EnReMilk

Title: Integrated engineering approach validating reduced water and energy consumption in milk processing for wider food supply chain replication

Final Publishable Summary

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The research leading to results in this project receives funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n°613968.

1. EnReMilk Project executive summary

The main objective of EnReMilk project was to achieve significant water (30 %) and energy (20 %) savings in representative dairy processing case studies, namely mozzarella and milk powder production, replicable in both SME and larger dairies. For this purpose, many technologies were developed in laboratory and pilot scale and their performances were evaluated in accordance to the successfully achievement of these objectives. The description of these technologies and their results are indicated in the different work packages explained in Section 3 of this report.

The following case studies and process scenarios were selected:

PRODUCTION OF SKIMMED MILK POWDER (SMP)	PRODUCTION OF ACIDIC QUARK POWDER	PRODUCTION OF SWEET QUARK POWDER	PRODUCTION OF MOZZARELLA
• Baseline SMP production • Pressure Chante Technology (PCT) for pasteurisation • Superheated Steam Technology (SHS) for Spray Drying and Pre-concentration • Closed Loop (CL) Technology for Spray Drying and Pre-concentration	• Baseline of acidic quark powder production • Microwave Technology (MW) in pre-heating for acid quark powder	• Baseline of sweet quark powder production • Microwave Technology (MW) in pre-heating for sweet quark powder	• Baseline of mozzarella production • Extruder Technology

The general results, based on the water and energy savings are explained at the end of section 3 (Figure 14 to 17) in this report. From these results, it can be concluded that there is a trade-off between the use of electricity and fossil fuel in most cases. The net impact of the technologies can only be calculated when the overall process is analyzed under different operation conditions. For instance, the use of microwave significantly reduces the number of cleaning cycles. New estimations considering different variants to optimize water and energy consumptions still need to be conducted. It is also recommended to calculate mix models, where one or more technologies are replaced by the proposed innovations.

The main impacts of this project, based on environmental and socio-economic impacts are explained in Section 4 of this report.

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2. Summary description of the project context and the main objectives

The food and drink industry is one of the major industrial sectors worldwide and it is known as a heavy user of water and energy. With 13% of the total European Food and Drink industry turnover in 2012, the dairy industry is considered one of the most important sub-sectors as well as and one of the highest energy and water consumers, both overall and per unit production: up to 6.47 MWh (5.55 MWhth and 0.92 MWhel) and an average of 2 m^3 of water per tonne processed milk. EC studies have reported that more than 80% of energy consumed in dairies is related to process heating, pasteurization, sterilization, drying and cleaning operations and that 98 % of the fresh water used is of drinking water quality.

Increasing awareness of the environmental implications of dairy industry's activities has resulted in several initiatives on long-term sustainability strategies to reduce environmental impacts. Dairy companies have recognized the potential economic benefits that can be achieved by implementing water and energy saving strategies as well as waste and waste water management systems. Accordingly, it has been acknowledged that significant saving achievements require investments in technology development and innovation to deliver substantial improvements

The EnReMilk project addressed the need to reduce energy and water consumption along the entire supply chain of the dairy industry. Because more that 70% of wastewater and over 90% of energy consumed along the entire supply chain are generated at the dairy processing plant, this project focused on milk processing operations. The aim was to achieve significant water (30 %) and energy (20 %) savings in representative dairy processing case studies, namely mozzarella and milk powder production, replicable in both SME and larger dairies. These savings were validated against a consumption baseline of existing operations, being validated in model simulations and in physical trials. Emerging and novel engineering technologies were optimised and implemented in key dairy unit operations to provide significant and simultaneous saving of water and energy, while ensuring food quality and safety. The project aims were achieved by:

- Identifying and monitoring water and energy consumption patterns of along the entire supply chain,
- Modelling and simulations to evaluate savings potential of a vast array of technological scenarios,
- Optimizing selected technologies in case studies with highest water and energy saving potential,
- Optimizing resource supply and use strategies, and

- Ensuring benefits for food producers and equipment manufacturers, while reconciling sustainability imperatives.

The EnReMilk project ensured a smooth translation into practical implementation, providing an innovation-driven increase in the competitiveness of the EU dairy sector. In addition, this project ensured that engineering innovations were verified as environmentally sustainable, economically viable and socially responsible, and that food quality and safety was not compromised.

Project overview and specific objectives

An overview of main project activities is shown in Figure 1.

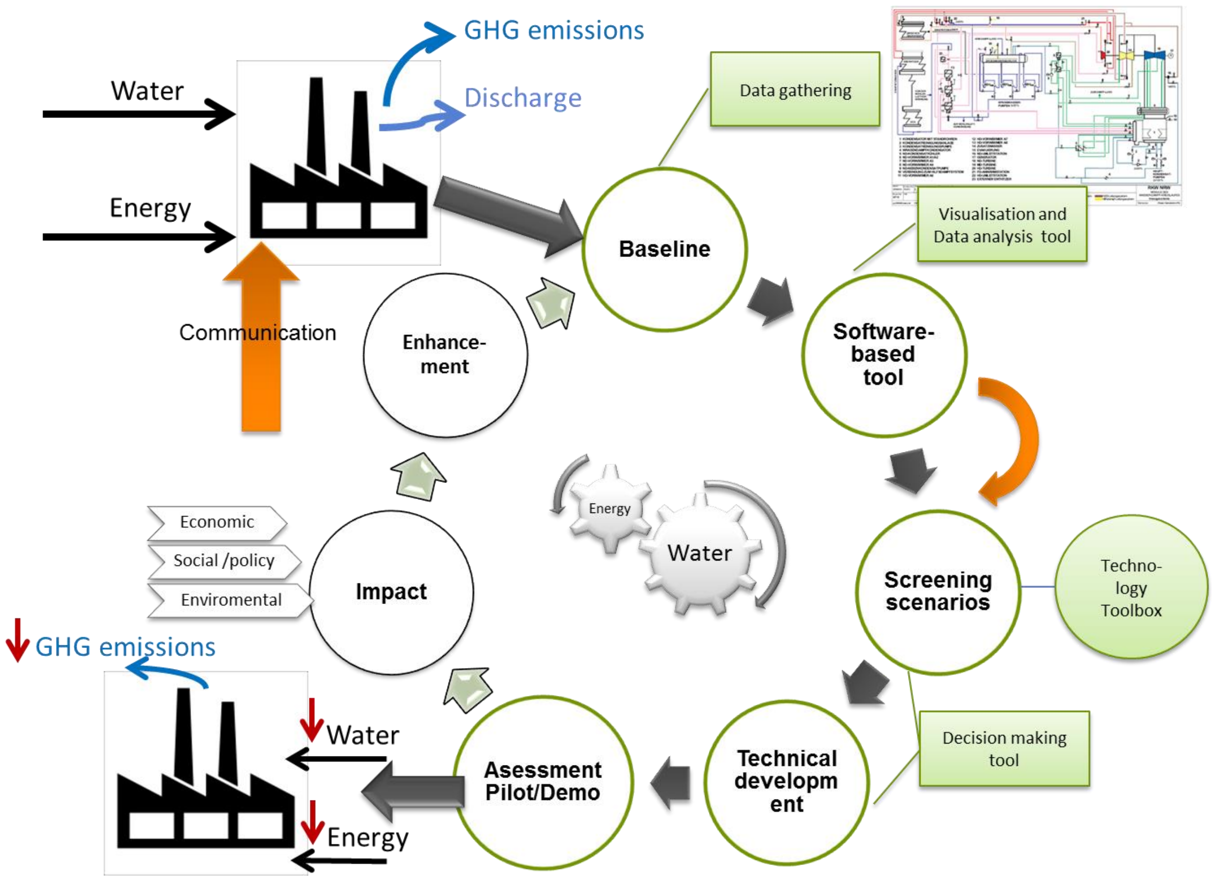

Figure 1: Overview of EnReMilk project activities

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Activities comprised the gathering of existing data to create a baseline of the water and energy consumption in the selected case studies. For a systematic data collation and further analysis, a software-based tool was required. The latter enabled process modelling to evaluate technological scenarios considering the use of novel technologies to replace current process operations at previously identified "hot spots" (in terms of water and energy consumption). Process modelling was based on knowledge-based assumptions and aimed at identifying savings potential of a specific technology in a defined context (process step in a production line). Accordingly, technology requirements were specified for the process and the specific conditions defined by each case study. This was a pre-requisite to validate the performance of the selected technologies for the specific process operations, which were clustered in microbial stabilization, heating, texturizing and drying operations. Furthermore, investigation of a wide array of process effluent treatment and water reuse technologies has been conducted. Studies were initially conducted at laboratory level for initial verification, followed by pilot studies for process assessment and implementation of required adaptations. Pilot studies were designed to confirm laboratory studies, enhance system configurations and evaluate the performance of the technology for the desired application. The latter was aimed to support the evaluation of actual potential of the proposed technologies and to enable decision making for further industrial implementation. Consequently, only most suitable, validated technologies and applications were further demonstrated at industrial sites. On the whole, the EnreMilk project includes decision-making tools for further development and implementation of technologies based not only on technological assessment but also on the economic validation of them. The innovation of this project consists on the evaluation of the introduction of new technologies in an existing system including a justification based on economic, environmental and social impacts, which are interlinked and assessed in their whole extension.

