SaltGae
algae to treat saline wastewater

Demonstration project to prove the techno-economic feasibility of using algae to treat saline wastewater from the food industry

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Title	Progress report on techno-economic evaluation, environmental, social and integrated sustainability assessments
Creator	Ana Martha Coutiño (RISE) Alexander Wahlberg (RISE) Greg McNamara (DCU)
Description	This deliverable is a process report of tasks 7.2 and 7.3 concerning the techno-economic and environmental evaluation of the SaltGae system. It also describes the plan forward to execute task 7.4 and 7.5 regarding the social and integrated sustainability assessments. The last section also includes a process report of the SaltGae Visualisation tool (SVT).
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Glossary

The glossary of terms used in this deliverable can be found in the public document "SaltGae_Glossary.pdf" available at: http://saltgae.eu/downloads-public/

Abbreviations and Acronyms

Abbreviation / Acronym	Description
AD	Anaerobic digestion
AP	Acidification potential
CAPEX	Capital expenditure
CF	Centrifugation
CHP	Combined heat and power plant
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DS	Dry solids
EP	Eutrophication potential
GWP	Global warming potential
HRAP	High rate algae pond
ISO	International organization for standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Cost
LCCA	Life cycle costing analysis
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
NPV	Net present value
OPEX	Operational expenditure
PBR	Photobioreactor
POCP	Photochemical ozone creation potential
POLIMI	Politecnico di Milano
RWP	Race way pond
SD	Sustainable development
SVT	SaltGae visualisation tool
TDS	Total dissolved solids
UF	Ultrafiltration
UV	Ultraviolet
VBA	Visual basic for applications
WP	Working package
WW	Wastewater
WWTSs	Wastewater treatment systems
2-AD system	Two step anaerobic digestion system

Table 1. Abbreviations and Acronyms

1 INTRODUCTION AND AIM

SaltGae project aims at demonstrating an efficient solution for the treatment of high salinity wastewater with innovative technologies, including algae/bacteria consortiums in HRAPs. The algae produced in the ponds is also valorized into different products. The scope of SaltGae includes, first the installation of three demonstration sites for treatment of industrial wastewater with algae; and also, several test of the valorization of algae into different products, including animal feed, platform chemicals for resins, adhesives and coatings, as well as composites and ceramic pastes.

In addition to water treatment and valorization of algae, the purpose of SaltGae project is to reduce the life cycle costs and environmental impact of current practices. The overall objective of Work Package 7 is not only to corroborate this positive effect, but also to assure that the systems developed within SaltGae do not affect negatively other cost and sustainability aspects.

The aim of this deliverable is to examine the environmental and economic performance of the installed demonstration sites, as well as selected algae valorization routes. The study should provide information for technology developers on the implications of design choices. A screening Life Cycle Assessment (LCA) and a Life Cycle Cost Analysis (LCCA) have been carried out to study the environmental impacts and cost incurred in the life cycle of two demonstration sites, namely KOTO in Slovenia and Archimede in Italy. Furthermore, only some valorization routes have been examined, namely composites and animal feed. A screening LCA and LCCA means that the study includes a combination of site-specific data, generic data from literature and databases, and some rough assumptions. Therefore, this deliverable is an interim report and the results presented need to be interpreted carefully. The estimated values and assumptions will be refined when further operational data from the consortium becomes available, and final conclusions will be reported in deliverable D7.3.

2 METHODOLOGY

The following section shortly describes the methodologies used in this report.

2.1 Life Cycle Assessment (LCA)

Life Cycle Assessment is an environmental system analysis tool that quantifies the potential environmental impact of products, processes and/or services. LCA is characterized by its systems perspective, considering the impacts associated to all life cycle stages of a product; such as raw material and fuel extraction and processing, manufacturing, use and end-of-life. A common objective of an LCA is to provide information for sound decision-making in terms of, for example, product development, process improvement and policy making [2]. In recent years practical applications of LCA include assessments of emerging technologies. LCA can be used to guide technology developers on the implications of design choices [5]. The LCA in this study follows as closely as possible the basic principles and framework described in the ISO standard 14040:2006. According to the standard, an LCA consists of four iterative phases (as depicted in Figure 1): goal and scope definition, life cycle inventory analysis, life cycle impact assessment phase and results interpretation. These phases are iterative, allowing for changes in scope to reach the goal of the study.

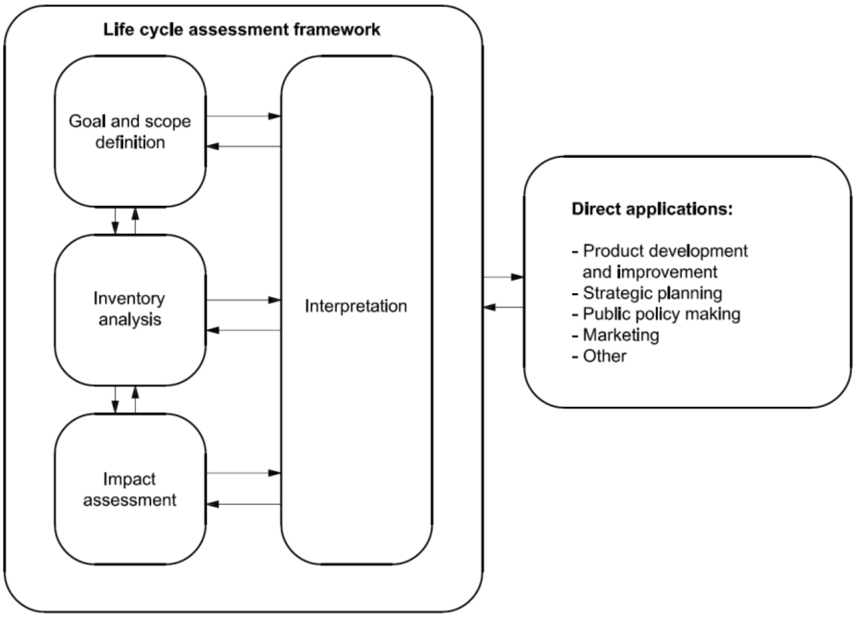

Figure 1. LCA phases according to ISO standard 14040:2006.

In the goal and scope definition, the context, aim, application and audience for the study are specified. Other key issues for the study are also defined, including: the products systems boundaries, modelling approach, allocation technique and type of environmental impacts considered. The second phase, inventory analysis, consists of compiling and analysing flows of the studied product system according to the defined system boundaries. This phase results in a mass and energy balance for the systems to be studied and is usually the most time-consuming. During the third phase, impact assessment, the LCA practitioners translate inventory results into environmental relevant information through aggregating inventory data into fewer parameters that describe potential environmental impacts, such as global warming potential (GWP). During the final phase, interpretation, the practitioners systematically identify, qualify, evaluate and present the conclusions of the LCA to meet the defined goal and scope.

2.2 Life Cycle Cost Analysis (LCCA)

Life cycle cost (LCC) has been defined as "total cost of incurred during the life cycle <an item>" and life cycle cost analysis (LCCA) as "process of economic analysis to assess the cost of an item over its life cycle or a portion thereof" [18]. Life cycle cost analysis is a tool designed to assist decision-makers to select among different alternatives by providing important data and guidance information in terms of economic figures.

Since the LCCA for this deliverable is made in combination with to LCA [6], its structure follows the LCA procedure which consists of four steps:

- Definition of goal and scope
- Economic life cycle inventory
- Interpretation and identification of hot spots
- Sensitivity analysis and discussion

The goal definition should state the application, aim and reason for conducting the study. Within the scope definition, the system boundaries should be determined and justified. It is important to bear in mind that by using these two methods, some difficulties can arise. To avoid double counting of environmental impacts and set both analyses in relation, the system boundaries as well as the functional unit needs to be harmonized and consistent in both LCA and LCCA. This requires identifying the relevant up- and downstream processes. Eventual future costs and revenues should be discounted [6].

The LCCA should reveal the hotspots of the respective technology. The interpretation of results can be quantitative or qualitative. The former is often the net present value or the payback period if discounting is applied and the revenue is also considered. For a pure cost analysis, a comparison of life cycle costs per functional unit with other products could be conducted. Additionally, the interpretation could be also based on qualitative criteria such as security of supply or competition for arable land. To identify hot spots, scenarios with varying assumptions should reveal to what extent the output reacts to changes of input parameters of the LCC model to assess the robustness of estimated parameters.

To capture and to compare present and future costs of an investment, LCC is commonly measured in Net
Present Value (NPV) method. Net Present Value represents the difference between the present value of cash inflows and the present value of cash outflows for an investment. It is used when considering capital investments to assess profitability [26].

The equation for calculating NPV is:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Where:

- Ct = net cash inflow during the period 't'
- Co = total initial investment costs
- r = discount rate
- t = number of time periods from 1 to T

2.3 Social assessment

The social dimension of sustainability will be covered in this report through a literature review. The aim of this literature review is to explore the state-of-the-art of the assessment of social issues of wastewater treatment and algae biorefineries. The expected outcome of this review is to obtain knowledge from previous research that will serve as a guideline for the selection of key indicators in future deliverables from WP7, where the most significant risks of negative social impacts for the SaltGae demo plants will be screened using Social LCA. Further, potential positive social impacts from avoided risk of negative impact by benchmark substitution will be evaluated.

This review will be carried out using the Scopus database. Two search queries will be applied. First, “social impact” AND “wastewater”. Second, “social impact” AND “algae”. The literature review will be limited only to scientific publications (conference and articles) from the year 2000 onwards. The result of the literature review will be two-fold. First, a summary of the findings will be presented outlining the main social issues found in the literature for systems comparable to those studied in SaltGae WP7. Second, a set of the most relevant social indicators will be chosen for the oncoming social risk screening based on the findings from the review.

2.4 Integrated Sustainability Assessment

An integrated analysis will be made to identify the most important hotspots and challenges related to sustainable development (SD), i.e. economic, social and environmental factors. In this analysis, weighting factors will most likely be established for all the sustainability aspects evaluated, using a stakeholder’s perspective. These results will be presented in Deliverable 7.3 as a roadmap for future development of the SaltGae technology, so it achieves its’ maximum potential in terms of contribution to SD. The schematic picture below shows how the Integrated sustainability assessment assembles the tasks in WP7.

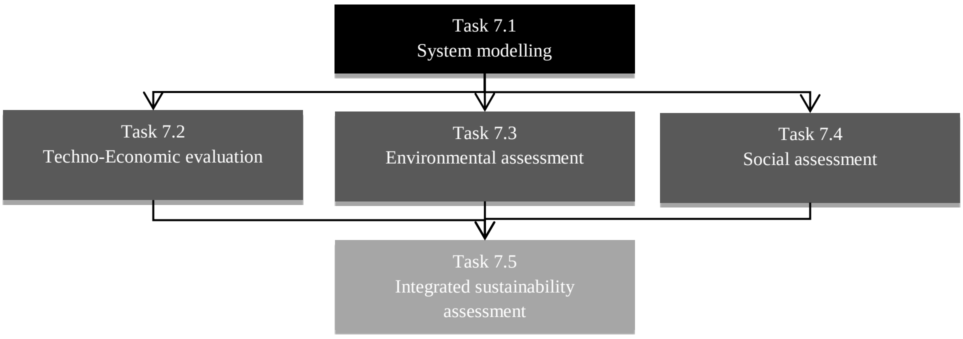

Figure 2. Schematic illustration of the links between the tasks in WP7.

3 GOAL AND SCOPE DEFINITION

3.1 Goal

The purpose of the study carried out under Tasks 7.2, 7.3, 7.4 and 7.5 is to assess the techno-economic feasibility, as well as the environmental and social impacts of the SaltGae technology. The assessment shall provide valuable input for future developments of the SaltGae concept, concerning the identification of potential social, environmental and cost hotspots in the wastewater treatment solutions. In other words, Task 7.3 and 7.4 will attempt to answer four questions:

1. Which steps in the process chain contribute most to the overall cost, environmental and

social impact of the SaltGae wastewater treatment solutions?
2. Where are the improvement possibilities in the life cycle of the SaltGae wastewater treatment solutions?
3. Compared to traditional industrial wastewater treatment processes, what are the advantages and disadvantages of the SaltGae systems from an environmental and social point of view?
4. What are the environmental, cost and social advantages or disadvantages of using algae grown in wastewater to replace existing raw materials in animal feed, adhesives and coatings, composites and ceramic pastes.

In terms of wastewater treatment, the present deliverable will only focus on the first two questions, i.e. the hotspot analysis of wastewater treatment. Further, this deliverable focuses on the KOTO and ARCHIMEDE sites only. Data for the Arava site and information about wastewater treatment benchmark systems will be incorporated in the next deliverable. As previously mentioned, this deliverable is a screening LCA and the estimated values and assumptions will be refined with site-specific data from the demo sites in the next deliverable.

In terms of biomass valorization, this deliverable focuses on understanding the advantages or disadvantages of using algae grown in wastewater as filler in composites (i.e. rubber and gluten-based composites) and additive in animal feed. Further, water valorization related questions are excluded from this deliverable; however, a specific water valorization question should be defined and answered in D7.3. A water valorization LCC has been already done in WP3. This LCC concerns the sub-system of reverse osmosis for KOTO and Arava, see D5.2.

3.2 Functional Unit

Two different functional units will be used in this deliverable. To answer the first three questions defined in section 3.1 above, the selected functional unit is **1 m^3 of wastewater treated**. The technical specifications of each demo site are provided below. The type of wastewater treated is different for the demo sites; therefore, it would not be correct to compare the two systems (KOTO vs Archimede). Thus, adhering to the goal set in section 3.1, the focus is on identifying the hotspots per system. To answer the third question above, in next deliverable, each demo site will be compared with a relevant benchmark using 1 m^3 of wastewater treated.

Table 2. Technical specification of demonstrations sites assessed.

SITE	KOTO	ARCHIMEDE
Average daily flowrate raw wastewater	1.75 m^3/day	16 m^3/day
Wastewater type	Tannery wash water	Dairy wash water
COD	2.86 g COD soluble /liter	16 kg COD / d
Salinity	43 g Na+/ liter	0.8 g TDS / liter
Ammonia	0.28 gNH3-N/ liter	0.001 g N / liter
Freshwater input	1.2 m^3/d (90 % in 2-AD)	4 m^3/d (Evapotranspiration)
Geography	Slovenia	Italy
Algae growth	12 g/m^2/day	15.6 g/ m^2/day
Algae harvested	1 kg DS algae / day	28 kg DS algae / day

To answer the fourth question in section 3.1, focus of the study switches to the algae production. Thus, the functional unit of **1 kg of product** is used to understand the environmental, cost and social advantages or disadvantages of using algae grown in wastewater in products. In this deliverable, algae used in composites and algae used in animal feed are evaluated.

