same level as the baseline. This scenario - which reduces the groundwater intake by 64%, resulting in a water use of 0,6 m^3/kg of milk which is among the low figures given in the literature - increases the eco-efficiency by more than four times. Installing technologies in the dairy which aim at using the water coming into the dairy with the milk instead of using freshwater is therefore a highly efficient scenario for dairies. Combining advanced oxidation, cleaning and reuse of condensate with anaerobic digestion will further increase the eco-efficiency - in particular for the climate change impact category- and this option (not assessed in the case study) may be the best overall choice for a technology scenario for milk powder producing dairies.

The installation of the technologies or a combination of technologies will increase the total net economic output (NEO), see Table 7. For the dairy, the NEO increases for all technologies and combinations of technologies, while the NEO only increases for the wastewater treatment operator and is either reduced or kept constant for the other technologies and combination of technologies. In fact, the increased NEO for the dairy results only partly from the decreased cost which the dairy has to pay for its water supply and wastewater treatment services to the water utility, as increases in NEO are also a result of reduced energy costs and other costs related to the operation of the dairy.

Table 7. Net economic output of baseline and combined technologies

Net Economic Output	Baseline	Anaerobic digester combined with Advanced Oxidation	Anaerobic digester combined with Advanced Oxidation and product and water recovery	Product and water recovery combined with cleaning and reuse of condensate	Advanced oxidation combined with cleaning and reuse of condensate
Water supply operator	882.569	404.928	404.928	660.051	224.817
Dairy	26.819.011	29.428.735	29.381.571	29.460.539	29.482.346
WWT operator	2.133.970	1.293.874	1.229.573	2.023.500	1.272.886
Biogas plant	83.008	69.326	68.314	81.245	69.271
Transport company	283.105	283.105	283.105	283.105	283.105
Total	30.202.000	31.479.870	31.367.493	32.508.442	31.332.427

3.4 Implementation of Eco-Efficient Technologies

The implementation of the technologies is now being considered by the actors in the value chain. The installation of more efficient blowers/diffusors by the WWT operator has already been decided and implemented. The upgrading of the CIP is being considered by the dairy as this investment has a relatively short pay-back time. For the advanced oxidation, research has been initiated to develop the technology and to document that this technology can actually secure the microbial quality needed for the reuse of the water.

3.5 Policies Which Can Promote the Implementation of the Eco-Efficient Technologies

The main policy implications of the scenarios are the following: i) There is a large potential in increasing the eco-efficiency of dairy water value chains if water from the milk can replace freshwater intake. This requires that food authorities accept that the water in milk does not cause any risks to the product. At least in some countries in Europe, including Denmark, it has been difficult to obtain this acceptance, as the authorities refer to the EU requirement concerning use of drinking water. The current ongoing revisions of the BREF documents for the dairy sector must secure that the water in milk can be used to a high degree and replace intake of freshwater. ii) A number of internal water streams in the dairy plant have very low levels of contamination and could be used not only in the dairy plant but also for purposes like agriculture, injection into the groundwater zone, etc. Presently, the quality criteria and control mechanisms for doing this are discussed as part of the implementation of the "Blue Print for Water Management in EU" and it is important that the dairy industry is considered as one of the sectors with a large potential to deliver water for these purposes.

4. Conclusion

The paper presented a methodological framework for the assessment of eco-efficiency in a dairy water value chain. The analysis of the baseline situation in the water value chain provided insight into the value created in the value chain, to the environmental performance and to the weak points in the value chain, which had the lowest eco-efficiencies.

The net economic output of the industrial actor (Arla HOCO) is the totally dominating factor of the complete value chain-with the price of the raw milk resource being the single factor determining the total value added of the entire system. Minor changes in the price of raw milk can completely change the TVA of the system-and as such the eco-efficiency indicators calculated.

Regarding the environmental and eco-efficiency performance of the system, the main weak points are the eutrophication and the acidification impact categories. However, both of them are mainly due to the background processes. The other two indicators with relatively low values, caused by the foreground system, are the climate change and freshwater resource depletion. Thus, technological solutions have been examined in order to reduce water and fossil fuels consumption in the dairy industry.