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3. Main S & T results/foregrounds

This report provides a general overview of the work performed by work package and summarizes the key findings of the project in terms of overall water and energy savings of the proposed technologies and innovation scenarios for the selected case studies. The overall economic, environmental and social impacts are also discussed.

WP2 Process Modelling:

During this work package a vast array of technological scenarios to optimise water and energy consumption through the incorporation of novel engineering approaches in the production of mozzarella and milk powder was evaluated through modelling. A software-based tool to create simulation models computing water and energy consumption in two representative dairy processing operations, mozzarella and spray-dried milk production was employed: this tool enabled the innovative water and energy saving technology benefits to be simulated prior to validation in pilot and demonstration activities, allowing iterative enhancements. This work package was completed during the first reporting period. The main results are:

- Baseline scenarios were specified in terms of input, output, and production process
- Mass and energy flows have been characterized, the results of which provided the structure for the database to be developed;
- A database has been developed and filled with data provided by data obtained from sampling points located at case-studies facilities (task 3.1).
- A multi-level hierarchical structure of the production process, including water and energy flows at three aggregation levels, (the highest level being a specific process e.g. pasteurize liquid), was designed;
- E-sankey was selected as a suitable tool for visualization of mass and energy flows.
- Five alternative scenarios in addition to the baseline scenarios were defined for the milk powder and mozzarella. Each of them was quantitatively modelled and analyzed for its possible energy and water saving potential relative to the baseline scenario.
- Modelling results of the baseline and alternative scenarios were validated, and possible consequences other than energy and water consumption (e.g. economic performance, labour conditions, air pollution, product quality, etc.) were identified.

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WP3 Consumption Monitoring and Process Management:

During this work package, a baseline consumption of water and energy of currently employed State-of-the-Art technologies was recorded. A smart metering methodology for water and energy consumption (hardware and software) is developed and implemented. Information was used to develop a global process management strategy that allowed optimizing the consumption of water and energy and to conduct further comparisons with proposed technology innovations. This work package was completed during the first reporting period. The main results are:

- Baseline energy and water consumption assessment of milk and mozzarella process were completed.
- Installation of new sensors that allowed monitoring the key points for the baseline energy and water consumption was finalized.
- The software tool was developed and successfully applied to both milk and mozzarella processes allowing assessment of the baseline energy/water consumption as well as further comparisons at a later stage.
- A software tool for global process management was developed and successfully applied to the milk and mozzarella processes.

WP4 Milk Processing:

- During this work package, the various unit operations and processing conditions identified through the simulations were practically replicated on a laboratory scale. The quality of the outputs was assessed and the water and energy consumption verified. The optimal process parameters and design configurations for a non-thermal microbial stabilization process (Pressure Change Technology, PCT), a microwave pre-heating system for milk concentrates, and a single-screw extruder for plasticization and texturisation of pasta filata type cheese were found. This practical work provided feedback to enhance the model developed in WP2. Requirements for upscaling and validation at pilot scale have been derived.

Key results:

Pressure Change Technology for milk pasteurisation

- Shelf life of pasteurized skim milk remained similar to thermal pasteurization, fulfilling the EC regulations. A significant inactivation of enzyme lipase (>40%) and microbiological stability for at least 6 days were achieved.

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Microwave Heating

- An experimental design for selected products - quark and yogurt- preheating was setup including the parameters microwave power, temperature of inflowing product and flow rate of product. Time-temperature raising profiles were monitored and compared with the conventional steam heating.
- Heating performance was clearly enhanced with the microwave heating due to rapid, volumetric and targeted heating of food products, thus increasing overall process efficiency.
- Key observations:
    - No significant fouling after microwave heating
    - Quark powder production throughput was increased by 11% due to the controlled pre-heating.
    - Reduction of CIP cycles (water, electricity, chemicals), saving 75% of CIP (clean in place) consumption for quark and 83% for yogurt. This enabled longer production periods between CIP cleaning
    - homogenous quality of product after MW heating and subsequent spray-drying
    - low level of meso- and thermophile spores

- Based on experiments, modifications of the unit to optimize performance have been delineated and implemented in WP7.

Figure 2: Microwave heating unit

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Single-screw extruder

- Key quality parameters, including dry matter, fat content and optical appearance of the mozzarella were evaluated; first assessment and sensory tests revealed that a good quality of mozzarella was obtained.
- UHOH conducted a series of experiments with the lab-scale single screw extruder. The primary aim of the experiments was to optimize the kneading section, by testing different kneading geometries, residence time and optimal process temperature to obtain adequate product composition and texture.
- Adaptation requirements and implementation of various configurations were evaluated for upscaling. Differently designed screws were built-up and tested in order to optimize the texturisation performance.

Figure 3: Production of Mozzarella using single-screw extruder at laboratory level

Further results

- The key variables to be monitored were defined for each technology and a database for data collection and exchange was created.
- Mass and energy balance of the process have been collected and updated during this task. E-Sankey Diagrams for visualization were uploaded to the internal project database.
- A preliminary consumption interface system was defined, according to the variables and process parameters identified during laboratory trials.

The findings of this work package were used to develop corresponding pilot-scale units for WP7.

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WP5 Process Effluent Treatment and Water Reuse:

This work package aimed to develop an efficient and self-sustained wastewater treatment strategy to close the water cycle by integrating water and management, enabling water to be reused within the dairy production process "fit-to-purpose" (e.g. cleaning operations) and residues to be extracted for further valorisation (e.g. whey proteins). It also aimed to ensure that the process effluent treatment and water reuse concept was designed according to requirements of SME and larger dairy operations. As a result of this WP activities, outcome streams from mozzarella and milk powder production were collected and characterized. Strategy to treat and recycle selected streams was elaborated. The most relevant (waste-) water streams from Mozzarella production at G.C.M. were identified according to the following criteria: (i) Amount of wastewater, (ii) current costs for disposal, (iii) potential for re-use as process, drinking water, or for cleaning operations (iv) potential for recovery of valuable materials. Clearly significant results of this WP were:

- Two main (waste-) water streams in mozzarella production were selected: a) pre-cooling water which represented about 70% of the total water effluents and; b) the "scotta" effluent from ricotta and cream production which was considered as a potential source of valuable protein.
- Concept to recover proteins from "scotta" using electro membrane filtration (EMF) technology was developed.
- "Pre-cooling" water treated with electro-oxidation (EO) technology could reach target COD values for recirculation into the process (e.g. for cleaning operations) and was attractive for cases where disposal without treatment was not possible.
- The key variables to be monitored were defined for each technology and a database for data collection and exchange was created.
- Mass and energy balance of the process were collected and updated during this task. E-Sankey Diagrams for visualization were uploaded to the internal project database.
- The consumption monitoring system was developed using LabView. In addition, an Excel-based system was developed for cases where the pilot plant was controlled directly by the PLC, to avoid compatibility issues. Both systems allow to obtain the defined performance indicators of the process.

The findings of this work package were used to develop corresponding pilot-scale units for WP7.

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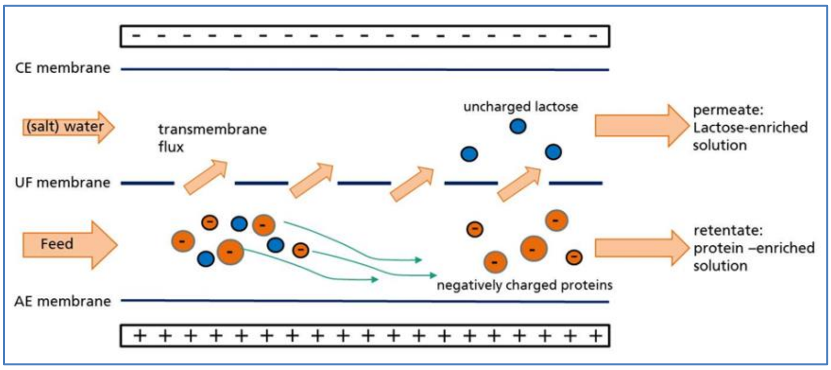

Figure 4: EMF system for the recovery of protein and lactose-enriched solutions

WP6 Drying:

During this work package the optimal process parameters and design configurations for superheated steam drying (SHSD) and closed loop spray drying (CL) of concentrated milk, enabling the targeted residual moisture content of below 5% and lowest energy and water consumption were defined. An equivalent product quality (microbial and organoleptic) to that achievable by using spray drying technology with hot air was verified. This practical work was used as feed back to WP2 for enhancing the process model and to WP3 for refining consumption monitoring. During this work package first experiments were conducted at the University of Hohenheim and necessary modifications on the laboratory-scale Closed Loop (CL) drying unit were undertaken to achieve the desired product quality attributes. Further activities included:

- Designing and building a chamber for spray drying of concentrated milk with superheated steam at atmospheric pressure.
- Conducting trials for comparisons with a standard powder provided by S-Milch.
- Implementing data acquisition system to evaluate energy consumption.
- Configuration of technology scenarios using Sankey-diagrams for mass and energy flows to enable subsequent data collection during validation studies at pilot level.

The findings of this work package were used to enhance the design of the units for WP7.

WP7 Pilot Study

During this work package, various unit operations from both mozzarella and dried skim milk case studies were up-scaled to pilot units of a relevant size or adapted according to process requirements, optimal design configurations and findings derived from the laboratory studies conducted in WP4, WP5 and WP6.

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In most cases, technologies were iteratively enhanced and performance and production trials were conducted. The quality of the products or outputs was evaluated, process model updated and the overall water and energy consumption assessed. The latter enabled data collation for further analysis on economic, environmental and social impacts.