Table 3. Products analysed, benchmarks and functional unit

Product	Alga-based product	Benchmark	Functional unit
Gluten composite	Gluten composite with algae as filler (two formulations)	Gluten composite without filler	1 kg of composite
Rubber composite	Rubber composite with algae as filler (two formulations)	Rubber composite with carbon black as filler (two formulations)	1 kg of composite
Animal feed	Animal feed with algae as additive (two replacement ratios)	Animal feed with fish meal as additive	1 kg of animal feed

3.3 System boundaries

This section describes the processes included in this deliverable. Life Cycle Assessment studies the environmental impact of all phases in the life cycle of a product/system. For the SaltGae system there are three phases differentiated in this deliverable, namely *construction phase*, *operational phase* and *disposal phase*. Each of these phases consist of the environmental impact of different activities.

The *construction phase* typically accounts for the activities related to the construction of a facility as well as the embedded environmental impact of the facility itself. The first set of activities concern the environmental impact of the actual construction of the site, for example the energy used in power tools for removing the soil. These activities are excluded from our analysis due to that they are temporary and not considered to be significant. However, the second set of activities, namely the impact related to the facility itself are included. These activities concern the environmental impact of the production of the equipment and infrastructure installed (i.e. major capital assets used in the water pre-treatment and algae cultivation). For specifics about which equipment and infrastructure was included in the analysis, see sections 3.3.1.

To understand the significance of the *construction phase* in relation to the *operational phase*, the environmental impact for the *construction phase* is calculated for the KOTO site. The results for KOTO showed that the *construction phase* impact is very small compared to the *operational phase* impact for KOTO, see section 7.1.1. Therefore, it was decided to focus only on the *operational phase* for ARCHIMEDE

In the economic analysis, the *construction phase* equates to the capital costs calculated. The capital cost for both demo sites are calculated and presented in Section 8. In terms of the valorization of biomass and water, only the *operational phase* will be included. Experiments conducted for water and biomass valorization are at a lab scale. *Construction phase* environmental impact and CAPEX cannot be scaled linearly from laboratory equipment, and further investigation/data acquisition is beyond the scope of WP7; therefore, the equipment for algae and water valorization is excluded from both sets of analyses.

The *operational phase* normally considers two set of activities: the use phase and the maintenance phase. The use phase is included in this analysis, thus all activities to operate the two demo sites are included in this study. See sections 3.3.1 and 3.3.2 for further description of activities included for each demo site. The maintenance activities are not included in the environmental analysis since the environmental impact of maintenance is deemed to be small. Furthermore, only insufficient data were available regarding maintenance activities since the demo sites have just started to be operated.

In the economic analysis, the *operational phase* equates to the operational costs calculated. The operational costs are calculated for both demo sites and presented in Section 8. The costs related to maintenance activities are included in the LCCA as 5 % of the investment cost for each year, other similar assumptions are presented in Annex IV and VII. In terms of the valorization of biomass, only the *operational phase* will be evaluated. Energy and raw materials used to produce algae-based products are considered in the environmental and cost analysis. The *disposal phase* refers to the end-of-life activities, namely the energy and materials required for the demo site demolition and disposal. The *disposal phase* is not included in the environmental analysis. In the economic analysis, the salvage value of the equipment has been considered for calculating the capital costs.

In terms of the *operational phase*, WP7 aims to study the cost, environmental and social impact of the full chain of processes as depicted in Figure 1. Data collection for all these processes within the system boundaries is ongoing. Data has been received for the processes installed in the KOTO and Archimede demo sites and these two sites are included in this deliverable, see Sections 3.3.1 and 3.3.2. Next deliverable, D7.3, will also include processes installed in the Arava site. Data have been received from Politecnico di Milano and Produmix for algae valorization activities and are included in this deliverable. Data from Extractis (i.e. algae refinement) are still pending; therefore, algae refinement is not included in this deliverable. However, it is the intention[1] of WP7 to include the environmental impact of all the activities depicted in activities Figure 1 in D7.3.

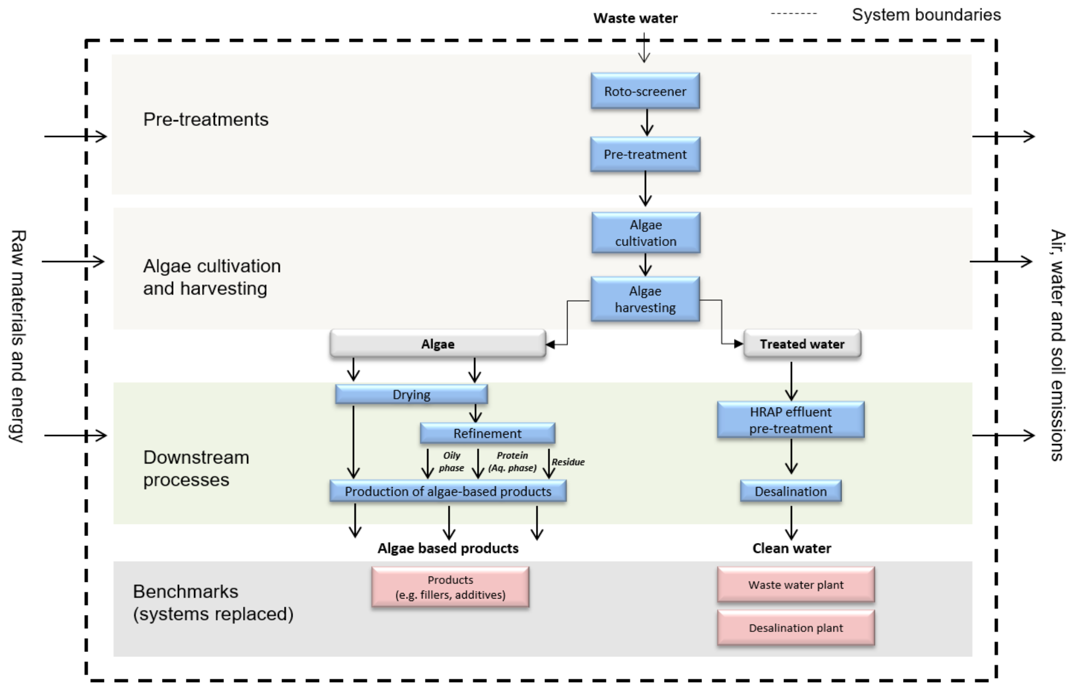

Figure 3. Graphic representation of system boundaries, operational phase.

[1] It is the intention of WP7 to include all activities depicted in Figure 3 in D7.3. However, the consortium needs to decide which processes will be included in the final deliverable D7.3. This selection depends on data availability and how the project progresses. If certain routes/processes are discarded throughout the project, these processes will not be included in D7.3.

Figure 3 categorizes the processes into four groups, namely *wastewater pre-treatment*, *algae cultivation & harvesting*, *downstream processes* and *benchmark systems*. The *wastewater pre-treatment processes, algae cultivation and harvesting* processes are specific for each demo sites. In other words, the processes selected for each site are specific to the wastewater characteristics (i.e. COD and salinity levels and volume of wastewater available). Sections 3.3.1 and 3.3.2, describe these processes more in detail for KOTO and Archimede demo sites, respectively. *Downstream processes* include water and algae valorization. Algae valorization processes include: drying steps (e.g. spray drying in Archimede) and algae refinement performed by Extractis. *Downstream processes* also include activities related to the production of the algae-based product, e.g. grinding of algae to be used in ceramic and pastes. See section 3.3.3 for further details.

The three SaltGae demo sites have installed (or are planning to install) equipment for the first two categories presented in Figure 3, namely *wastewater pre-treatment* and *algae cultivation & harvesting*. Therefore, our analysis is based on demonstration-scale data for these processes. In contrast, the demo sites have not installed (and are not planning to install) equipment for the *downstream processes*, namely equipment for water or biomass valorization. Tests and experiments are being carried out by partners in the consortium to develop these *downstream processes*, therefore our analysis is based on laboratory-scale data (i.e. formulations and yields) with some assumptions based on industrial scale-scale data (i.e. energy demands for processes).

3.3.1 KOTO demonstration site

This section summarizes the processes and activities included in the evaluation of the KOTO demo site. The flowchart of the KOTO demonstration site below, Figure 4, shows all process included in our analysis of the *operational phase* impact and cost. The *pre-treatment processes* in KOTO demo site consist of a roto-screener and a two-step anaerobic digestor (2-step AD). The raw wastewater from the tannery industry enters to the roto-screener where solids are removed, then it goes into a buffer tank. The raw wastewater is then fed into the two-step anaerobic system. The Saltgae set up is designed for the treatment of high salinity wastewater while generating biogas. It consists of two phases: acidogenic and methanogenic. The biogas that is produced in this process is sent to the existing CHP plant where it is burned to produce heat and electricity. This step requires a large amount of freshwater, some salts and heat.

The pre-treated water is then transferred to the algae pond where it is further treated with algae. In the algae pond, CO_2 sourced from the adjected biogas CHP plant is added. Heat is also added through a floor heat exchanger. No extra nutrients are added to the pond, as all the nutrients needed for algae growth are in the wastewater. Finally, the algae are harvested using sedimentation and dissolved air floatation (DAF). The KOTO demo site excludes any equipment for the drying of the algae. Therefore, the two flows coming out of the KOTO demonstration site are: algae concentrate with only 4 % dry matter and treated wastewater. There are 18 pumps installed in KOTO also considered in our analysis, see the list in ANNEX I. Pumps in KOTO All energy (i.e. electricity and heat) for the site is sourced from the adjacent CHP plant. The data used to model the processes for KOTO is presented in ANNEX VIII. LCI KOTO Operational phase.

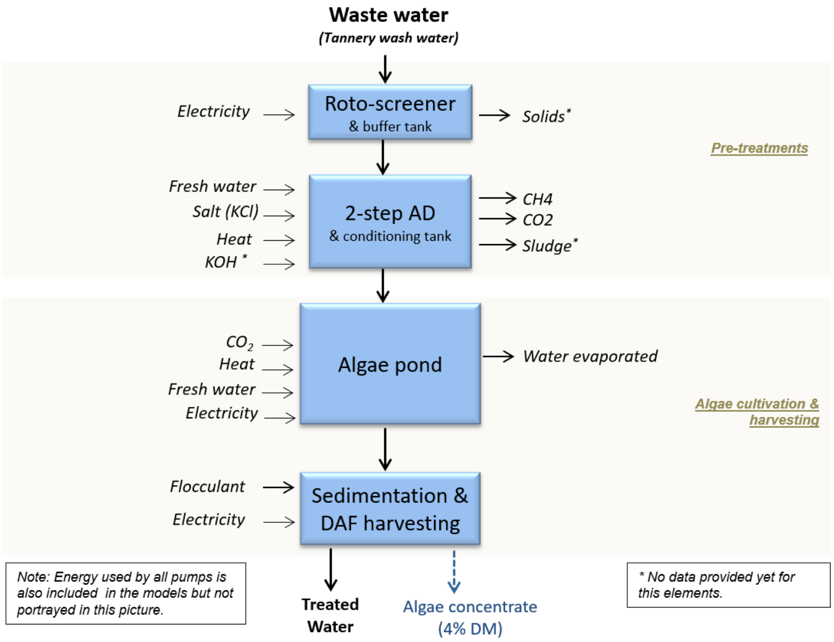

Figure 4. Flowchart of the KOTO demonstration site.

In terms of the *construction phase* impact, the equipment and infrastructure necessary to operate the processes shown in Figure 4, are considered. An estimation of the *construction phase* impact was done including the pumps used in the roto-screener, the distribution system for the 2-step AD, the conditioning tanks used throughout the whole demo site, the greenhouse covering the algae pond, the pond heating system, the CO_2 addition system and the control centre. The impact related to the 2-step AD reactors and the roto-screener are excluded. ANNEX III. Construction phase KOTO outlines all the materials included in the calculations of the environmental impact of KOTO's *construction phase*.

3.3.2 ARCHIMEDE demonstration site

This section summarizes the processes and activities included in the evaluation of the Archimede demo site. The flowchart below, Figure 5, depicts all process installed in the Archimede demonstration site. The processes included in our analysis of the wastewater treatment *operational phase* impact and cost are the activities for water *pre-treatment* and *algae cultivation and harvesting*, namely the roto-screener & tank, the DAF & tank, the algae ponds and the ultrafiltration & centrifugation used for harvesting. The *construction phase* impact was not calculated for ARCHIMEDE due to the low contribution observed in KOTO. See section 7.1.1.

Wash wastewater from the dairy industry is transported to the site by lorry where it is stored in two existing storage tanks. It is then pumped to the roto-screener where solids are removed. It then goes into a transfer tank where the pH is balanced using phosphoric acid. The wastewater is then fed into the DAF where it is further pre-treated with coagulant and flocculants and sludge is extracted. The pre-treated wastewater is then pumped to a buffer tank where electricity is used for mixing the wastewater. The pre-treated water is transferred to a small pond for algae growth and then moves to a bigger pond for algae starvation. Freshwater is added to the pond, to balance the evapotranspiration.

A small amount of micro-nutrients is used to enhance algae growth in the pond. The CO_2 gas added to the pond is bought from the market. There is CO_2 produced in the adjacent CHP; however, this CO_2 cannot be used in the ponds since it is not food grade CO_2. In this deliverable, the CO_2 was assumed to be bought in gaseous state. In the next deliverable the impact of buying the CO_2 in liquid state[2] will be evaluated. Heat sourced from the adjacent CHP plant is used to control the pond temperature. According to Archimede, the heat has no extra cost. To separate the treated water from the algae (i.e. to harvest the algae) an ultrafiltration and centrifugation process is used. Out of the harvesting process algae concentrate with 20 % dry matter is obtained, as well as treated water. There are 15 pumps installed in Archimede demo site considered in the analysis, see the list in ANNEX II. Pumps in . All electricity used is sourced from the Italian grid.

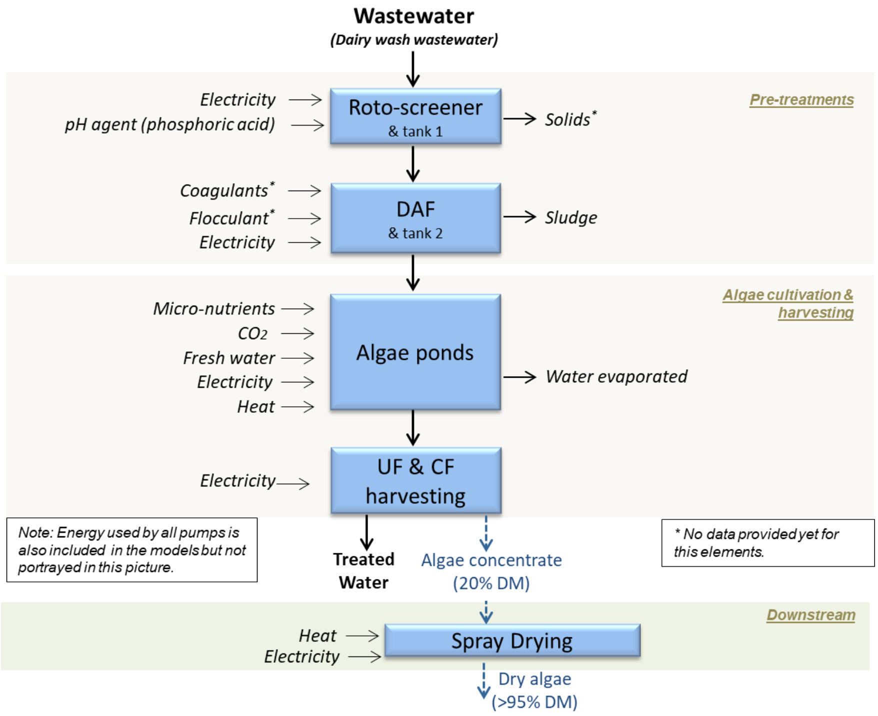

Figure 5. Flowchart of the ARCHIMEDE demonstration site.