The implementation of anaerobic pre-treatment and advanced oxidation and more efficient blowers in the wastewater treatment plant showed the highest improvements of eco-efficiency for climate change and water resources depletion and also either improved the other seven eco-efficiency indicators or left them at the same level as the baseline. Implementing only the anaerobic pre-treatment or advanced oxidation, however, resulted in an improvement of the indicators almost similar to the combined technologies measured as climate gas and water resources depletion.

The installation of the technologies or combination of technologies increases the total net economic output. For the dairy, the NEO increases for all technologies and combinations of technologies, while the NEO only increases for the wastewater treatment operator and is either reduced or kept constant for the other technologies and combination of technologies. In fact, the increased NEO for the dairy results partly from the decreased cost which the dairy has to pay for its water supply and wastewater treatment services to the water utility.

The implementation of the technologies is being considered by the actors in the value chain. The installation of more efficient blowers/diffusors by the WWT operator has already been decided. The upgrading of the CIP is being considered by the dairy, as this investment has a relatively short pay-back time. For the advanced oxidation, it has also been decided to apply for funds to document that this technology can actually secure the microbial quality needed for reusing the water.

Furthermore, the analysis indicates that the methodology provides useful results which can make a useful contribution to decisions concerning installation of technologies which are eco-innovative, providing both an increased economic output and environmental performance.

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Glossary

Term	Definition
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.
Characterization factor	Factor derived from a characterization model which is applied to convert an assigned life cycle inventory analysis result to the common unit of the impact category indicator.
Eco-efficiency	Aspect of sustainability relating the environmental performance of a product system to its product system value
Eco-efficiency indicator	Measure relating environmental performance of a product system to its product system value
Elementary flow	Material or energy entering the system being studied that has been drawn from the environment without previous human transformation (timber, water, iron ore, coal), or material or energy leaving the system being studied that is released into the environment without subsequent human transformation (e.g. CO_2 or noise emissions, wastes discarded in nature).

Term	Definition
Endpoint method	The category endpoint is an attribute or aspect of natural environment, human health, or resources, identifying an environmental issue giving cause for concern. Hence, endpoint method (or damage approach)/model is a characterization method/model that provides indicators at the level of Areas of Protection (natural environment's ecosystems, human health, resource availability) or at a level close to the Areas of Protection level.
Environmental impact	A consequence of an environmental intervention in the environment system.
Environmental performance	Measurable results related to environmental aspects
Function	Performance characteristics of the system being studied. A system may have a number of possible functions and the one selected for a study depends on the goal and scope of the analysis.
Functional unit	The functional unit names and quantifies the qualitative and quantitative aspects of the function(s) along the questions "what", "how much", "how well", and "for how long".
Impact category	Class representing environmental issue of concern e.g. climate change, acidification, ecotoxicity etc.
Impact category indicator	Quantifiable representation of an impact category e.g. kg CO2-equivalents for climate change.
Indicator	A numerical value representing an issue (e.g. climate change) which is typically based on parameters of different quantities (e.g. values of CO2. and CH4).
Life cycle assessment (LCA)	The assessment of every impact associated with all life stages of a product, from raw material extraction, over production, selling and application and up to disposal or re-use, often in comparison with another, competitive product.
Life cycle impact assessment (LCIA)	The third phase of an LCA, concerned with understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study.
Midpoint method	The midpoint method is a characterization method that provides indicators for comparison of environmental interventions at a level of cause-effect chain between emissions/resource consumption and the endpoint level.
Multifunctional process	Process or system that performs more than one function, e.g.: processes with more than one product as output (e.g. NaOH, Cl2 and H2 from Chloralkali electrolysis) or more than one waste treated jointly (e.g. mixed household waste incineration with energy recovery).
Reference flow	The flow to which all other input and output flows (i.e. all elementary flows and non-reference product and waste flows) quantitatively relate.

Term	Definition
Resource efficiency	An overarching term indicating the general concept of using less resources to achieve the same or better outcome (resource input/ output). It is an input-output measure of technical ability to produce "more from less".