The performance and quality trials of each technology is summarized below:

Pressure Change Technology

- Continuous system was adapted to enable aseptic filling of the treated product (Figure 5)
- It was confirmed that cold pasteurization of skimmed milk using PCT (<25°C using Argon or Nitrogen as process gas) was comparable to thermal pasteurization (71,7°C for 15 s), both requiring cool storage not exceeding temperature of 6°C immediately after treatment (Council Directive 92/46/EEC Commission Document 392L0046)
- Microbiological studies showed that PCT treated skim milk can be stored for up to 6 days as an intermediate product in dairy plants. Skim milk maintains its “freshness” during storage and can be further used for a variety of milk products.
- This case study as well demonstrated that using the PCT technology energy input can be reduced by up to 50 % in comparison with classical pasteurization.

Figure 5: Pressure Change Technology (PCT) pilot unit

Microwave Heating

- Microwave pre-heating unit was refurbished according to results obtained in WP4 (Figure 6). Iterative enhancements of the pre-heating unit enabled process stability and homogeneous heat input to the product, confirming an increase in temperature of up Δ50 °C without problems, no fouling formation and a significant reduction of shut-down times for cleaning operations.

Figure 6: Microwave pre-heating unit

- Pre-heating operation prior to spray drying using microwave technology resulted in slight changes in final products: powder obtained was finer, taste and color of powder was slightly influenced, bacterial count in the yogurt and quark powder was significantly reduced.
- According to previous results, the main advantages of microwave technology were the elimination of fouling and the subsequent significant reduction of cleaning efforts. Thus, a new, flexible, multipurpose pilot unit (double reactor) for pre-heating, pasteurization and sterilization at temperatures up to 140°C and flow rates of up to 1000l/h (including energy recovery system (regeneration) for implementation in various process scenarios has been developed and commissioned (Figure 7)

Figure 7: Microwave multipurpose unit (double reactor) for pre-heating, pasteurization and sterilization.

- Theoretical estimations for and cooling high viscous products like milk concentrates or fruit preparations using state of the art technology resulted at a rate of 1000 l/h and a total power required for the energy source of 333 kW. With the new microwave and heat regeneration system a total save of 123 kW on heating and 123 kW on cooling was obtained, meaning energy savings of **73.8%.** These savings still require validation during post-project activities.

Single-screw extruder

- Continuous production of pasta-filata cheese by single screw extruder was developed based on rheological experiments (gel-sol temperature; critical shear strain) process parameters established in WP 4. Temperature control was adapted to match the sol-gel transition temperature (~ 58 °C).
- Scale up of single screw extrusion from ~15 kg/h to ~150 kg/h (approx. 1200 L/h milk input) was done (Figure 8).
- During extrusion no water input was necessary until cooling step and the energy consumption was about 150 to 200 kJel/kg product.
- Large scale extrusion provided pasta-filata cheese containing 47.8 % dry matter and protein > 26.6 % matching the target values and the quality parameters of small scale extruded cheese. However, Fat-in-DM content was at 38.8% was significantly lower than expected.

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Figure 8: Large scale extrusion of cagliata in the facilities of the Dairy for Research and Training (University of Hohenheim); top: filling section, middle: extruded pasta-filata strand, bottom: stretching of pasta-filata.

Spray-Drying technologies:

1. Closed loop

- The setup was adapted on some critical parts to perform trials with concentrated milk under high humidity conditions. Additional insulation was applied and trials under high humidity were performed.
- Earlier trials showed that fouling at the product exit was critical. A new drying chamber outlet were designed and built.
- The obtained powder from the closed loop trials and the industrial reference form S-Milch were analyzed regarding particle size distribution, water content, solubility, contact angle and particle morphology.
- Trials with increased humidity to increase the dew point temperature showed, that it was possible to dry skimmed milk concentrate (35% dry matter) with a dew point temperature inside the drying chamber of 70.7 °C. The quality of the obtained powder was comparable to the industrial reference product.
- A promising potential for energy saving in combination with heat pump technology could be concluded. Therefore, this application should be considered for high volume products such as skimmed milk powder

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Superheated steam spray drying

- SHS-spray-drying PLC and data acquisition system were updated to enable not only a stable start up, steady state and shut down procedure but also to record data on process performance and energy consumption.

Figure 9: Super-heated-steam spray-dryer after several modifications during project

- It could be shown that with superheated steam drying energy savings in envisaged amount were feasible on large scale. However, the product quality of the industrial reference skimmed milk powder could not be matched.
- The application of superheated steam technique for commodity skimmed milk powder, which stands for high volumes in dairy and hence for substantial energy consumption is not recommended.
- Nevertheless, the application test of this project has demonstrated interesting product qualities regarding specialty products.

Electro-membrane filtration for protein recovery

- The EMF was aimed to treat the "Scotta" effluent from the Mozzarella production at G.C.M. for two purposes:
  - Enabling cheap disposal of the wastewater, and especially
  - Recover whey proteins from the waste water.
- A concept to obtain two main fractions: "lactose-enriched" and "protein-enriched" fractions was developed and tested. However, the lab scale performance tests did not show reliable performance of the EMF process.
- It was concluded that the separation of large molecules (proteins) in high purities from a complex matrix, requires more technical and scientific work in post project activities. No further calculation on energy consumption was performed.

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Electro-oxidation for waste water treatment

- "Pre-cooling water" from mozzarella manufacturing was selected for treatment using electro-oxidation (EO) technology since it represented more than 70% of the water consumed during the process.
- A Pilot unit for EO was built and integrated with pre and post-treatment units (e.g. pre-filtration, activated carbon filter and UV treatment) acquired for the project.

Figure 10: Electro-Oxidation Pilot Unit with post-treatment units

- Trials conducted showed that pre-filtering of effluent was necessary to avoid deposits in the electrodes. The latter significantly reduced the content of COD in the treated pre-cooling water from mozzarella production. Thus, the use of this technology cannot be economically justified in small-scale cheesemaking factories.

Further activities conducted within WP7

New insights that have evolved from this work package led to enhancements of the process model developed in WP2. This involved updates in the process descriptions of the presented scenarios. For each scenario updates may involve:

- Enhancements in the configuration of the scenario
- Enhancements in the mass balance regarding resources and products of the scenario
- Enhancements in the energy balance of inputs and outputs of the scenario

Subsequently, the enhancements impacted the views in which the cumulative results of the process scenarios were visualised. For each scenario the following visualizations of process characteristics were relevant:

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- The amount of water consumed
- The amount of input fuel burned
- The overall loss of thermal energy
- The volume of electricity consumed
- The amount of product and by-products produced

Diagrams can be visualised for each technology as well as for state of the art (baseline) in the project internal database (http://www3.lei.wur.nl/enremilk/Data.aspx)

This data is the basis for further analysis performed in WP11 (Life Cycle Analysis). An overview of key results is also presented in this final report.

WP 8 Demonstration

This work package aimed at implementing the outputs of WP7 in industrial operations (milk powder and mozzarella) in order to monitor water and energy savings under real manufacturing conditions. Moreover, it aimed at demonstrating technologies during their operation to visitors and potential customers.

The following technologies were demonstrated:

- Microwave heating technology for pre-heating (prior to spray-drying) (S-Milch, Germany)
- Single-screw extruder for mozzarella manufacturing (G.C.M., Italy)

Key results of these activities are:

- Earlier experiments and process parameters were successfully transferred into industrial scale enabling the production of pasta filata products by single-screw extrusion.
- Microwave technology has been successfully transferred into industrial scale. Achievements and limitations of microwave heating used in the S-Milch factory have been evaluated.
- Product quality is very good, but acceptance will depend on customer requirements. These issues were discussed with visitors and potential customers during an Open-day demonstration conducted on November 8th 2017.

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Figure 11: Pictures of visit and live demonstration event at S-Milch, November 2017

- Product quantity (e.g. dried acid quark) increased by 12,3% when Microwave pre-heating step was introduced in the production line. At the same time, electric energy consumption increased by 39,6%. Nevertheless, a 5-day campaign with no cleaning intervals saved ca. 17 KWh electric energy, 130 Kg steam and 11 m^3 of water as compared to cleaning intervals every 36 hrs.

WP9 Economic Validation

This work package was designed to ensure the development of an economically sustainable business and exploitation strategy of the project results (WP12). The Opex (operating expenditure) and Capex (capital expenditure) of the various milk processers (technology implementers) and the revenues generated by the equipment suppliers (technology providers) were validated. An optimal business deployment strategy (size and localisation) was prepared. Financial mechanism that can be applied in different regions of Europe was selected. An integrated financial and business package to support the wider deployment of the innovations was prepared.

Primary data was collected from dairy processing firms in 3 countries: Spain, Germany and Italy. The primary objective of the survey was to collect data on i) diary firm innovation orientation, ii) dairy firm environmental orientation and iii) pay-back period expected after the adoption of eco-innovations. The main conclusions are:

- To be attractive to potential adopters, EnReMilk technologies must achieve clear, demonstrable cost-savings for adopters.
- Pay-back period for investment in EnReMilk technologies cannot exceed 3 years

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Further socio-economic aspects analysed in this work package will be discussed in the next section of this report.

WP10 Social impact and policy

During this work package, widespread knowledge and evaluation of the acceptance of the EnReMilk innovations as good environmental practices at policy makers and consumers levels were conducted. In order to understand the acceptance of new technologies in relation to environmental performances, health and safety issues social and market dynamics with regard to the adoption of innovation at firm level were analyzed.