The Archimede demonstration site has also spray drying equipment installed. The environmental impact and cost related to this equipment is not included in the wastewater treatment results in Section 7.2; however, the energy data for drying was used to calculate the environmental impact of the biomass valorization routes. The output of the spray drying is algae with less than 5% water content and in powder form. See following section 3.3.3. The spray dryer uses heat from natural gas and electricity from the Italian grid. The data used to model the processes for Archimede is presented in ANNEX IX. LCI

3.3.3 Downstream processes

This section describes the downstream processes as presented in Figure 3. This deliverable focuses on three biomass valorization routes namely, gluten composites, rubber composites and animal feed. Notice that the activities related to HRAP water valorization such as water treatment (e.g. ultrafiltration) and desalination (e.g. reverse osmosis) are not included in this deliverable. Close collaboration with WP3 will continue to decide if there are any relevant questions and pathway to analyses in D7.3 or if the analyses done in WP3 are sufficient.

The activities related to algae/biomass valorization include: algae drying, algae refinement and further processing of algae (e.g. grinding and mixing) until it is incorporated in the algae-based

[2] Information that the CO_2 is bough in liquid state came too late (September) to incorporate to the environmental models used in this deliverable. It is known that liquefaction is energy demanding, so the environmental impact of CO_2 in liquid state will be explored in next deliverable.

products. Aligned with the goal of this study, this deliverable includes three algae-based products namely gluten composites, rubber composites and animal feed. Notice that the functional unit is 1 kg of product when analyzing the algae valorization routes. See explanation in section 3.2. Politecnico di Milano (Polimi) aims at incorporating the low value algae fractions (i.e. algae residues) in composites and ceramics, as a filler. The production of two types of composites is being explored by Polimi, namely gluten and rubber composites. Polimi is also exploring the production of algae-based ceramics; however, this product is excluded from the present deliverable. Incorporating algae into ceramics could increase ceramics printability. However, the algae added into the ceramics is not replacing an existing filler in the ceramic paste production. This means that algae-based ceramics are not easily compared to existing products; thus, the question stated in the goal definition cannot be answered within the resources set for this project[3]. There are available data to model the environmental impact and cost of producing algae-based ceramics. Consequently, the consortium will decide if it is interesting to do a hotspot analysis of algae-based ceramics and include it in D7.3.

Figure 6 depicts the processes included in the algae-based composite LCA. Production of both algae-rubber and algae-gluten based composites starts with the production of algae. This is assumed to happen in Archimede. Then the algae are sent for refinement to Extractis where the algae are processed for extraction of proteins or lipids. The extraction protocol yields a high value fraction (i.e. protein or lipids) and a low value fraction (i.e. algae residues). The algae residues are sent to Polimi for valorization into composites. All the environmental impact of algae production and drying, as well as algae refinement is allocated to the proteins or lipids produced. The assumption is that the algae residues are waste that would otherwise be sent to disposal. See allocation section 3.5.5.

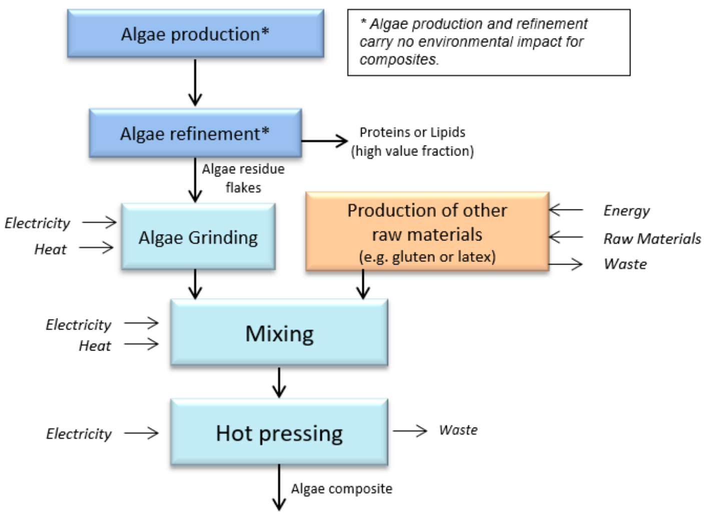

Figure 6. Flowchart of algae-based composite production.

The algae residues are sent as flakes and need further grinding. After grinding the algae is mixed together with the other raw materials. The final step is hot pressing the mix to form the composites. Notice that all energy used in the composite production is assumed to be from the Italian electricity grid. Two formulations have been assessed for the gluten composites, one with high algae content (29 %) and one with a low algae content (9 %). Two formulations have also been assessed for the rubber composites, one with high algae content (26 %) and one with a low

[3] The algae included in ceramics improve mechanical properties of a material, this implies that this new material has a higher value. An environmental and economical comparison between this new material and market available materials become too complex to execute within the budget set for this project.

algae content (8 %). The composite formulations and energy demand are presented in Annex V. Gluten and Rubber composite formulation and LCI sources

According to the goal stated in section 3.1, a benchmark system must be identified for the algae-based composites. The algae used in rubber-based composites is replacing another filler, namely carbon black. Two formulations have been assessed for rubber-based benchmarks, one with high carbon black content (26 %) and one with a low carbon black content (8 %). For the gluten composite, the algae are not replacing another filler since the literature shows that the gluten composites are currently not using any fillers. Thus, the contents of octanoic acid and gluten in the composite formulation sum up to 100 %. This implies that our models assume the replacement of both octanoic acid and gluten with algae. The benchmark composite formulations and energy demand are presented in Annex V. Gluten and Rubber composite formulation and LCI sources

Figure 7 depicts the flowchart for animal feed production. Produmix is exploring the replacement of fish meal and antibiotics with algae. This study explores the environmental impact of the replacement of fish meal with algae powder in piglet diet. It is assumed that the animal growth and food intake will be the same for the algae-based animal feed and fish meal-based feed. It is also assumed that another feedstuff is provided to the animal. This feedstuff is the same for both fish meal-based feed and algae-based feed; therefore, the upstream impact of the other feedstuff production is excluded from the results. Notice that two replacement ratios have been studied for the algae-based animal feed, one with high replacement ratio (algae 2.5 % and fish meal 2.5 %) and one with low replacement ratio (algae 1.25 % and fish meal 3.75 %). The benchmark product is the control case in Deliverable 4.2, that is 0 % algae and 5 % fish meal. The replacement of antibiotics with algae is not included in this study. See ANNEX VI. Animal feed formulation and LCI sources

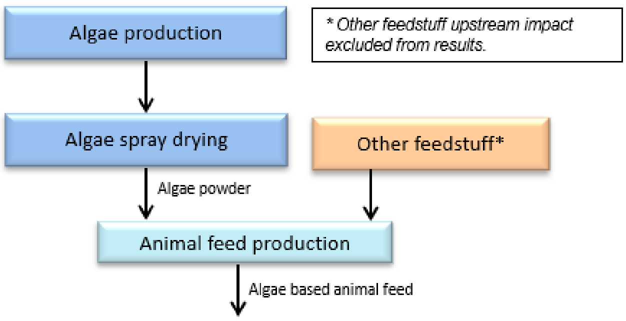

Figure 7. Flowchart algae-based animal feed.

WP4 is exploring many different pathways for developing algae-based chemicals to be used in coatings and adhesives. Assessing all pathways for algae-based coatings and adhesives requires a vast amount of data and assumptions. WP7 intend is to include one algae-based coating value chain and one-algae based adhesive value chain in D7.3. However, the consortium is yet to decide if an LCA and LCC assessment for coatings and adhesives is valuable to include in D7.3.

3.3.4 Cut-offs

The system cut-offs are processes that are categorically excluded from all WP7 deliverables. Some of the process excluded have been already mentioned through the report. However, this section provides a summary and overview of all activities excluded.

In terms of the environmental impact of the *construction phase*, activities related to the actual construction of the site are excluded since they are assessed to be small. For instance, the energy use to remove the soil to build the algae pond is excluded from the analysis. Further, the impact related to steel used for the 2-step AD reactors and the roto-screener are excluded.

In terms of the environmental impact of the *operational phase*, the following activities are excluded from the analysis:

- The impact related to the industrial processes generating the wastewater are excluded. Information about the wastewater characterization (e.g. COD) is provided in Table 2. However, the environmental impact of e.g. leather production is excluded since this is beyond our system boundaries, see Figure 3.
- Transportation of the wastewater to the demo sites is also excluded. The intention of the demo is to prove a technology. When the technology is fully on the market, the logistics of the wastewater will be optimized, and the wastewater treatment plants will most likely be located at the industry itself or near the industry from which the wastewater comes from.
- The environmental impact related to the maintenance activities of the demo site are excluded, e.g. using chemicals for cleaning. This impact is expected to be small and not enough data is available since the demo sites have just started to be operated. However, the average daily and annual flowrate used as reference unit (i.e. related to the functional unit) considers that the demo sites will operate 330 days a year, so 35 days are destined for maintenance activities.
- In terms of downstream processes, the transportation of the harvested algae to the refinement facility, or to the ceramics or animal feed facility is excluded.

3.4 Geographical boundaries

Defining the geographical boundaries is necessary for the LCA, a S-LCA and LCCA. Archimede demo site is placed in Imperia, Italy. KOTO demo site is placed in Ljubljana, Slovenia. Arava demo site is placed in Israel.

Geographical boundaries affect the impacts from electricity production (i.e. the impact of electricity production is dependent on the electricity grid of each country). In the case of Archimede, Italian electricity grid is mostly based on fossil fuels, namely natural gas (33 %) and hard coal (15 %), but also some hydropower (16 %). In the case of KOTO, the electricity used is from the adjacent biogas CHP plant. Data for the environmental impact of the heat and electricity of a biogas CHP plant was obtained from the Eco-invent database. Geography also affects algae growth [4]. The table below presents some key geography dependent parameters considered in this assessment.

Table 4. Parameters affected by the location of the demo site.

Site	Thermal energy (kWh /d)	Biomass growth rate (g / m2 / d)	Evapotranspiration (liters / d)
KOTO (Slovenia)	11.6 (pond) 0.45 (2-AD system)	12	170
Archimede (Italy)	545 (pond)	15.6	4072

To calculate the environmental impact and cost of the biomass valorization routes it is assumed that the production of the composites would take place in the same place as the production of the algae, namely Italy. Thereby, all energy used in the production of the composites is from the Italian grid mix. Geographical boundaries also affect data selection for social impacts. The latter will be further defined in D7.3.

3.5 Allocation

An important choice when conducting an LCA is how to allocate the environmental burden of multi-functional processes between the several products/functions. In the present study there are several important allocation problems that need to be clarified.

3.5.1 Biogas produced by 2-step AD system

The 2-step AD system installed in KOTO performs two main functions: the treatment of water and the production of biogas. Consequently, the question is how much of the environmental impact of the 2-step AD system can be allocated to the treatment of water and how much to the biogas production. To avoid this allocation problem, system expansion is recommended by the ISO standard. The system expansion method considers one of the functions to be a by-product and this by-product is an alternative to an existing product on the market. In the case of KOTO, the biogas produced from the 2-step AD is the by-product. This biogas is sent to the biogas CHP plant, nearby. Therefore, the biogas produced by the 2-step AD system will replace the fuel in this CHP plant, and in turn it will replace the produced heat and electricity from the CHP plant. In this study the avoided emissions of heat and electricity of a biogas CHP plant are accounted as credits given to the KOTO system. Based on Eco-invent data approx. 14 MJ of heat and 8 MJ of electricity are produced per 1 m^3 of biogas. The AD system produces approx. 0.5 m^3 biogas per day.

3.5.2 CHP heat and electricity

The KOTO site receives all its heat and electricity from the adjacent biogas CHP plant. This plant produces both heat and electricity. The dataset of Eco-invent was used to calculate the environmental impact of the CHP plant. This dataset uses exergy allocation to split the environmental impact between the heat and the electricity, this leads to higher resources and emissions per kWh of electricity compared to kWh heat. Approximately 80 % of the resources and emissions are allocated to the electricity and 20 % to the heat [25].

The Archimede site receives the heat for the pond from the adjacent vegetable oil CHP plant. This heat is waste heat (low temperature) from the CHP plant. The high temperature heat from the CHP plant is used in their biorefineries which are outside our system boundaries. The heat used in the algae ponds carries no upstream environmental burden. See ANNEX IX. LCI .

3.5.3 CO_2 input to algae pond

For KOTO, the CO_2 added to the pond comes from the adjacent biogas CHP plant and it carries no environmental burden as it is a by-product that could otherwise be a direct emission. All of CHP environmental burden is assigned to the heat and the electricity produced by the CHP plant.

For Archimedes, the CO_2 is bought from the market and it carries environmental burden. ThinkStep life cycle inventory (LCI) dataset was chosen to represent the environmental impact of CO_2 production. This carbon dioxide is used in food industry and it is in gas state[4]. This carbon dioxide is produced by the well-known HABER-BOSCH process which main products are both CO_2 and ammonia. The allocation in the foreground system is based on an extended allocation where 95 % of the impact allocated to ammonia and only 5 % to carbon dioxide.

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[4] Information was received that the CO_2 is in liquid state. Liquefaction is expected to increase the environmental impact of the production of this CO_2.

3.5.4 Allocation between wastewater and biomass

The main allocation problem in this study is how to divide the environmental impact of the whole algae production system (KOTO or ARCHIMEDE) between its two main functions, namely algae production and wastewater treatment. To answer the first two questions of this project (see goal definition in section 3.1) it is not necessary to split the environmental impact between these two products. Thus, for the hotspot analysis presented in section 7.1.2 and section 7.2 all the environmental impact of the Archimedes and KOTO system is assigned to the treatment of wastewater [5].

To understand the environmental advantages or disadvantages of using algae grown in wastewater to replace existing raw materials in animal feed and composites (i.e. the fourth question in this study section 3.1), we need to divide the environmental impact of the Archimede system between wastewater treatment and biomass production. The worst-case scenario is presented in section 7.3. For the animal feed LCA all impact of the Archimede site is allocated to biomass production. In a future deliverable, a scenario could be done using economic allocation (i.e. economic value of the two outputs). In this case, it is necessary to know how much Archimede could get paid per liter of water treated and how much Archimede could get paid per kg of biomass produced and then split the environmental impact accordingly.

3.5.5 Allocation biomass refinement

After the algae are harvested and dried, they are sent to Extractis. The process of refinement performed by Extractis yields two algae fractions, namely a high value fraction and a low value fraction. The high value fraction is either lipids or protein, depending the extraction protocol. The low value fraction is algae residue. This residue is sent to Polimi and is used as filler in composites and ceramics. The alternative fate of the algae residue is assumed to be waste that would be sent be sent for disposal, therefore all the environmental impact of refinement and algae production is allocated to the high value products and the production of the algae residues carries no environmental impact.