A survey on mozzarella producers was conducted to analyze energy consumption, main innovation adopted in order to reduce energy and water consumption and waste production, the adoption of environmental management tools and certifications, main investments realized in the field of energy and water management.

Labelling/branding tools for the products in order to increase awareness of the consumers and to achieve price premiums to the environmental innovations were assessed. In order to ensure that the innovations are also compliant with regulatory requirements in all EU-27 member states and that they are spread in food industry, policy measures were defined.

For sustainability assessment 7 attributes and with corresponding indicators were proposed according to feasibility, data availability and relevance. A graphic representation of the utilized criteria is provided in the Figure 12 below.

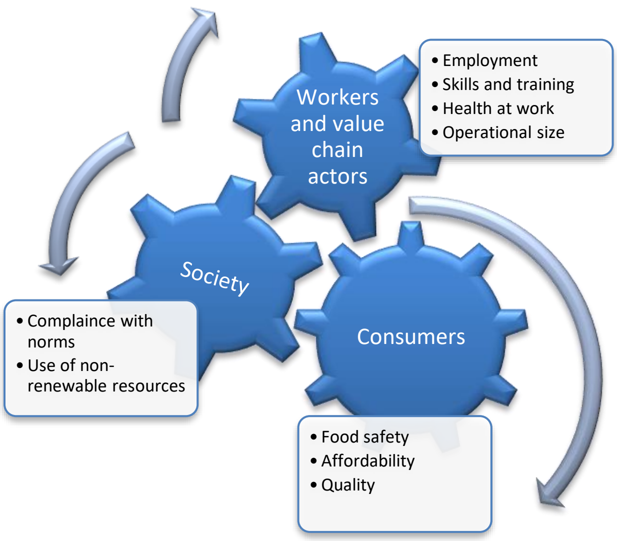

Figure 12: Criteria for sustainability assessment

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WP11 Environmental sustainability

In this study an environmental impact assessment was done based on a Life Cycle Assessment (LCA). LCA is a technique to assess potential environmental impacts associated with all the stages of a product "life", from sourcing the required raw materials from nature to its waste treatment. The four steps of this approach are shown in Figure 13.

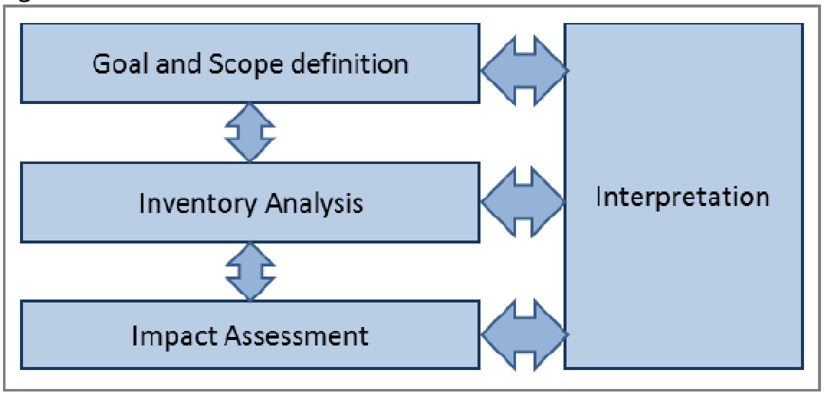

Figure 13 The four steps in a LCA according to ISO standard 14044

Overview of approach applied for this project is provided below:

Goal & Scope Definition

- To identify the environmental hotspots producing skimmed milk powder, quark powder and mozzarella in three distinct case study
- To compare the environmental aspects of different innovations in these production processes with respect to energy and water consumption.
- To support decisions on the selection and improvement of innovations in processing of dairy and other foods

Target audience

- The dairy processing sector, including small and medium enterprises and the project partners.
- The European Commission, who requires environmental impact assessment for project funding

Scenarios and comparisons

- The baselines and the innovations in the three cases were modelled as complete production processes (from entry of raw milk to exit of final product)
- All models were balanced in terms of energy and mass and milk dry matter.
- Each innovation was compared with the baseline of the same product.
- Ten of such models were made in total:
  - *Four scenarios for skimmed milk powder:*

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o Baseline SMP production

o Pressure Change Technology for Pasteurization (PCT)

o Superheated Steam Technology for Spray Drying and Pre-concentration (SHS)

o Closed Loop Technology for Spray Drying and Pre-concentration (CL)

- *Four Scenarios for quark powder:*

  o Baseline sweet quark powder production

  o Microwave Technology (MW) in pre-heating for sweet quark powder (during spray drying stage, before the actual spray drying)

  o Baseline acid quark powder production

  o Microwave Technology (MW) in pre-heating for acid quark powder (during spray drying stage, before the actual spray drying)

- *Two scenarios for mozzarella:*

  o Baseline

  o Extruder Technology

Functional unit and reference flow

- The mass-based functional unit was defined as "the availability for sale of 1 kg of the product (skimmed milk powder, quark powder or mozzarella) at the facility's storage"
- Reference flow simply defined as "1 kg of the product".

System boundaries

- The main inputs to the facility were included in this study: raw milk, water, electrical power, natural gas, fuel oil, and capital goods. The usage data on the inputs to the processing facility were the most important data items.
- The capital goods (factory building, including equipment) required for processing dairy were included by using secondary data to provide a basic estimation of their impact in processing. Their contribution to mineral resource depletion was major and substantial to non-renewable cumulative energy demand and toxicity impacts.
- The bacteria culture and the rennet for curdling and ripening in mozzarella production was excluded, as well as the life cycle phases of packaging, transport, consumption and end-of-life because the innovations did not affect these phases. This LCA study neither addresses the environmental impact of administration, research and development.

Life Cycle Inventory & modelling approach

- An attributional modelling approach was selected
- Input consumptions were provided by the process model provided datasets for all studied scenarios. The process model also covered the technology to generate steam

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for all dairy facilities and the consumptions of base, acid and disinfectant for CIP in the SMP and quark powder scenarios.

- The process model depicted the level of unit operations, and these were aggregated to the major process stages in the dairy facilities
- The impact of wastewater treatment (WWT) was determined by the emissions through the treated water, the direct air emissions and by energy use and other indirect impacts.

The impact of electricity was modelled by following primary data for S-Milch and EcoInvent 3.3 data for Latticini Orchideia on power generation technology mix.

Life Cycle Impact Assessment

- A broad set of environmental impact categories was preferred for this assessment to assess dominance of impacts as well as interactions between impact categories.
- From the aim of the project (to reduce energy and water use), was derived that climate change, fossil resource depletion and water use impacts are of interest for the audience. It was assessed to which extent energy use affects related impacts like acidification, eutrophication and particulate matter formation. Furthermore, the analysis enabled identification of trade-offs between environmental impact categories

Main results of LCA and interpretation (Environmental Impact) are presented in the following section.

GENERAL RESULTS: OVERVIEW OF WATER AND ENERGY CONSUMPTIONS

As already explained above, a model to process water and energy consumptions was developed in WP2 and constantly updated as technologies were developed to enable comparisons of various scenarios with the corresponding baselines. The tool developed during this project was very powerful and can be further expanded and refined. Nevertheless the data presented here is the best dataset we could obtain by the end of the project.

The following process scenarios were selected. Comparisons refer to the introduction of a single new technology in a specific unit operation of the mentioned process:

- *Production of skimmed milk powder:*
  - o Baseline SMP production
  - o Pressure Change Technology for Pasteurization (PCT)
  - o Superheated Steam Technology for Spray Drying and Pre-concentration (SHS)
  - o Closed Loop Technology for Spray Drying and Pre-concentration (CL)

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- *Production of acidic quark powder:*
  o Baseline of acidic quark powder production
  o Microwave Technology (MW) in pre-heating for acid quark powder (during spray drying stage, before the actual spray drying)
- *Production of sweet quark powder:*
  o Baseline of sweet quark powder production
  o Microwave Technology (MW) in pre-heating for sweet quark powder (during
- *Production of Mozzarella*
  o Baseline
  o Extruder Technology

Skimmed milk powder production showed non-significant energy savings when Pressure Change Technology was used for milk pasteurisation. However a decrease on water usage of 18% was observed for the PCT Technology. In terms of new spry-drying technologies, superheated steam drying consumed 15% less electricity and 11% less fossil fuel than the baseline. With respect to closed loop technology, important energy savings have been reported elsewhere.

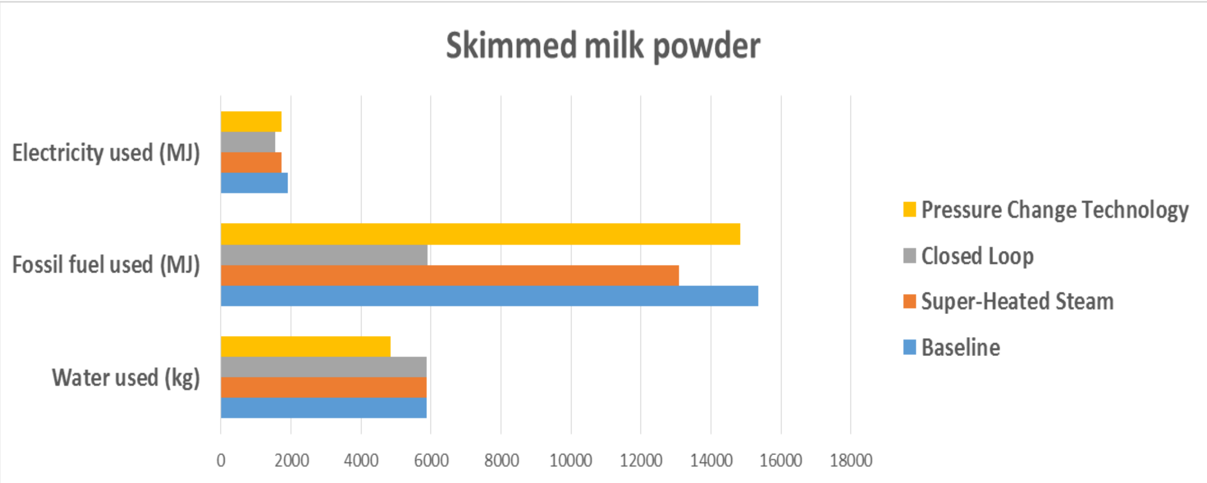

Figure14: Comparison of water and energy consumption of using Pressure Change technology, Closed Loop and Super Heated Steam drying technologies with the production baseline

Acidic quark powder production showed a significant increase of electricity usage (4,5 times more) used when microwave technology was applied (figure15). By contrast, 32% less fossil fuel was used. It has to be noticed that current calculations only evaluate direct consumptions and that the net effect including the reduction of cleaning cycles was not considered.

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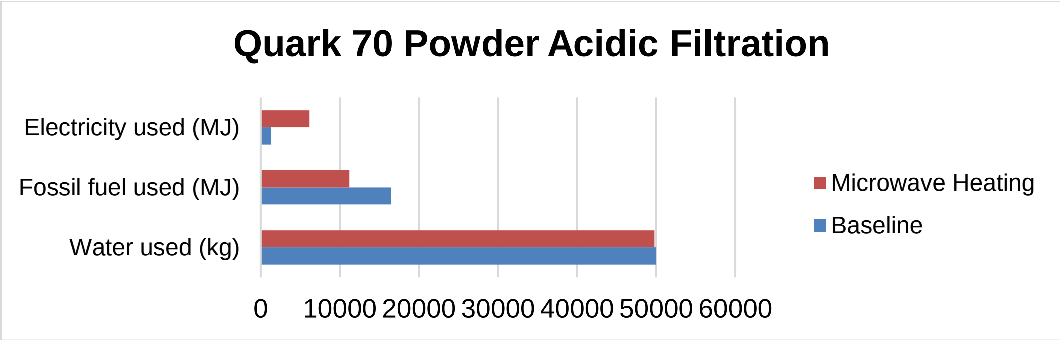

Figure15: Comparison of water and energy consumption of microwave technology for pre-heating prior to spray-drying of acidic quark with the production baseline

Similar to acidic quark powder production, sweet quark powder production showed a significant increase of electricity usage (5,9 times more) used when microwave technology was applied (figure16). By contrast, 58% less fossil fuel was used. It has to be noticed that current calculations only evaluate direct consumptions and that the net effect including the reduction of cleaning cycles has not been considered. A significant decrease of 84% on water usage was observed in this scenario.

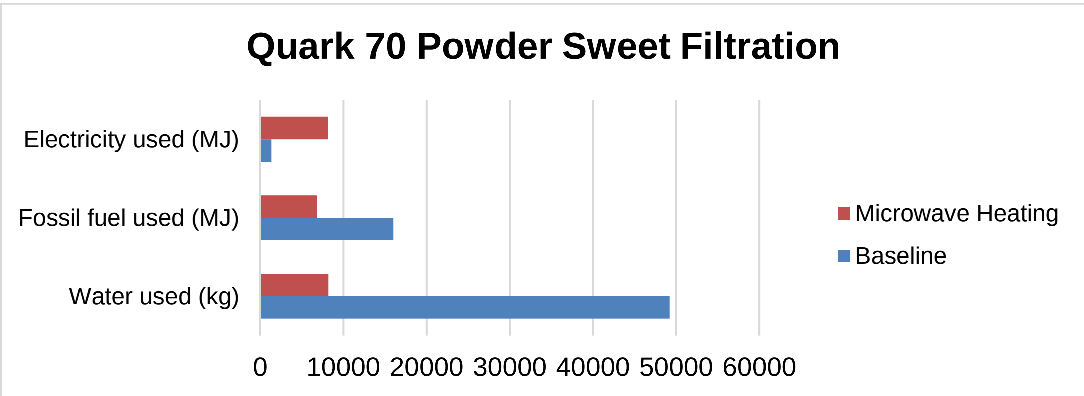

Figure16: Comparison of water and energy consumption of microwave technology for pre-heating prior to spray-drying of sweet quark with the production baseline

As shown in Figure 17, the extruder technology consumed more electric energy than the baseline production, since new technology relied on electrical devices. However, a significant decrease on fossil fuel used of 78% was observed. Decrease on water usage represented only 8%

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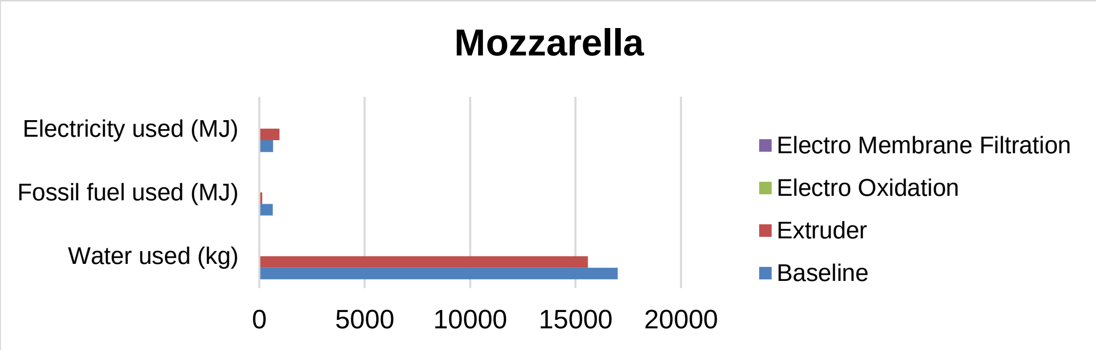

Figure17: Comparison of water and energy consumption of extruder technology for texturizing mozzarella with the production baseline

Conclusions:

From the results presented above it can be concluded that there is a trade-off between the use of electricity and fossil fuel in most cases. The net impact of the technologies can only be calculated when the overall process is analyzed under different operation conditions. For instance, the use of microwave significantly reduces the number of cleaning cycles. New estimations considering different variants to optimize water and energy consumptions still need to be conducted.

It is also recommended to calculate mix models, where one or more technologies are replaced by the proposed innovations.

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4. Description of the potential impact and the main dissemination activities and the exploitation of results

As explained previously, the savings aimed during the project life were at least 20% in energy and 30% in water consumption compared to the current production of mozzarella and milk powder. Although these savings were not achieved in all case scenarios and with all the technologies, EnReMilk achieved significant and quantifiable savings at pilot and industrial demonstration levels.

The main impacts of the results of this project are classified in environmental and socio-economic impacts:

Main Results of LCA Assessment & Environmental Impact:

Skim Milk Powder

- In SMP production, climate change was the most important environmental impact, contributing to 50% to human health impacts and more than 70% to ecosystem impacts of the dairy processing stage. Fossil resource scarcity contributed more than 99% to resource depletion impacts (Figures 18 and 19).

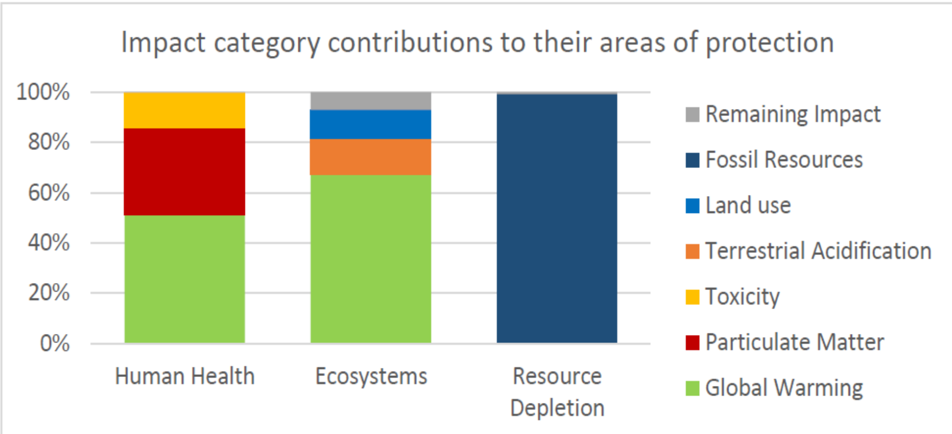

Figure 18: Distribution of environmental impacts of SMP over the three areas of protection

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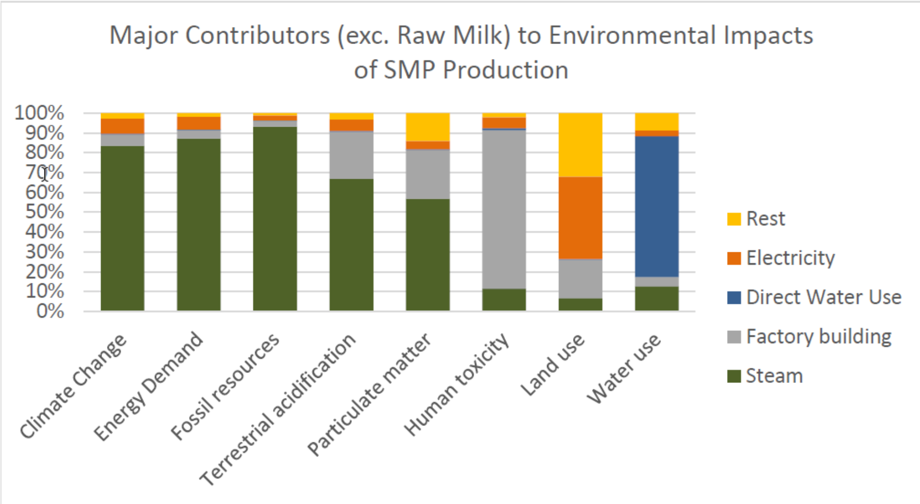

Figure 19: Major contributions to the most relevant environmental impacts of skimmed milk powder production, excluding the agricultural phase of raw milk production ("Gate-to-gate" or "Processing" Impact).