[5] All environmental impact of the Archimede system is assigned to wastewater treatment, except for the environmental impact of spray drying. The spray drying impact is only accounted in the biomass valorization LCA. See Figure 5.

4 ENVIRONMENTAL INDICATORS

Table 5 below shows the environmental indicators used throughout this study and the respective sources. For the analysis where 1 m^3 of wastewater treated is used as functional unit, all the environmental indicators below are assessed. See sections 7.1 and 7.2. However, for the analysis where the functional unit is 1 kg of product, only GWP was used. See section 7.3.

Table 5. Environmental indicators

Indicator	Life cycle impact assessment (LCIA) method	Unit for characterization
Water footprint	Blue water consumption according to the water footprint assessment methodology [16].	m^3 water consumed.
Acidification Potential (AP)	Acidification Potential based on impact assessment CML-IA (2016) [13].	kg SO_2 equivalent.
Eutrophication Potential (EP)	Eutrophication Potential based on impact assessment CML-IA (2016) [13].	kg Phosphate equivalent.
Global warming potential (GWP)	Global warming potential with 100 years perspective (GWP100), excluding biogenic CO_2 emissions. Based on impact assessment CML-IA (2016) [13]. In line with IPCC AR5 (2013).	kg CO_2 equivalent.
Photochemical Ozone Creation Potential (POCP)	Photochemical Ozone Creation Potential based on impact assessment CML-IA (2016) [13].	kg Ethane equivalent.
Primary energy demand	Renewable and non-renewable (net cal. value)	MJ

For this first deliverable a sub-set of impact indicators were chosen based on our knowledge of the sector's main impacts. In deliverable 7.3, a reevaluation of the impact categories selected will be done. Further, the selection of assessment method will be aligned with those recommended by the Joint Research Centre of the European Union.

5 ECONOMIC INDICATORS

Table 6. Economic indicators

Indicator	Life cycle cost analysis (LCCA) method	Unit for characterization
Investment cost (CAPEX)	Purchasing cost	Euro per m^3 water consumed
Operational cost (OPEX)	Operating costs, including utility costs such as maintenance, water use and energy costs	Euro per m^3 water consumed
Net-present values (NPV)	The net present value of the project, in today's euros	Euro per m^3 water consumed
Pay-back time	The time it takes to pay back the investments in the project	Years

6 RESULTS -- Social assessment

The results of the literature review of social impacts from wastewater treatment and algae biorefineries are presented in this section. The first subsection includes a summary of the research findings in previous research on the subject, while the second subsection presents the social indicators chosen based on the research findings.

6.1 Social impact of wastewater treatment

The earliest attempt found to discuss the social aspects of wastewater treatment is the comparative analysis of different wastewater odor abatement alternatives carried out by Estrada *et al.* [8]. Their study was highly subjective and did not include quantitative assessments. The discussion revolves around two social aspects; the health and safety of workers in the wastewater plants and the life quality of the nearby population. The health and safety of workers is somewhat easier to quantify as there is enough data for worker's accidents and occupational disease. On the other hand, measuring impacts on nearby population is more challenging since they involve aesthetic and emotional associations. On the same subject of odor control was a follow-up study by the same group [20]. Here, different odor control technologies were evaluated using reliability and sustainability criteria using existing sustainability metrics by the Institution of Chemical Engineers. However, even as the social dimension of sustainability is somewhat discussed, the main results of the study have a clear focus on environmental and economic performance, and the social benefits are a consequence of these rather than indicators of their own.

The work by Heck *et al.* presented a valuable outline of research findings concerning social perception of seawater desalination plants [14]. They identify environmental impacts due to open-ocean intake, brine discharge, greenhouse gas emissions, costs and loss of coastal access and scenery as the common critiques to seawater desalination projects. Their study also highlights the importance of threat perceptions and contextual situations in public support of wastewater desalination projects. For example, people in zones with severe water shortage may be more in favor, while local perceptions of the quality of marine environment may reduce acceptance. Their study used surveys to measure public perception under different settings for key variables. They found that the public's perceptions about water resource availability and costs and benefits of desalination were significant predictors of support. They also highlight the importance of demonstrating the need for desalination, greenhouse gas emission abatement and impact on marine areas must be clearly communicated to the public.

Finally, Mondal et al. analyzed social aspects of a specific wastewater treatment technology in India through surveys and stakeholder engagement, mostly using surveys [22]. The results of the study confirm the importance of the level of stakeholder awareness about the environmental problems that the wastewater solution is aimed to mitigate, and the importance of active communication of these issues with the community to ensure positive perception.

6.2 Social impact of algae biorefineries

Studies concerned with the social issues of algae biorefineries or algae-based industrial systems were more elusive than those concerned with wastewater. Some studies were found, dated between 2008 and 2014, where social benefits of algae value chains were named and/or implied. However, none of them measured or studied the subject. Most of these studies consider microalgae-based processes a promising alternative to existing high-impact technologies such as fossil fuels. A great deal of discussion is laid in the trade-offs between achieving their economic feasibility and decreasing environmental impacts, but social aspects are often ignored [21]. Montagne *et al.* presented a short qualitative discussion about social issues of algae-based processes, more specifically local work creation in low-employment areas, negative public opinion and competition with tourism [23]. As part of the FUEL4ME research project, a methodology to assess the social aspects of algae cultivation systems was developed [19]. The work in this project concerning social LCA focused in the identification of the categories and subcategories that a company must be careful with, so-called hot-spots. They found that the most relevant hot-spots are in the category “society”, including the engagement with local citizens, local employment and transparency to foster the acceptance of the new technology.

Karklina *et al.* carried out a Social LCA of biomethane production from algae biomass in Latvia. Multi-criteria analysis was used to evaluate the social performance of different scenarios, performance that was evaluated semi qualitatively based on data from literature, statistics and legislation. They found an overall positive impact for the implementation of biomethane production facilities in Latvia for all the selected indicators, with notable positive impacts in employment, standard of living, rational use of natural resources, environmental protection and security of energy supply.

D-Factory is another European project where Social LCA was used to evaluate the social risks of one microalgae biorefinery [24]. The results show that the D-Factory concept shows a significant potential for mitigation of negative social impacts, but the magnitude of this potential can be affected by key variables such as yield assumptions and location. Another key aspect is whether the concept successfully substitutes the high-value products that it aims to. As said, the results depend heavily on the country where the plant is located, and if it is implemented in any country outside the European Union, special measures need to be implemented to avoid local social risks.

7 RESULTS -- Environmental assessment

In this section the results of the environmental assessment of KOTO, Archimede and the algae valorization routes are presented. First, the results for the *construction phase* and the *operational phase* of the KOTO demonstration site are presented in Section 7.1. Second, the results of the *operational phase* of the Archimede demonstration site are presented in Section 7.2. For both assessments the functional unit is 1 m^3 of raw wastewater treated. Section 7.3 presents the results for the three algae valorization routes and compares them with their respective benchmark systems. The results in Section 7.3 are calculated per 1 kg of product.

All results are normalized, thereby the magnitude of each impact category is lost due to the normalization. In other words, the highest value is 1 for each of the impact categories. The intention of the normalized results presented below is to identify the elements that contribute the most to each of the environmental impact categories. These elements are the hotspots and can be regarded as improvement possibilities for the system. Investments and efforts to reduce the impact of the hotspots could result in greater overall improvements.

7.1 KOTO LCA results

The environmental impact of both, the *construction* and *operational phases* of the KOTO demonstration site were assessed. In section 3.3, the activities included in each of the phases are presented. The KOTO results are presented per phase in Figure 8.

The contribution of the *construction phase* per impact category is low compared to the *operational phase*. It is only in the impact category of primary energy where the construction phase represents around 10 % of the impact. Primary energy is energy embodied in resources extracted from nature, for example crude oil. Primary energy includes the embodied energy in the feedstock material, for example crude oil or natural gas in plastic. The impact of the production of the plastic used in the tanks represent around 30 % of the primary energy used in the *construction phase*, that equates to around 3 % of the overall primary energy used in the system.

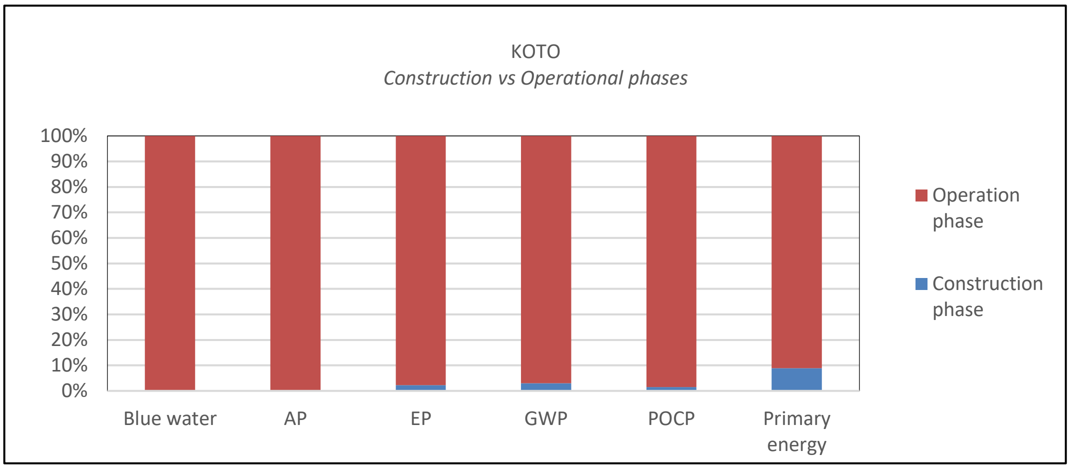

Figure 8. KOTO results. Construction phase vs Operation phase, all impact categories normalized.

7.1.1 KOTO LCA construction phase results

The *construction phase* results are analyzed using seven sub-systems:

1. Roto-screener pumps
2. Distribution system 2-step AD
3. Tanks
4. Greenhouse system
5. Pond heating system
6. CO_2 addition system
7. Control center

The materials constituting each of the sub-systems and their respective lifetimes are presented in the ANNEX III. Construction phase KOTO. The total impact is then analyzed in terms of material/component contribution.

The lifetime of the whole KOTO system was assumed to be 30 years and the average lifetime flowrate was assumed to be approximately 17 300 m^3, that equates to an average daily flowrate of 1.75 m^3 with a system operating 330 days per year. The 2-step AD system dilutes the raw wastewater with fresh water on a ration of approximately 1:3, that is for 1 m^3 of raw wastewater processed there are 3 m^3 of freshwater added. Therefore, the reference flow is approximately 4 500 m^3, that is approximately ¼ of the total annual flowrate.

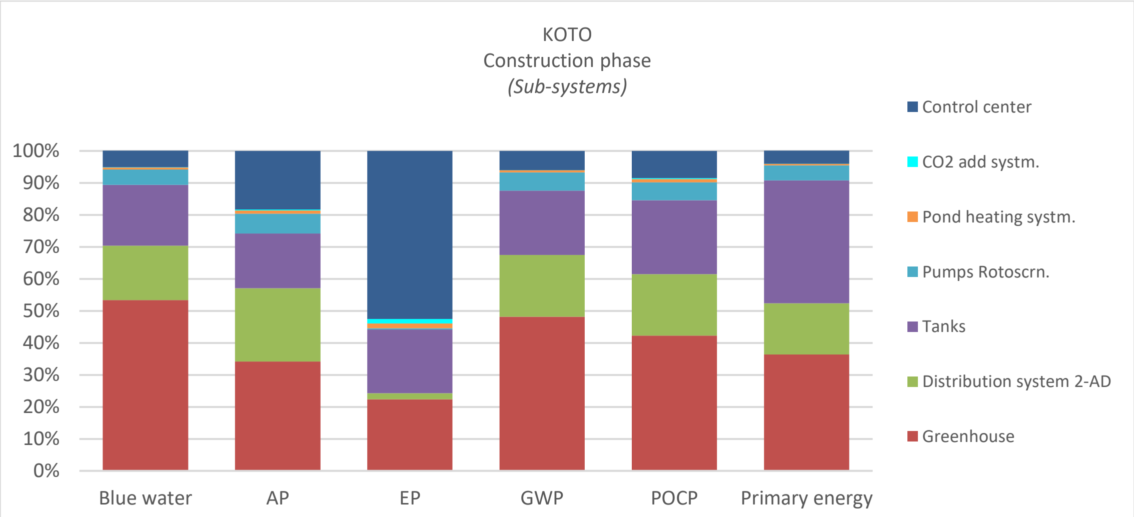

Figure 9. KOTO construction phase – relative influence of subsystems per impact category, all impact categories normalized.

The results presented in Figure 9 show that three subsystems account for more than 75 % of all impact categories (except for EP), namely the greenhouse, the distribution system to 2-step AD and the tanks. These three subsystems account for 45 % of the impact of EP, while the control center is also very significant representing 53 % of the impact. Specifically, the production of the computers used in the control system have large amounts of phosphate water emissions, most likely from the fuels used for glass manufacturing. Computers are then the main contributor to the EP impact (50 %), followed by steel with 20 % of the impact. The largest amount of steel is used for the construction of the greenhouse. As shown in Figure 10, steel is also significant for the rest of the impact categories, especially for GWP and POCP.

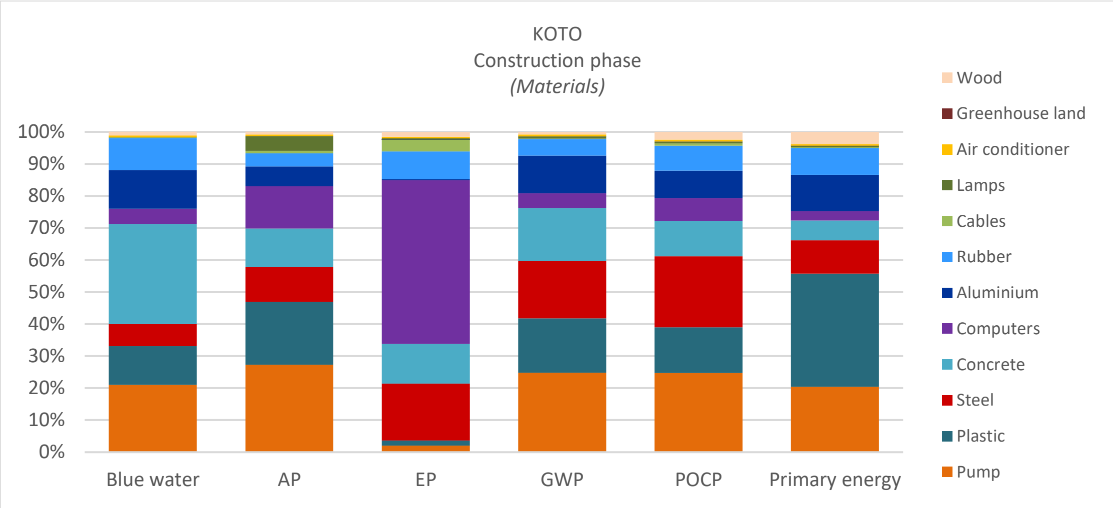

Figure 10. KOTO construction phase – relative influence of materials per impact category, all impact categories normalized.