- Raw milk and steam production determined the different environmental impacts. The contribution of raw milk production represented 65 – 99 % to the most relevant 5 environmental impacts
- Spray drying innovations strongly reduced environmental impacts. Closed loop technology reduced the climate change impact by 22% (Figure 20). The steam usage in pre-concentrating and spray drying milk, the largest contributors to steam demand, reduced drastically.
- The superheated steam scenario reduced the steam demand of spray drying to zero, since all heat was supplied during pre-concentration, resulting in a reduction of 24%.

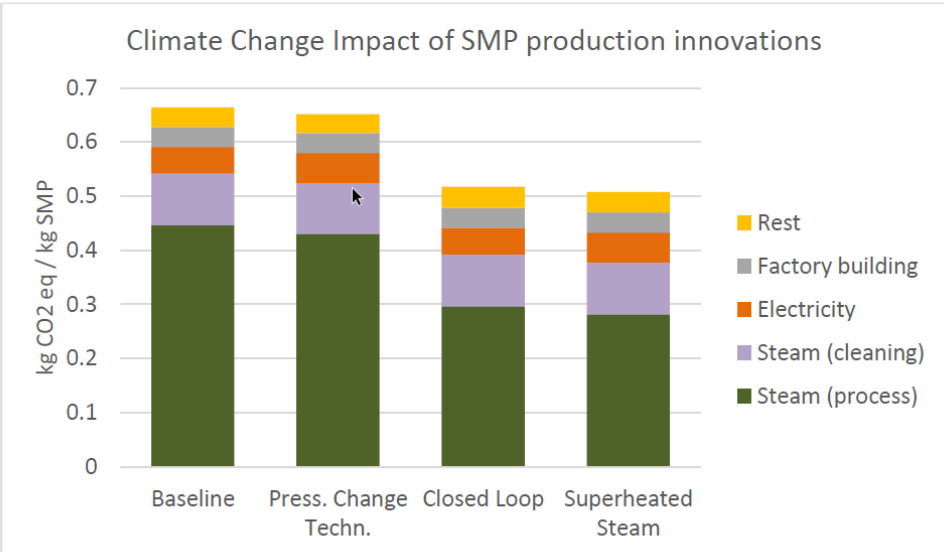

Figure 20: Climate change impact of different scenarios involving three innovations (and the baseline) in skimmed milk powder production.

- Pressure Change Technology (in pasteurization) reduced the climate change impact by 2% (Figure 21). Only half of the steam consumed during the pasteurization was consumed as electrical energy when using PCT, so that the climate change impact of

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the pasteurization energy contribution was reduced by 26%. However, the amounts of steam used for milk concentration and spray drying were much larger.

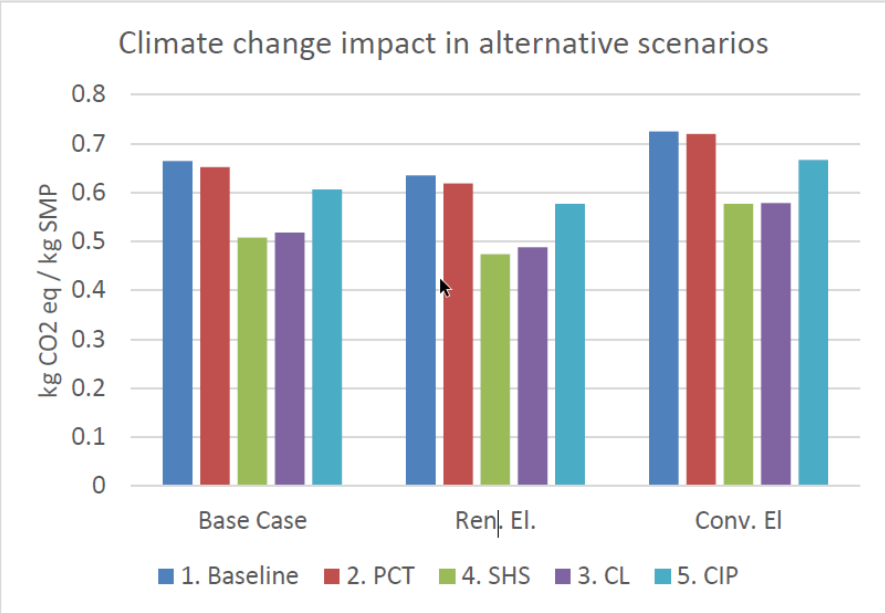

Figure 21: Changes in climate change impact of the three innovation scenarios and a scenario with a halved water and energy usages for CIP, under varying electricity mixes: Base Case corresponds to the electricity mix of S-Milch, Ren.El. is Renewable Electricity and Conv. El. Is Conventional Electricity

Quark Powder

- Microwave pre-heating technology prior to spray drying was assessed
- In quark powder production, climate change was the most important environmental impact contributing to approximately 50% to human health and 70% to ecosystems impact Figure 22.

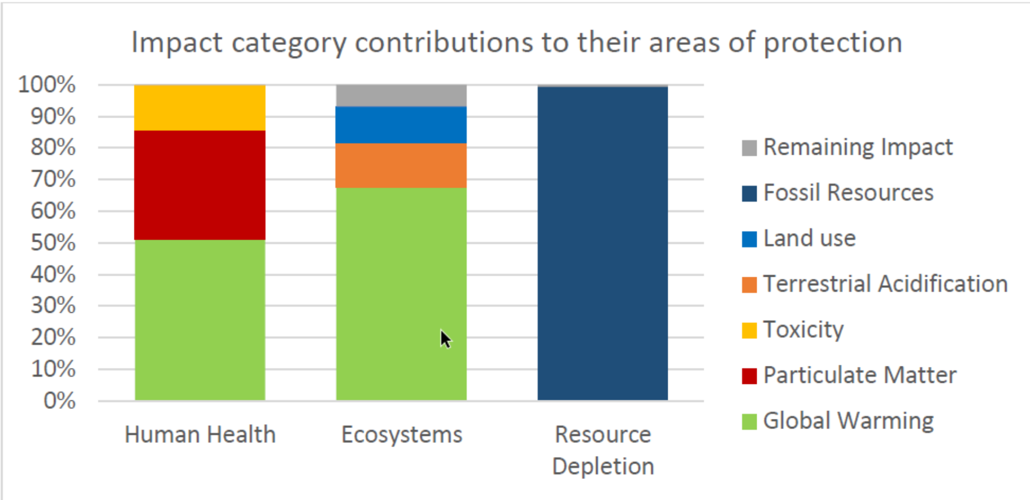

Figure 22: Distribution of environmental impacts of quark powder over the three areas of protection

- The environmental impacts were determined by raw milk and steam, like for SMP. Therefore, reductions in raw milk impact and in raw milk waste had strong effects.

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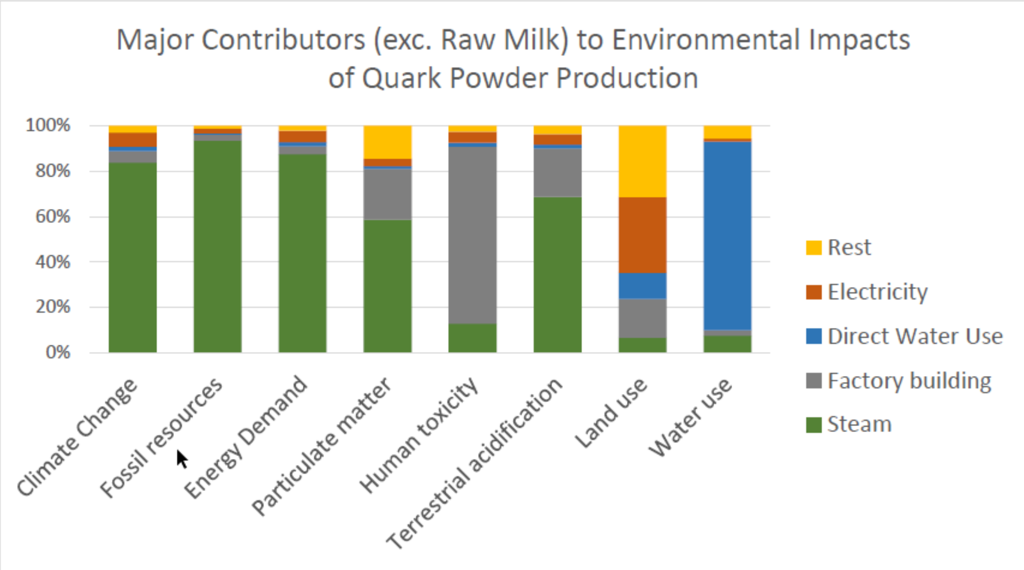

Figure 23: Major contributions to the most relevant environmental impacts of quark powder production, excluding the agricultural phase of raw milk production.

- The environmental effects of introducing microwave technology were small, since steam use for heat was exchanged with the same amount electricity. Climate change impacts (per unit of energy) of the steam and the electricity in the S-Milch facility were very similar, resulting in hardly any effect on climate change impact for both sweet quark powder (+1%) and acid quark powder (>-1%) (Figure 24).
- CIP was required twice less often for this step because fouling was reduced, but this decrease was insignificant compared to the total steam demand for CIP.

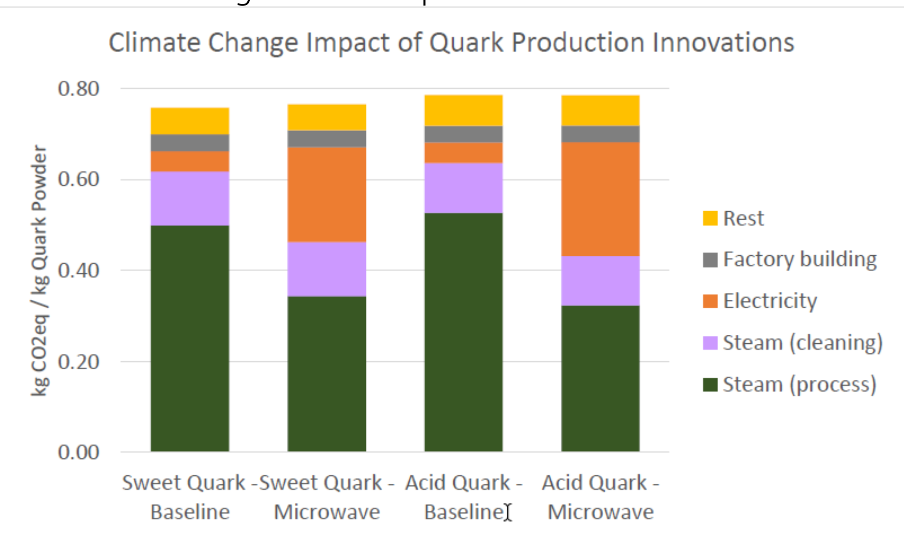

Figure 24: Climate change impact of the baseline and the microwave innovation scenario for sweet quark powder and acid quark powder production

- A change to renewable electricity without a technology change had no-to-little effect in climate change. A combination of microwave technology and renewable energy resulted in a clear reduction in the climate change impact of producing both sweet and acid quark powder. Conversely, the use of conventional electricity increased the impact and this increase was stronger after including microwave technology since more electricity was used (Figure 25).

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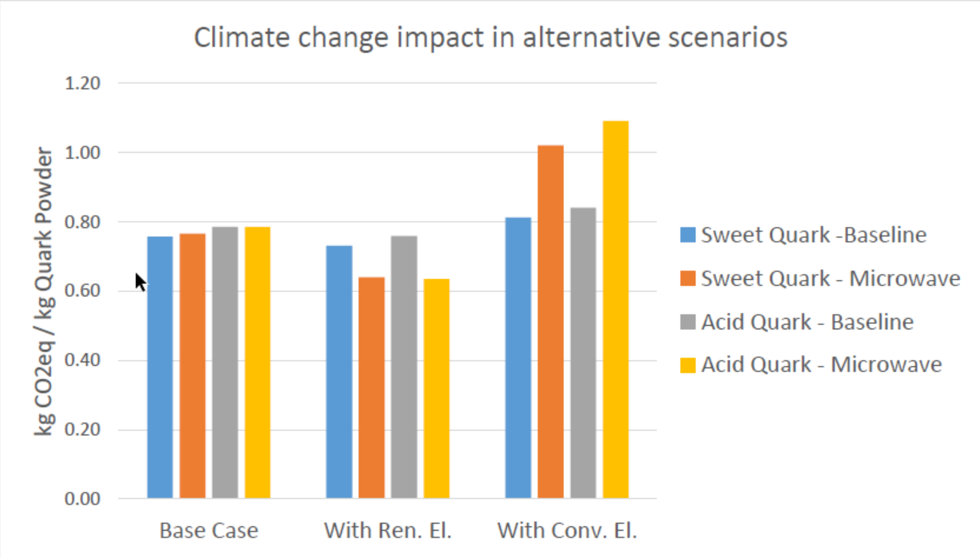

Figure 25: Changes in climate change impact of introducing microwave technology for sweet and acid quark under the S-Milch-specific, renewable and conventional electricity mixes and under reduced CIP resource use; Ren.El. is Renewable Electricity and Conv. El. is Conventional Electricity.

Mozzarella

- Extruder technology was piloted on mozzarella production where original pasta filata stretching machine was replaced by a device inspired on molding machines from the plastics industry.
- For mozzarella production, climate change was a good indicator of total environmental impact, contributing by 30% to human health impacts and 50% to ecosystem impacts of the dairy processing stage (Figure 26). Fossil resource scarcity dominated resource depletion impacts. Fine particulate matter formation contributed strongly to human health impacts (35%), as did toxicity (30%) because the production was less energy intensive.

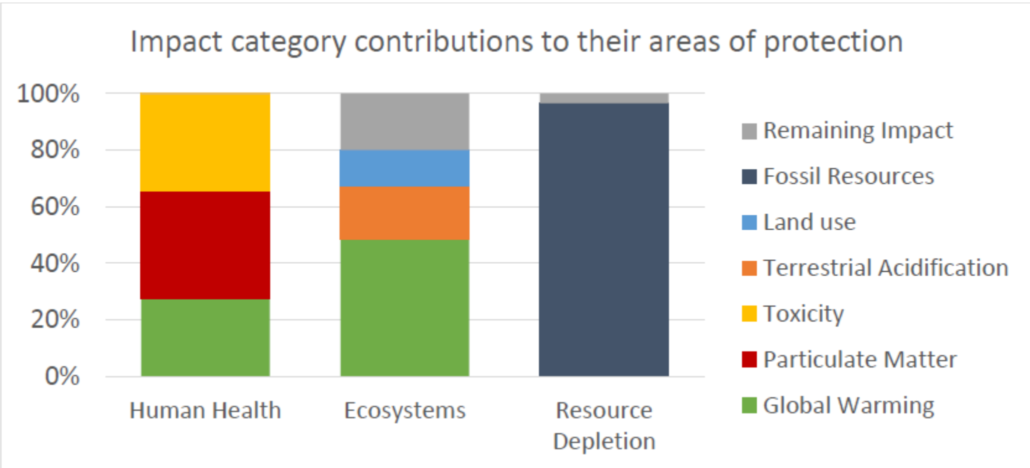

Figure 26: Distribution of environmental impacts of mozzarella over the three areas of protection

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- Mozzarella production was not energy intensive so that various inputs contributed to the impacts. Accordingly steam did not contribute as strongly to the total impact including milk production, while the impact of the factory building depicted a stronger contribution.

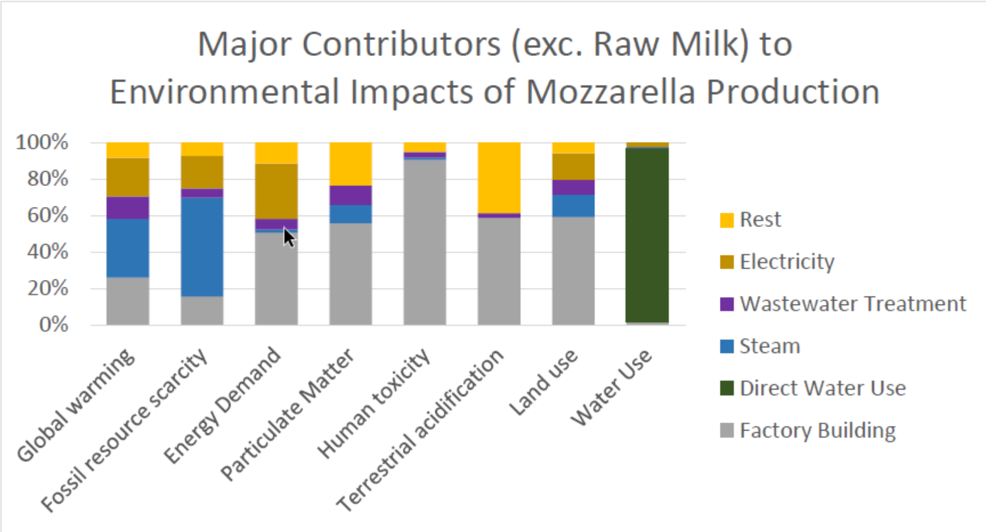

Figure 27: Major contributions to the most relevant environmental impacts of mozzarella production, excluding the agricultural phase of raw milk production ("Gate-to-Gate" or "Processing" Impact). Water use is the gross water intake instead of the water scarcity indicator of ReCiPe 2016.