Pumps, represented in orange in Figure 10 above, are a major contributor to all impact categories, except for EP. The pumps constitute around 20 % of each impact category. Concrete is very significant for blue water consumption and GWP. This concrete is used in the greenhouse system. Plastic is significant for AP, GWP and primary energy use. This plastic is used in the production of the six tanks in the system.

7.1.2 KOTO LCA operational phase results

The *operational phase* results are analyzed using the four sub-systems presented in Figure 4 plus a category specific for all pumps installed throughout the system.

1. Roto-screener & tank
2. 2 step-AD & tank
3. Algae pond
4. Harvesting
5. Pumps

It is important to clarify that the first four sub-systems include the direct energy used by the specify equipment only. For example, the *2 step-AD system & tank* category includes the thermal energy used in the AD system and the electricity used for the tank mixer; meanwhile the *pumps* category includes the energy used for the feed pumps, recirculation pump and diluting pump to the AD system. Thus, the categorization is done for analytical purposes only.

For the first impact category, namely blue water consumption, the *2-step AD system* is overwhelmingly the main contributor to the overall water consumption of the system. As already mentioned, for every 1 m^3 of raw wastewater used in the system, 3 m^3 of fresh water are added to the system in the *2-step anaerobic digester*. The freshwater added in the pond due to evapotranspiration is also visible, constituting 10 % of the total water consumed.

The freshwater added to the 2-step AD system is for treating wastewater salinity, this dilution process is very inefficient. **Figure** 11 below shows a scenario where the amount of freshwater added to the 2-step AD system is set to 0 so all the water flow in the system is raw wastewater. The scenario is included only for illustration purposes, to show the inefficiency of this dilution process.

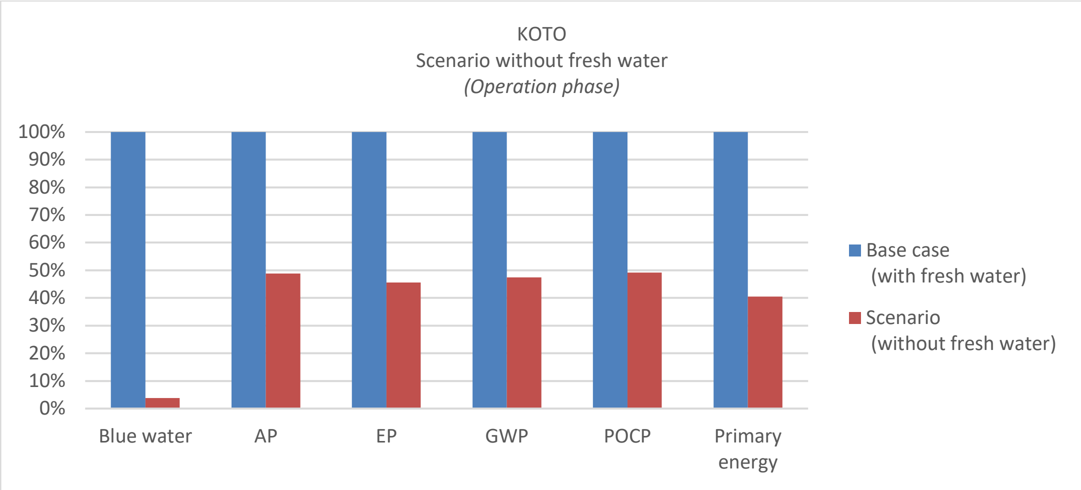

Figure 11. Scenario results for KOTO operational phase, normalized per impact category.

Figure 11 shows that the overall results for all impact categories is drastically reduced to around 40-50 %[6].

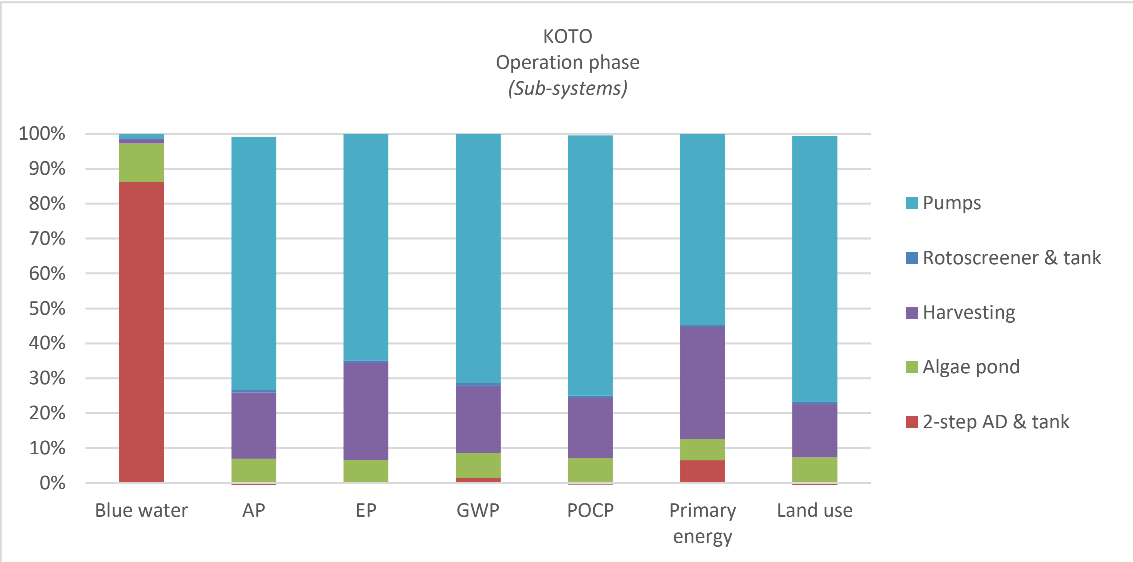

Figure 12. KOTO operation phase – relative influence of subsystems per impact category, all impact categories normalized.

Figure 12 shows that the major contributor to AP, EP, GWP, POCP and primary energy consumption are the pumps used throughout the system, constituting from 55-75 % of each environmental impact. Specifically, five pumps contribute from 40-55 % of the overall operation phase impacts: feed pump to AD 1, feed pump to AD 2, pre-treated water pump, recirculation pump to AD 1 and recirculation pump to AD 2. All together these five pumps accounts for 65 kWh/ m^3, becoming the greater contributors to the pump and overall energy use of the system. It must be noted that the energy used for all pumps will be modified in next deliverable. The energy figures used in this analysis are too high and not representative. The energy data collected consider the nominal power of the pumps and not the actual power used. Operational data from

[6] The reduction does not equate to ¼ of the total impact since there are some pumps that are not affected by this flow.

KOTO will be collected in 2019, when the demo site has been running continuously for a representative amount of time.

Harvesting is also an important contributor to all impact categories, representing from 15-30 % of the impact of each category, see Figure 12. For AP, GWP and POCP, the electricity used for harvesting in the DAF contributes to around 15 % of the overall impact. For EP and primary energy used, the production of flocculant used in the DAF causes around 15 % of the overall impact of each category.

The 2-step AD system produces biogas. This biogas implies credits in terms of emission and resources reduction for the whole SaltGae system. These credits are quite significant. In terms of GWP, the credits equate to 4 % of the overall impact of the whole system. These credits are considered under the category *2 step-AD & tank*, therefore the contribution of this category is only 2 % of the total GWP impact as shown in Figure 12.

7.2 Archimede LCA results

The *operational phase* results for Archimede are analyzed using the four sub-system presented in Figure 5 plus a category specific for all pumps installed throughout the system.

1. Roto-screener & tank
2. DAF & tank
3. Algae ponds
4. Harvesting
5. Pumps

It is important to clarify that the first four sub-systems include the direct energy used by the specify equipment only. For example, for the *roto-screener* category, only the energy used for the screen drum motor is considered, thus the energy used for pumping the water to the roto-screener is under the category *pumps*. Accordingly, the categorization is done for analytical purposes only. Notice also that drying is not included in this analysis.

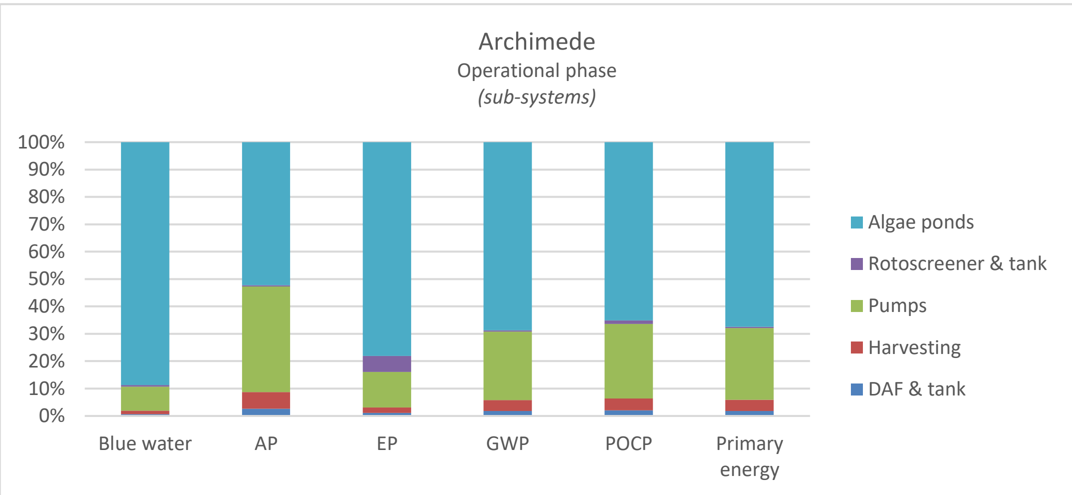

Figure 13. Archimede operation phase – relative influence of subsystems per impact category, all impact categories normalized.

Figure 13 shows that most of the environmental impacts are associated to the algae cultivation in the ponds. Two specific activities classified as *algae pond* activities contributes to most of this impact, namely the CO_2 addition and the electricity. The electricity used in the pump is PBR air bubbling blower, the cooling tower fans and the two paddle wheels. Figure 14 shows desegregated results per activity.

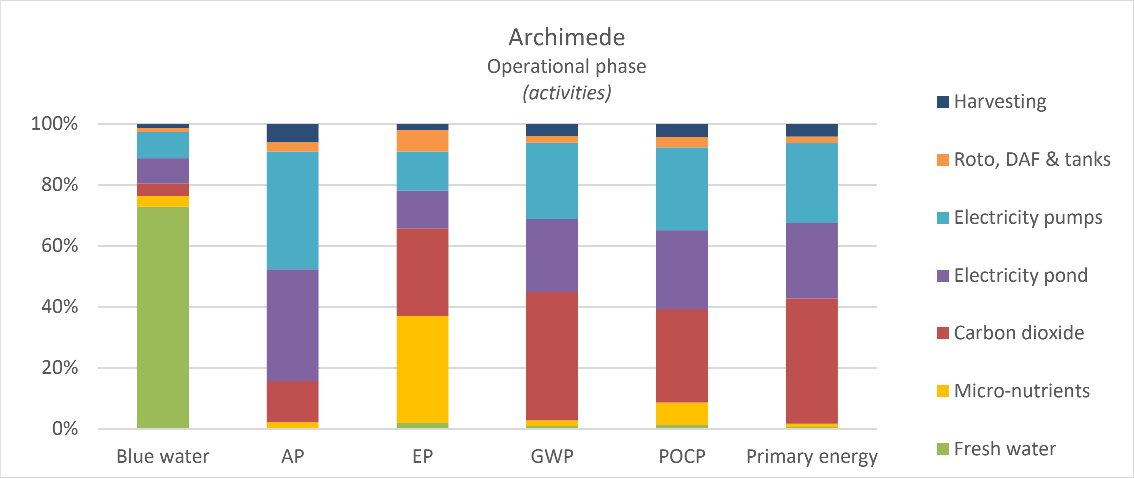

Figure 14. Archimede operation phase – relative influence of activities per impact category, all impact categories normalized.

As shown in Figure 14, the CO_2 added into the algae pond for algae growth constitutes around 40 % of the overall GWP impact of the Archimede system. The CO_2 added into the pond is produced through the Haber-Bosch process which is energy and resources intensive. The electricity used in the pumps and the electricity used in the pond contribute to another 50 % of this impact (i.e. each activity contributing 25 % each). A major hotspot is the electricity used for the two PBR air bubbling blower which contributes to 15 % of the GWP. Primary energy demand and POCP have a very similar activity profile.

The contribution per activity for the AP is also similar to the GWP profile; however, the relative contribution of the CO_2 added is much lower with only 15 % of this impact. The production of electricity for the pumps and pond are the largest contributors with 75 % of this impact. Hydrogen sulfide air emissions from electricity production have a great impact in AP.

In terms of EP, the major impact is from the production of the micro-nutrients are highlighted as a hotspot, equating to 35% of this impact. Most of this impact is related to the phosphate emissions to freshwater in the production of monosodium phosphate. The production of the CO_2 added into the algae pond is also a large contributor with around 30 % of this impact. Electricity is still significant for EP with 25 % of this impact. For water consumption, the fresh water directly used in the ponds (i.e. to replenish evapotranspiration) constitutes to around 75 % of the total water consumed. Water pre-treatment (Roto-screener and DAF) and harvesting activities are only marginally contributing to the overall impacts.

7.3 Algae valorization LCA results

The results presented in this section are the *operational* environmental impacts of the production of 1 kg of algae-based product and its respective benchmarks. Three sets of results are presented for gluten composites, namely a case with high algae content (29 % algae), a case with low algae content (9 % algae) and the benchmark with no algae. Notice that only GWP is assessed here. Figure 15 shows that the algae-based gluten composites in the best-case scenario (29 % algae content) have an improvement of 6 % reduction of GWP compared to the benchmark system. The improvement is not large due to that the GWP from hot pressing and mixing are the main contributors.

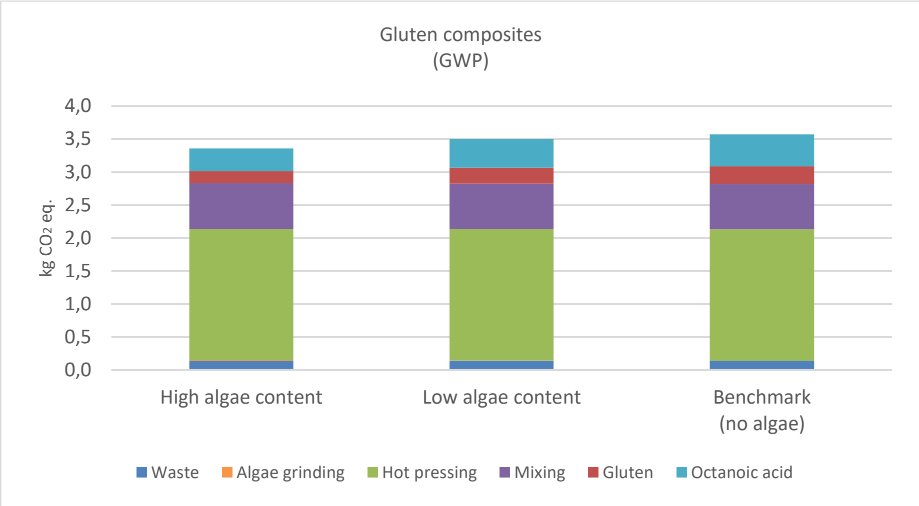

Figure 15. GWP impact of two algae-based gluten composites and benchmark.

The impact from the production of raw materials (i.e. gluten and octanoic acid) is 20 %. In the best-case, the impact from gluten and octanoic acid production is reduced by 30 % equating to an overall 6 % GWP reduction. It is important to consider that the climate impact of mixing and hot pressing is dependent on the climate impact of the electricity grid. The Italian electricity grid is heavily fossil fuel dependent, mainly natural gas and coal (equating to 55 % of electricity grid). In an opposite case like in Sweden, which has a low carbon grid, the contribution from hot pressing and mixing would be reduced and the GWP reduction for the algae-based composited would be greater.

Four sets of results are presented for rubber composites in Figure 16 below. The first two model to the left represents the best-case scenario where the rubber composite formulation has 26 % of carbon black which is replaced with algae. In this case a 15 % climate impact reduction is achieved. The two sets of result to the right represent a scenario where the rubber composite formulation has only 8 % of the black carbon which is replaced with algae. In this case only 5 % reduction is achieved.

Hot pressing and mixing are important contributors to the overall environmental impact of rubber composites. However, the climate impact related to raw material production is also significant, and carbon black contributes to 15 % of the climate impact in Benchmark 1 (i.e. 26 % of carbon black in formulation). This impact is almost completely reduced with the use of algae, since algae carries no environmental burden from production and only the grinding energy is considered as impact.

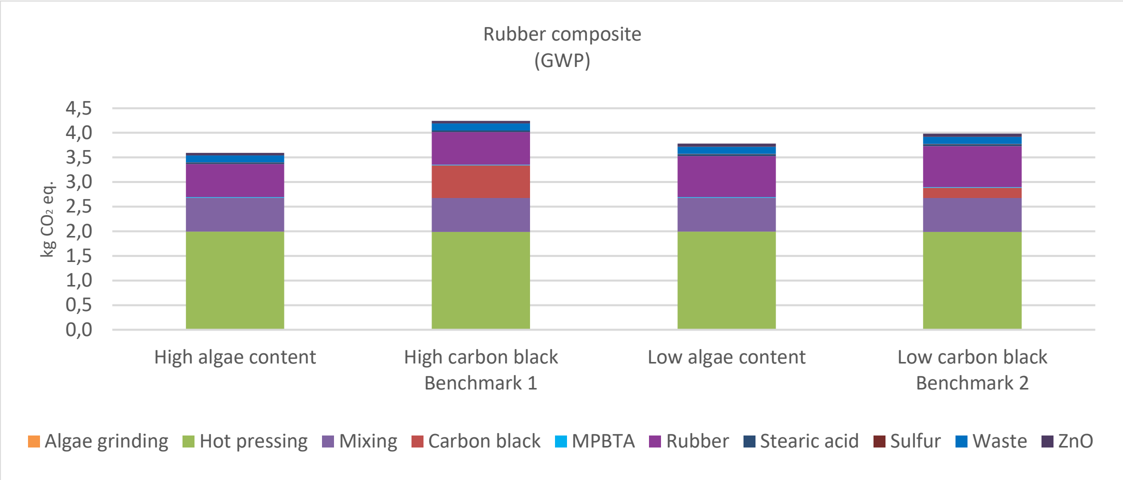

Figure 16. GWP impact of two algae-based rubber composites and benchmarks.

It is important to notice that for both type of composite the best improvement would be achieved if the algae reduced the amount of energy used in mixing and hot pressing. In this assessment it was assumed that this energy would not be affected by the addition of algae.

In terms of animal feed, two different cases were assessed with different algae contents and a benchmark product with no algae. The dataset represents the environmental impact of the production of animal feed where the fish is Norwegian fish purposely caught for animal feed. The market also offers a fish meal with lower environmental impact, where the fish used for fish meal production is a by-product from fish aimed for human consumption. This latter type of fish meal is not considered in this study.

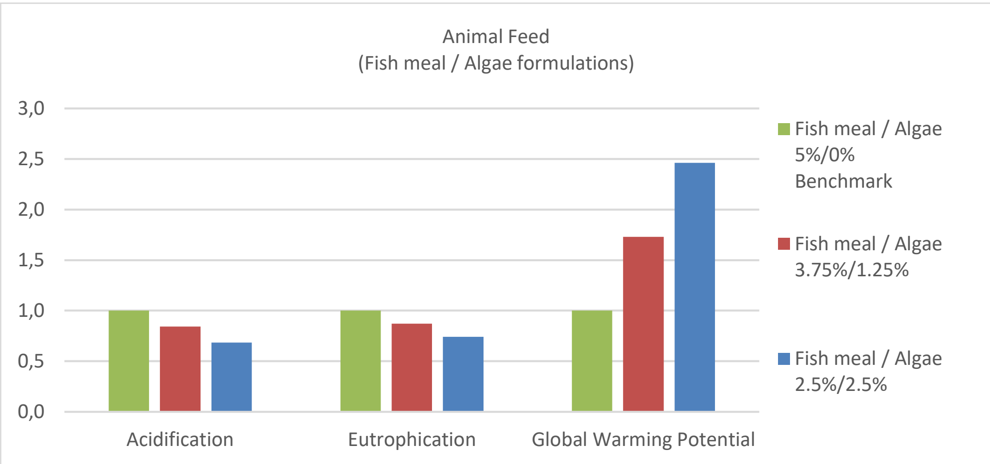

Figure 17. Animal Feed results for three impact categories, normalized to benchmark**.**

Figure 17 shows the results for three impact categories, namely AP, EP and GWP. These results are normalized to the benchmark, namely the green column where no algae are used in the animal feed. For AP and EP, the benchmark case has the highest impact. This implies that the use of algae as additive in animal feed yields environmental improvements. For AP and EP, the addition of 2.5% of algae yields around 30% reduction of this impact. However, for GWP the benchmark case has the lowest environmental impacts. In other words, the use of algae in animal feed is not expected to reduce the GWP impact.

Figure 18 below shows the relative results for the AP, EP and GWP for one kilogram of fish meal versus one kilogram of algae produced in Archimede. The figure below is normalized per impact category to the highest number. For the first two impact categories, namely AP and EP, algae produced in Archimede has from 40-50 % lower impact than fishmeal from purposely caught fish in Norway. However, for GWP the algae produced in Archimede has higher GWP impact than fishmeal from purposely caught fish in Norway.

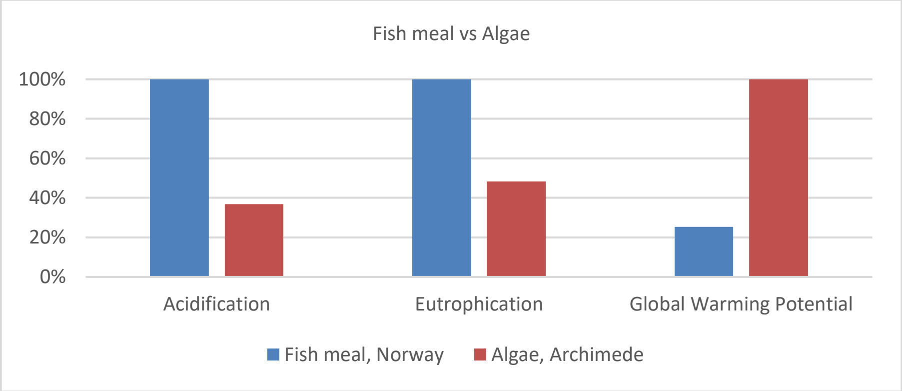

Figure 18. Environmental impact of 1 kg of fish meal versus 1 kg of algae, normalized per impact category.

When analysing Figure 17 and Figure 18, consider that all the environmental impact of the Archimede demo site is assigned to its biomass production. If price numbers for algae and wastewater treatment become available, the impact related to algae production would be reduced and the numbers in Figure 17 and Figure 18 would change. Deliverable 7.3. should include a sensitivity analysis for this allocation procedure.

8 RESULTS -- Economic assessment

In this section the results of the economic assessment of KOTO, Archimede and the algae valorization routes are presented. Similar to the structure in Section 7 (Environmental assessment), the results for the *construction phase* and the *operational phase* of the KOTO demonstration site are presented first in Section 8.1. Second, the results of the operational phase of the Archimede demonstration site are presented in Section 8.2. Notice that for both of these assessments the functional unit is 1 m^3 of raw wastewater treated. Section 8.3 presents the results for the three algae valorization routes and compares them with their respective benchmark systems. Notice that the results in Section 8.3 are calculated per 1 kg of product.

8.1 KOTO results

8.1.1 KOTO LCCA construction phase results

As mentioned before, in the economic analysis, the construction phase equates to the capital costs calculated. The investment costs or capital expenditure (CAPEX) is one of the key performance indicators used by decision makers. To estimate the CAPEX for the SaltGae concept, which consists of several different configurations, cost models are needed. In this report, the cost models used for the analysis consisted of cost functions for component cost based on cost values from the two demo sites and valorization routes, with respective material and labour cost multipliers, to ensure that results are sensitive to the specific location considered.

The *construction phase* results are analyzed using five sub-systems:

1. Roto-screener pumps
2. Distribution system 2-AD
3. Tanks
4. Greenhouse system
5. Harvesting (DAF)

Notice, that in comparison with the LCA chapters, the sub-systems Control center and pond heating are included in Greenhouse system, and the cost for CO_2 addition system are included in the 2-step AD system since these could not be separated or were too small.

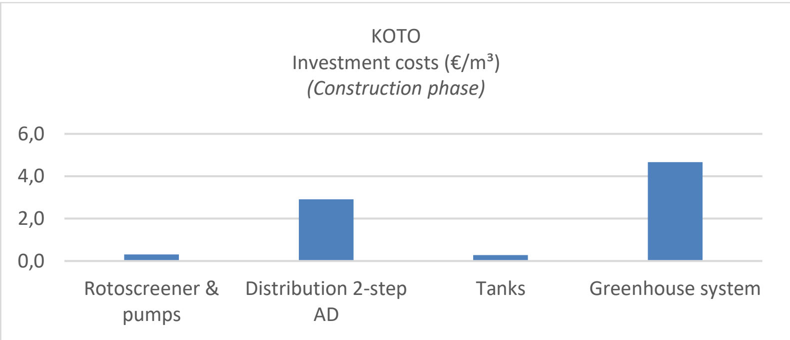

Figure 19. KOTO construction phase cost results per sub-system.

The results presented in Figure 19 show that the greenhouse system account for more than 50 % of all cost of the sub-systems in the construction phase. Except for the greenhouse it also includes the costs for the pond, the mechanical equipment and electrical equipment for controlling the system, which makes it the largest cost contributor in the construction phase. The second largest, the distribution 2-step AD sub-system account for around 30 % of the construction phase. It mainly includes costs for pumps and the anaerobic reactor.

8.1.2 KOTO LCC operation phase results

The operational expenditures (OPEX) as a performance indicator, relates to all operational and maintenance (O&M) costs incurred in the normal operation of the demo site throughout a period of time, usually a 'typical' year.

The typical annual OPEX refers to utility costs, service costs, labor costs, insurance costs and other miscellaneous (contingency). Utility costs relate to electricity and external water, for instance. Service costs relate to all normal maintenance included in the service agreements with the O&Ms. OPEX cost models are sensitive to reference cost values and scaling coefficients. The data provided by the Demo sites for this study are based on rough estimations, specially energy costs and maintenance costs. Section 8.1.3 includes a sensitivity analysis to the OPEX assumptions and their impact on other financial indicators

The *operational phase* results are analyzed using the four sub-systems presented in Figure 4 plus a category specific for all pumps installed throughout the system.

1. Roto-screener & tank
2. 2 step-AD & tank
3. Algae pond
4. Harvesting
5. Pumps

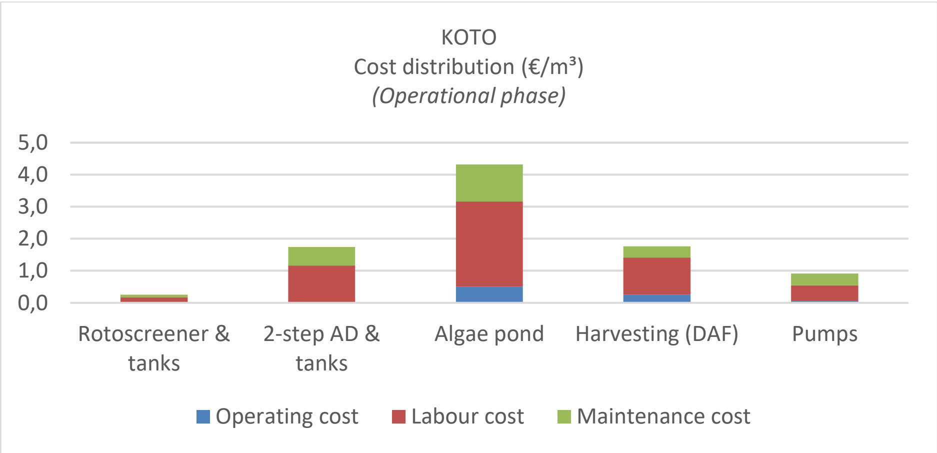

Figure 20. KOTO operational phase cost distribution per sub-system.

The major operational phase cost expenditure encountered in KOTO is for the algae pond where labour cost is the main contributor, as shown in Figure 20. Salaries were taken from average labour costs in Slovenia (Annex IV). The total annual labour time was based on data from the demo site and the total cost of labour amounts to 17300 €/yr. Maintenance costs for each category is in average around 30 % of the category's total impact, which can be changed when the concept goes from demo to an industrial site.

For the pumps it is mainly the pumps connected to the anaerobic digesters (feed pumps, recirculation and diluting pumps) that contributes to the cost in the operational phase. They also contribute with the highest energy consumption for each of the sub-systems.

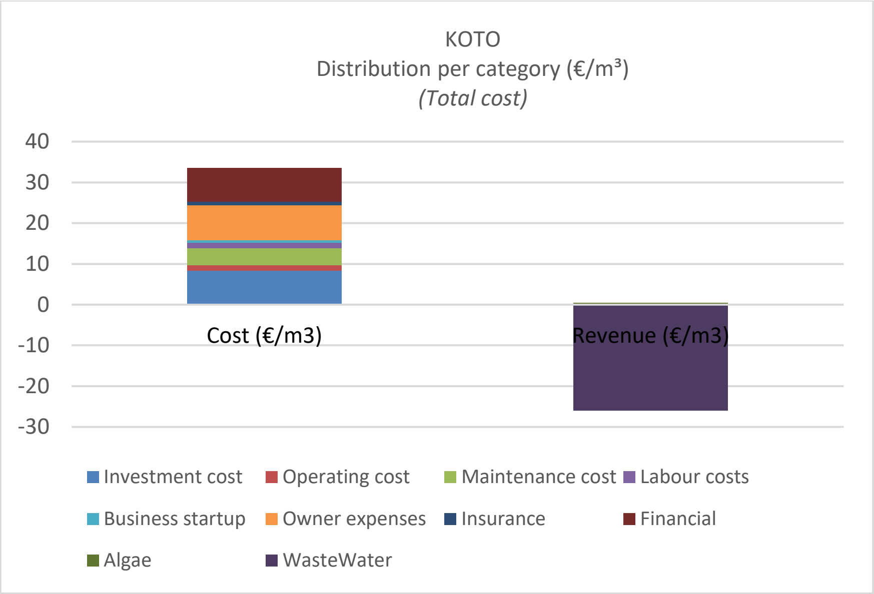

Figure 21. KOTO total cost distribution per category with break-even revenue.