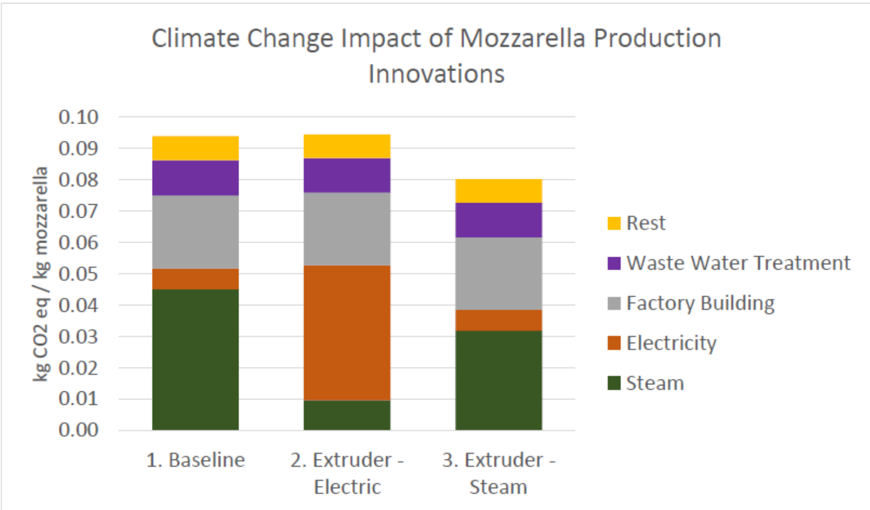

Figure 28: Climate change impact of the baseline and the extruder innovation scenarios, employing electricity and steam as a heat source

- Electricity and steam sources influenced the effect of the extruders. If renewable electricity would be used in the baseline scenario, a modest reduction in climate change impact would be achieved. Since the electric extruder scenario consumed more electricity, renewable electricity would result in a large reduction.

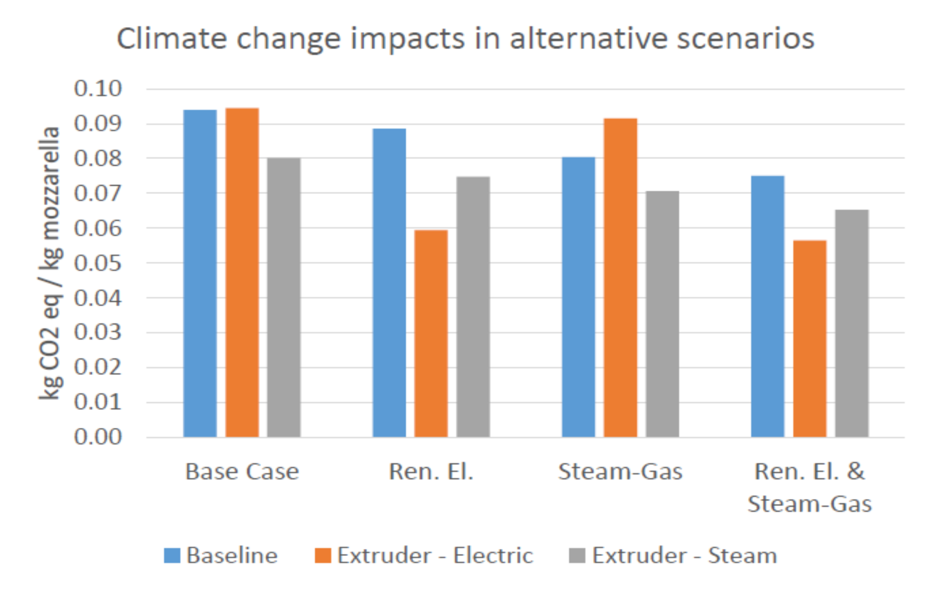

Figure 29: ***Climate change impact of introducing two extruder technologies under varying energy sources: Base Case: Italian conventional electricity, renewable electricity, gas-based steam instead of fuel-oil-based steam, and a combination of these changes***

General conclusions of environmental impact:

- Raw milk and steam production determined the environmental impact of the three studied products, with smaller contributions from electricity use and the factory building. Climate change impact contributed most to human health and ecosystem damages, and is a good proxy for other important environmental impacts like particulate matter formation, terrestrial acidification and fossil resource use.
- Three environmental impacts that do not correlate well with climate change contributed to a limited extent to the overall environmental impact. These were human toxicity due to the factory building (including equipment), land use due to renewable electricity and water scarcity effects due to direct water consumption. Although the EnReMilk project focused among others on reducing water use, the impacts of water use were hardly relevant for the overall impact, when considering all impact categories. The three impact categories did not lead to substantial trade-offs and deserve less attention in the remaining conclusions.
- Technologies that reduce steam use without increasing electricity use would reduce processing impacts most strongly. Several of the studied innovations may also reduce raw milk waste, which would reduce the total environmental impact of the production. An exchange of steam for electricity only reduces the impact if the impact of electricity (per unit energy) is lower than that of steam. This can be achieved with limited effort by sourcing renewable electricity.

Main results on socio-economic impact

- All the technologies that have been tested at the pilot scale have been proven to be safe, to require some additional training for existing workforce, and to produce relevant savings in terms of energy and water consumption.
- The innovations did not impact on the number of jobs.

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- In terms of safety, some consumers had concerns on the effects of radiations on the final product, like in the case of Microwave heating, which has to be taken into account when communicating about the technology.
- In the case of Electro-membrane filtration, there are concerns that system needs special supervision.
- With regard to the Extruder in mozzarella production, main concerns regarded the quality of the final product as the difference in texture resulted in a different type of product and require a new market.
- With respect to the willingness to pay, it was concluded that the introduction of energy labelling is a major challenge due to growing number of "quality" logos already in existence and it becomes difficult to attract consumer interest.
- When successful energy policies are implemented, the probability to innovate increases. Also the presence of specific policies for SMEs has a positive impact on firms to introduce process innovation activities. The price of energy has not resulted to be significant and this is in line with the economic literature.
- A major barrier for EnReMilk innovations is the low importance attributed to energy consumption in non-energy intensive industries as the food and beverage. A second barrier is represented by insufficient returns and too long payback times.
- In particular SMEs have limited access to information, low energy share on their expenditures, too high transaction costs for fund searching, cost disadvantages in obtaining or developing innovation. These problems need to be specifically addressed by policy measures.
- The relevance of drivers like the availability of information and of financial resources at the enterprise level, the presence of new organizational methods such EMAS, the positive role of firms' engagement in R&D activities has been demonstrated. At the same time crisis in the demand at firm level is a major barrier to process innovation.
- Innovations could be enhanced by measures addressed to:
  - Reducing the cost of information in order to support informed choice: support energy auditing in SMEs as a tool to track energy consumption and costs throughout a facility and identify of opportunities to reduce energy use, increasing entrepreneur's awareness.
  - Reducing barriers to the adoption of voluntary codes of conduct such as the Environmental management Systems: through simplifications in permit-issuing procedures, reduction of administrative costs, reduction of financial guarantees, tax reductions;
  - Contrast the low private investment in R&D in SMEs for process and energy saving innovations through public-funded RD&D or promoting enterprises aggregation in networks.

Main dissemination activities and exploitation of results

During EnReMilk project in the period of 2014 to 2017 different dissemination activities were performed, mainly in the form of:

- Website
- Conferences

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- Posters
- Exhibitions
- Presentations
- Workshops
- Video

A total of 46 dissemination activities were performed during the project period and also some post-project activities were planned. All these activities were summarized in a final plan of use and dissemination presented in Deliverable 12.3. Additionally, publications (papers) were also other mean of dissemination. They are summarized in Deliverable 12.5.

These activities were performed with the cooperation of all the members of the consortium. During the preparation of the plan, questions about the interest from potential users have been identified.
The consortium has agreed that the circulation of a questionnaire to members of the dairy industry could provide suitable feedback in the development of the project exploitation plans, with relevant information as acceptable pricing for the technologies, return of investment expectations, payment plans and technical considerations.
As described in D9.1, each technology was evaluated with different drivers of adoption for possible technology adopters. Five drivers were evaluated for each technology: a) Relative advantage, b) Compatibility, c) Cost, d) Triability and e) Observability. According to the results of this evaluation, three technologies had at the moment acceptability for part of technology adopters:

- Microwave heating
- Super-heated steam and closed loop drying
- Electro-membrane filtration

According to the business plan prepared by ESADE, the main market for adoption of the technologies was the Dairy Sector. The dairy sector´s SMEs recognized the importance of innovation for survival. Most dairy sector SMEs were engaged in either product or process innovation, and many were engaged in both types of innovation. Saving energy, furthermore, was recognized as an important element, especially in process innovations. However, the primary data collected through the survey showed that dairy sector firms did not have a strong environmental orientation. In these firms, innovations were not adopted due to environmental concerns, but rather due to market and cost concerns. Cost savings were especially important for dairy sector firms when adopting process innovations. These firms expected that process innovations will result in cost savings. Furthermore, most firms expected a payback period of 1 to 3 years.

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Partners

RTD

Process Engineering (DE)

Process Validation (DE)

Water Monitoring (ES)

Sustainability (NL)

Social Impact (IT)

Economic validation (ES)

SMEs
Technology providers

Dairy Equipment (NL)

Microwave Technology (UK)

Electroch. Processes (DE)

Waste water treatment (CZ)

Extrusion technology (DE)

Energy monitoring (DE)

OTH
Technology providers

Drying technologies (DE)

End User
Case studies

Mozzarella Manufacturer (IT)

LE Dairy (DE)

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