Most of the costs of the KOTO system are associated with the costs originating from the construction phase and financial/ business categories. Owner expenses, which can be seen in Figure 21 includes costs for procurement, supervisory and administration for the demo site, and this was assumed to be 10 % of the investment costs (Annex IV). Since the algae production low, the revenue category is also low and can be seen as just a theoretical post for the moment. The negative expense shows the cost disposal of the waste water if the system wasn't there (26 €/m^3) [11]. Calculating the NPV shows a negative value of -979 k€ after 30 years, with the algae price set to the assumed market price (5 €/kg). To receive a positive NPV, the minimum price which is needed if the demo site wants to be self-sufficient, it would be needed a market price of around 300 €/kg, or which is more likely, a higher algae production.

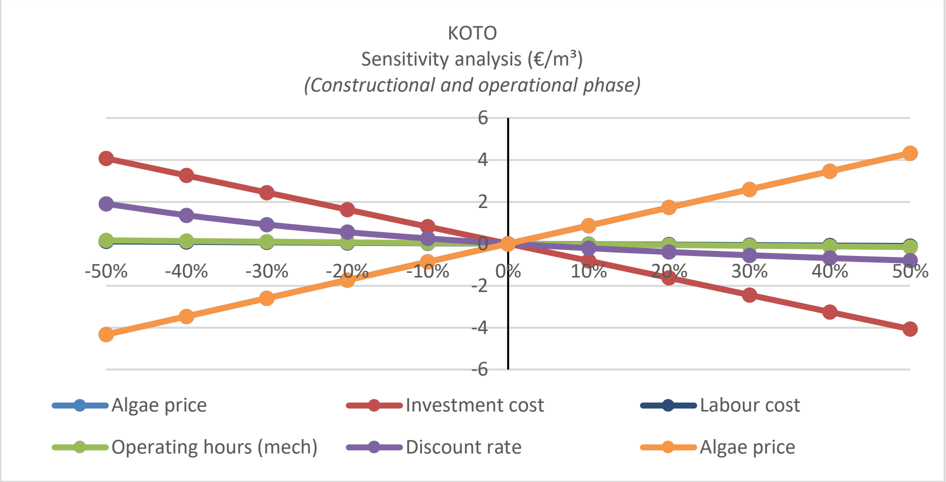

Figure 22. KOTO sensitivity analysis per category**.**

Figure 22 shows the sensitivity analysis for six cost parameters, namely the algae price, investment cost, labour cost, the operating hours, the energy price and the discount rate. These results are normalized to the break-even price (€/m3), the case where the costs are covered by the theoretical revenue from Figure 20. Except for percentual changes in algae price, the greatest impact category is changes in investment cost. Changes in energy price contributes little to the overall algae price, even with a 50 % change the break-even price stays almost unaffected.

8.2 Archimede LCC results

The *constructional* and *operational phase* results for Archimede are analyzed using the five sub-system presented in Figure 5 plus a category specific for all pumps installed throughout the system.

1. Roto-screener & tank
2. DAF & tank
3. Algae ponds
4. Harvesting
5. Pumps

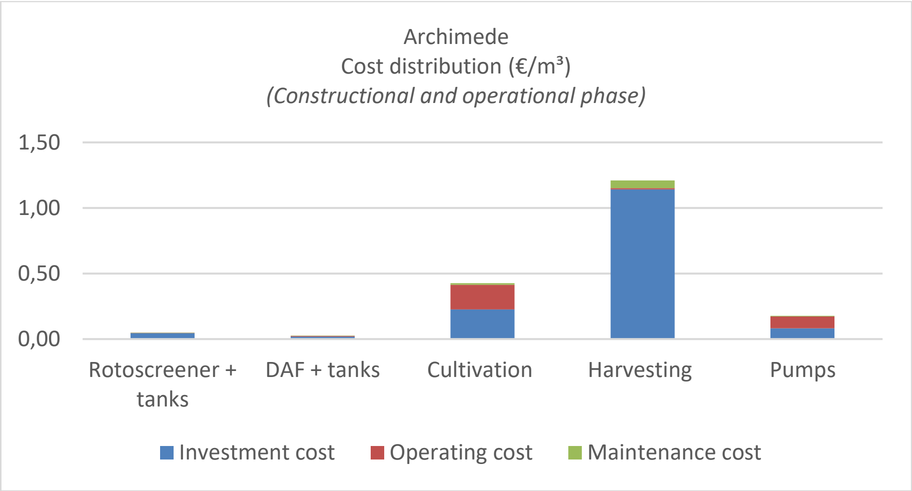

Figure 23. Archimede constructional and operational phase cost distribution per sub-system. Cost for labour is excluded in the figure since the category is an overall cost.

The results in Figure 23 show that most of the costs for Archimede are associated with the algae cultivation in the ponds and harvesting. For cultivation the main cost input is originating from operating costs, where electricity and nutrients stands for most of the costs. For the harvesting case the main contributor is the investment cost during the constructional phase. Each of the ultrafiltration or the centrifuge equipment need investments making them the highest contributors to initial capital investment. The pumps are in comparison with the other sub-systems presented in Figure 23, rather small. But they are a major contributor to the energy demand. The energy used in the pumps represent approximately 50 % of the total energy demand of the Archimede demo site.

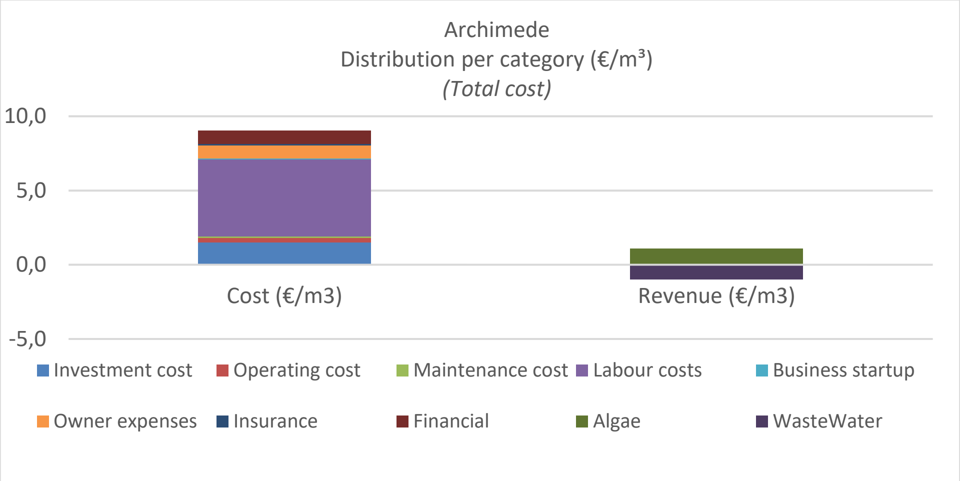

Figure 24. Archimede total cost distribution per category with break-even revenue.

Figure 24 shows that most of the costs are originating from labour costs. Salaries was calculated with average labour costs in Italy [10]. The total annual labour time was based on hiring three persons and the total cost of labour amounts therefore to 147 k€/yr. Similar to Figure 23 the main cost, except for labour cost comes from the harvesting part and the cultivation which stands for the major impact on the operating cost of the algae systems. The negative expense shows the cost disposal of the waste water if the demo site system was not there (1 €/m3) [12]. The revenue category is corresponding to an assumed sell market price of 5 €/kg algae which results in a negative NPV of -1648 k€ after 30 years. [1], [17], [27].

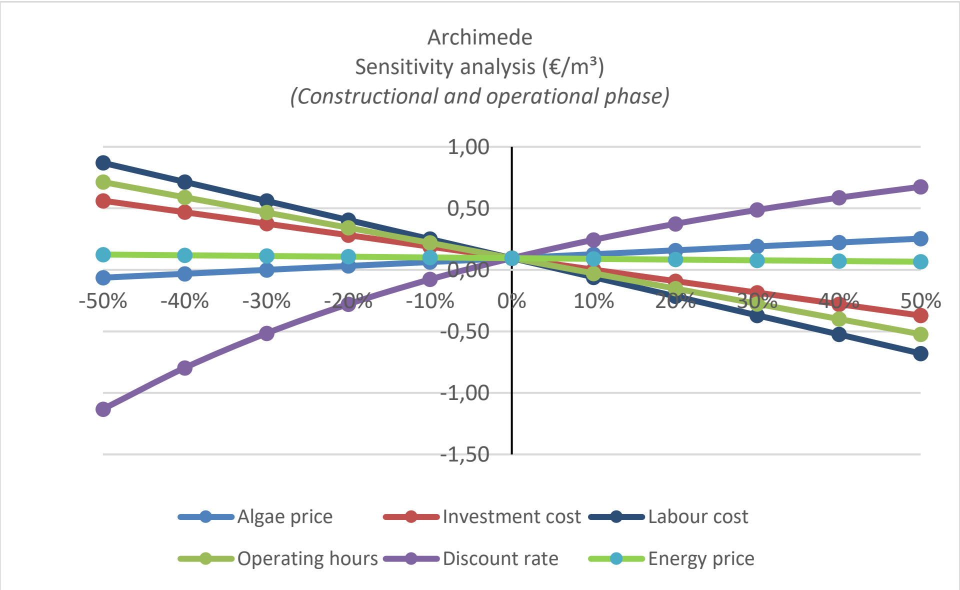

Figure 25. Archimede sensitivity analysis per category.

Figure 25 shows the sensitivity analysis for Archimede based on six impact categories, namely the algae price, investment cost, labour cost, the operating hours, the energy price and the discount rate. These results are normalized to the break-even price, the case where the costs are covered by the theoretical revenue from Figure 24. Except for percentual changes in investment and labour cost, the greatest impact category is in operating hours. A 50 % change in operating hours affect both the cost of operating the demo site but also labour cost. Changes in energy price contributes little to the overall algae price, even with a 50 % change the break-even price stays almost unaffected.

8.3 Algae valorization LCC results

Similar to the results in section 7.3, the results presented in this section are the *operational* environmental impacts of the production of 1 kg of algae-based product and its respective benchmarks. Three sets of results are presented for Gluten composites, namely a case with high algae content (29 % algae), a case with low algae content (9 % algae) and the benchmark with no algae. Because some data of the stage between producing and valorization of the algae were missing there is a difference between the LCCA and LCA assessment. For the economical part, instead of using data from the demo sites and our partner, a market value for the algae is used as data input (5 €/kg). This will be changed to the next deliverable. In Annex VIII more of the assumptions and data input are described.

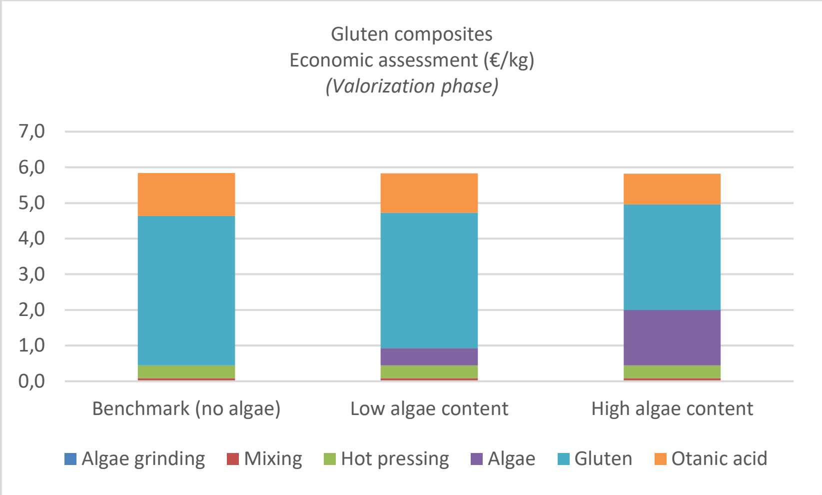

Figure 26. Economic assessment of two algae-based gluten composites and benchmark.

Figure 26 shows that the algae-based gluten composites either in the high-case scenario (29 % algae content) or in the low-case scenario (9 %) have no improvement or deterioration in the economic assessment. The changes in algae content are almost the same cost as when the gluten and octanoic acid part is changed.

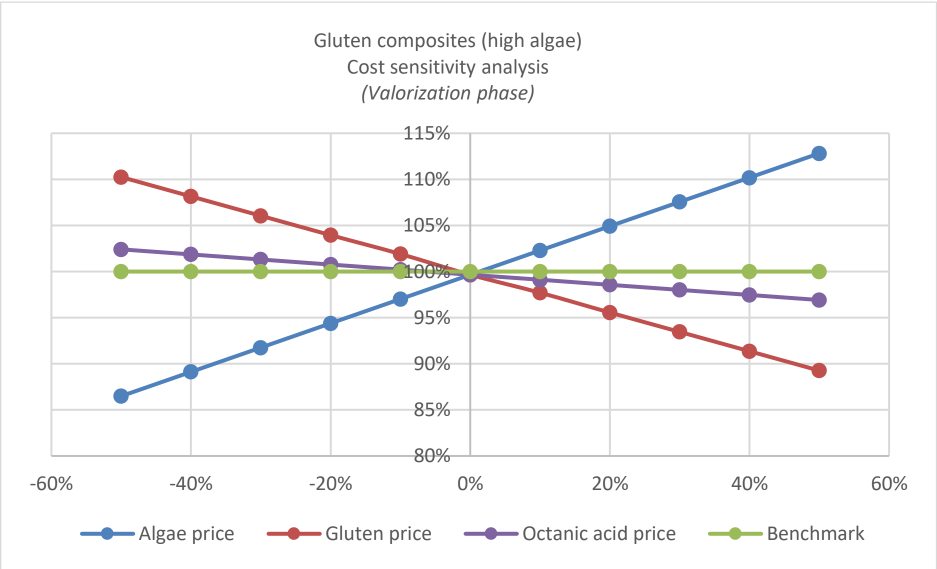

Figure 27. Cost sensitivity analysis of the high algae-based gluten composite case.

For the high algae-case scenario (29 % algae) a 5 % change in the algae price makes the price for the algae-based gluten composite around 3 % less expensive than the benchmark scenario. Resulting in making it more profitable for the market for the algae-case scenario. But on the other hand, if the gluten price would decrease with 5 %, then the price for the algae-based gluten composite would increase making the benchmark scenario more profitable.

Four sets of results are presented for rubber composites in Figure 28 below. The first two model to the left represents the low-case scenarios where the rubber composite formulation has only 8 % of carbon black which is replaced with algae. The two sets of result to the right represent a scenario where a high content (27 %) of black carbon is replaced with algae (content in Annex V).

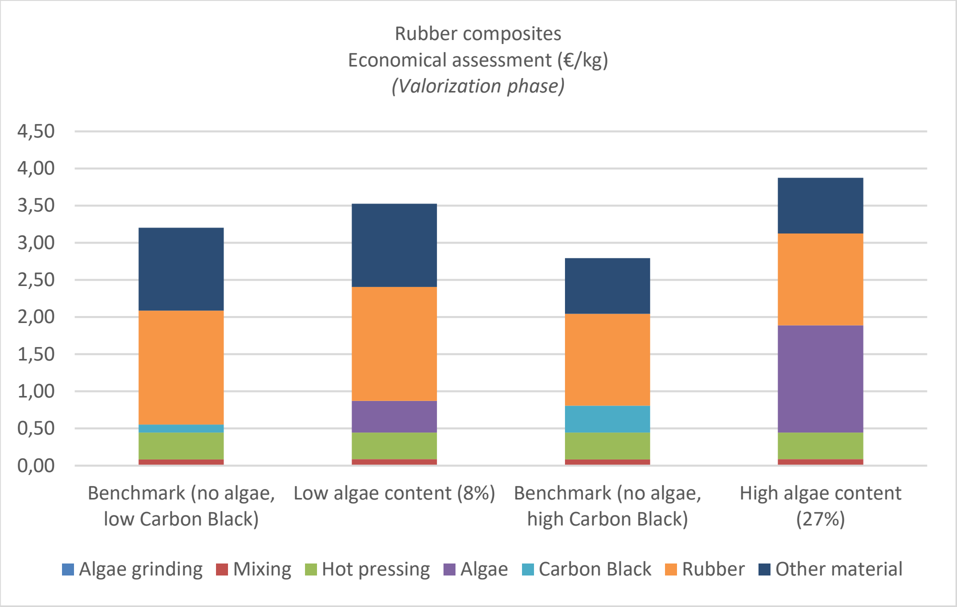

Figure 28. Economical assessment of two algae-based rubber composites and benchmarks.

Since the market price of algae are significantly higher than the market price of Carbon black, it is more profitable from an economical point of view to invest in the Carbon black case. For the low algae-case scenario (8 %) it is almost a 10 % increase in costs. From a cost sensitivity analysis, even a 50 % decrease of the algae market price would not make the low algae-based rubber composite more profitable than the benchmark. For the content and raw material costs in the categories, see Annex VII.

In terms of animal feed, two different cases were assessed with different algae contents and a benchmark product with no algae. Three sets of results are presented for animal feed, namely a case with high algae content (2.5 % algae and 2.5 % fish meal), a case with low algae content (1.25 % algae and 3.75 % fish meal) and the benchmark with no algae.

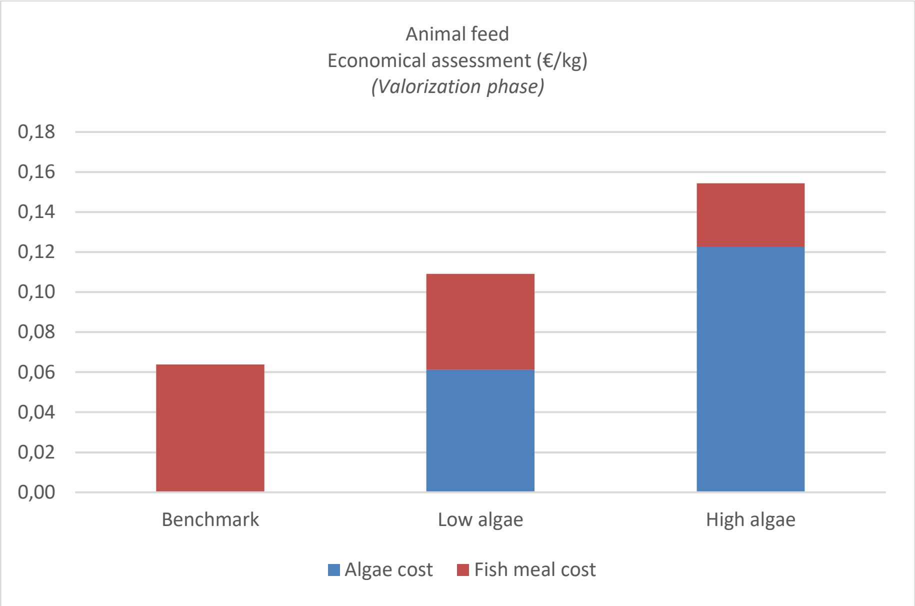

Figure 29. Economical assessment of two algae-based animal feed and benchmarks.

Figure 29 shows the economical assessment of three types of animal feed. Since the market price of algae are also significantly higher than the market price of fish meal, it is more profitable from an economical point of view to invest in the benchmark case. For the low algae-case scenario (1.25 %) it is almost a 70 % increase in costs with the assumed costs as mentioned in Annex VII. From a cost sensitivity analysis, even a 50 % decrease of the algae market price would not make the low algae-based animal feed more profitable than the benchmark.

9 CONCLUSIONS AND FURTHER WORK

9.1 Social conclusions

The results of the literature review suggest that the following aspects are highly relevant for the social impacts of algae-based wastewater treatment systems:

- Health and safety of workers
- Access to drinking water and sanitation of local communities
- Decent work creation, local employment
- Engagement with local citizens
- Location of the plant (country)
- Substituted products

Next deliverable will include a Social LCA with quantified results for one or two of the wastewater treatment and algae production demo sites.

9.2 Environmental conclusions

The first goal of this study was to identify the process steps contributing the most to the overall environmental impact of the SaltGae wastewater treatment systems and the possible improvement possibilities. This section presents the conclusions and further work for KOTO, Archimede, composites and animal feed.

For KOTO, the impact related to the construction of the system is relatively low compared to the impact related to the operation of the system. The only impact category where *construction phase* contribution is more than 10 % is primary energy use. Around 30 % of this impact (i.e. around 3 % of the overall primary energy used in the KOTO system) is due to the production of the plastic of the tanks. Several improvement possibilities are suggested for the future design of a SaltGae wastewater treatment system: first, the number of tanks could be the reduced; second, the chosen tanks could be light weighted; third, bio-based plastic could be chosen as material for the tanks. For the improvement possibilities suggested to be environmentally effective, it is important to assure that the life time of the tanks remains the same or increases.

The major improvement possibilities for the KOTO system rely in the freshwater used in the 2-step AD system. This water consumed not only increase the water footprint of the system, but it also makes the overall environmental performance of the system to decrease. The functional unit of this study is 1 $m^3$of raw wastewater treated, if freshwater can be replaced with actual raw wastewater without a significant increase in energy and materials used, then the specific environmental[7] impact of the system would be reduced by around 50 % for all impact categories and 96 % for water consumption.

It is important to notice that reducing the amount of freshwater used (or any changes made to the system) should not reduce the amount of biogas production in the 2-AD system. The 2-AD system produces biogas, it is important to maintain the rate of biogas production since for every 1 m^3 of biogas produced the system receives credits for avoided emissions.[8] In the current system 4 % of the overall climate change (GWP) impact of KOTO are avoided thanks to this biogas production.

[7] Specific environmental impact refers to the environmental impact per m^3 of wastewater treatment.

[8] For more information see section Section 3.5 for calculation method for the credits.

Another important improvement possibility for the KOTO system is to reduce the energy consumed by the pumps. This energy contributes from 55-75 % of each impact category. Harvesting is also significantly contributing to the impact for all categories. A significant reduction in the amount of electricity used would lower the AP, GWP and POCP impacts significantly. Notice that the energy figures used in this analysis are too high and not representative (i.e. based on nominal equipment power). Operational data from KOTO will be collected in 2019, when the demo site has been running continuously for a representative amount of time.

For the Archimede site, the CO_2 added to the algae ponds is a major hotspot of environmental impact. Especially for GWP, EP, POCP and primary energy demand. To significantly reduce these impacts, another source of CO_2 needs to be explored. The adjacent CHP plant has bio-based CO_2 emissions, if this CO_2 could be captured, refined to be food grade and added to the ponds the overall climate impact of the Archimede system would be significantly reduced.

The electricity used in Archimede's ponds and pumps is also a significant contributor to AP, GWP, POCP and primary energy used. A major hotspot is the electricity used for the two PBR air bubbling blower; alone contributing from 15-25% of the impacts. A possible improvement possibility is to use green electricity instead of regular Italian grid electricity. The Italian electricity grid is heavily using fossil fuels, mainly natural gas and coal[9]; with green electricity the environmental impact of the pumps would be significantly reduced. Notice that directly using the adjacent vegetable oil CHP electricity could be also beneficial.

In terms of EP, the major impact is from the production of the micro-nutrients used in the Archimede ponds; mainly the production of monosodium phosphate and its phosphate emissions to freshwater. When possible, avoid any overuse of micro-nutrients. In terms of further work, all energy numbers from the Archimede site will be revised with actual operational numbers when the demo site starts running. Furthermore, an LCA for the Arava site will be included in D7.3.

A goal of this study has been to understand the environmental advantages or disadvantages of using algae grown in wastewater to replace existing raw materials in animal feed and composites. In terms of composites, the LCA showed that the climate impact of rubber-based composites significantly improves (15 % reduced) when waste algae substitutes carbon black in a composite formulation with 26 % of carbon black. For gluten composites, the replacement of gluten and octanoic acid with waste algae does not yield significant improvements or worsening of the climate impact of this composite. Future work on this area includes a sensitivity analysis where algae is not waste algae from Extractis, but algae directly from Archimede (i.e. thereby carrying some environmental impact). Further, the consortium should decide if understanding the hotspots of ceramic paste should be added to D7.3.

In terms of animal feed, these preliminary LCA shows that there is an environmental advantage of using algae as additive in animal feed to replace fishmeal from purposely caught fish. This advantage is in the reduction of AP and EP impacts. However, the addition of algae in animal feed does yields a higher GWP impact. Notice that our analysis focuses on typical environmental impacts quantified in LCA. However, the main environmental impacts of fishery cannot be easily quantified with LCA. For instance, it is known that overfishing affects biodiversity, ecosystems and fish stocks. In turn, biodiversity and ecosystem losses impact the resilience of our marine ecosystems to deal with climate change. These issues and other important environmental issues of the fishing industry are not quantified in this study; however, this should be considered in decision making. Future work on this area include a sensitivity analysis for the allocation procedure chosen for algae.

[9] The Italian grid has 55 % of electricity from coal and natural gas.

In terms of platform chemicals for resins, adhesives and coatings, the consortium needs to decide if simplified LCA for some routes should be performed in D7.3. In the case some routes will be explored, the environmental impact of algae refinement (Extractis) should be included. In terms of water valorization processes, a specific water valorization questions should be defined by the consortium and answered in D7.3. Furthermore, the final report will also include an integrated sustainability assessment where the main social, environmental and economic issues will be weighted together using a stakeholder's perspective.

9.3 Economic conclusions

The first goal of this study was to identify the process steps contributing the most to the overall economic impact of the SaltGae wastewater treatment systems and the possible improvement possibilities. This section presents the conclusions and further work for KOTO, Archimede, composites and animal feed. It is important to consider that this study is based on data originating from demo sites which hasn't been operating for a long time, so the results can change when scaling up to industrial.

For the KOTO site, the construction phase is relatively high compared to the impact related to the operation phase. It is the algae ponds and greenhouse system that has both the highest investment and labour costs. The costs could be reduced by similar steps described in Section 9.2 Environmental conclusions, if it doesn't affect the production quality. Considering that the system avoids potential environmental taxes, the demo site and technology becomes valuable. From an economic point of view, one goal for the demo sites is to be self-sufficient, another improvement could be to optimize the processes and increase the algae production, which is for the moment only producing 1 kg / day. It is important to notice that the demo site has not been running for so long, and have had some issues during the period of this study so for instance maintenance and energy cost are based on rough estimations.

For the Archimede site, the major improvement possibilities are in decreasing the labour costs since it is clearly the largest cost contributor. If disregarding the labour cost, then operating costs of cultivating and investment costs of harvesting are the two largest cost categories. They each stands for approximately 1/3 of the total costs. Therefore, if it already has not been done, it would be preferable to do an economic assessment for finding cheaper technologies to replace ultrafiltration and centrifugation.

Overall, the market price for algae is widely diverse, ranging from 0.5 €/kg up to 100 €/kg depending on cost efficiency of the algae productions and the quality of the algae. Techno-economical assessment which have been performed on similar demo sites has set a minimum price between 12 €/kg to 69 €/kg putting Archimede in the lower department. But the system will need further improvements to be able reaching the market price of 5 €/kg.

Another goal for this study was to understand the environmental advantages or disadvantages of using algae grown in wastewater to replace existing raw materials in animal feed and composites. For the gluten composites it has the same costs and could therefore be a good contender as a substitute for gluten; if the algae market price could decrease. In terms of rubber composites and animal feed, the LCCA showed that the market price for algae are currently too high for replacing the benchmarks. For further assessment it is therefore important to also consider if the material becomes more valuable by increased qualities, and consequently be sold for a higher price.

10 TOOLKIT PROGRESS REPORT

10.1 Objectives

The Saltgae Visualisation Toolkit (SVT) was conceptualised to demonstrate the potential of the Saltgae solution. Work package 7 deliverables include both environmental LCA, and economic life cycle cost analyses (LCCA) of the three Saltgae demonstration sites. This reporting will provide environmental and economic profiles of the Saltgae solution as it is applied to three different types of wastewater (WW). The results of the analyses can then be used as benchmarks and provide validation for the system models that have been developed. Additionally, the inventories that have been compiled for the LCA and LCCA provide the basis for the SVT. The primary objective of the SVT is that of a marketing tool. While reporting from the three demonstration sites provides information about the performance of the Saltgae solution with specific WWs in specific locations, potential stakeholders and interest groups may find it difficult to translate these results to other industrial sectors that experience variations in WW, climate, specific cost elements (water, energy, and chemicals), discharge limits, and region-specific environmental concerns. The solution was to provide a site-specific visualisation tool that would allow a user to select similar conditions to those in their location and produce site-specific economic and environmental profiles of the Saltgae solution.

10.2 Challenges

There were some significant challenges involved with the design of the SVT architecture.

10.2.1 Platform

The SVT had to have universal application for effective dissemination and marketing, and therefore needed to be designed on a commonly used platform. It was decided that Microsoft Excel Visual Basic for Applications (VBA) fitted this requirement. However, this involved a trade-off with programming power. Large sub-system and process models such as the anaerobic digestion (AD) and high rate algae pond (HRAP) require significant computational power. Running these models in VBA would take a considerable amount of time, and in some cases has the potential to crash the program, which was not considered practical for its objective as a marketing tool.

10.2.2 Data acquisition

The SVT requires a significant amount of data beyond those from the demonstration sites. To appeal to a wider industrial audience, it was decided that the SVT should include a broader range of WW types and strengths. Wastewater characterisation data required to run simulations in an AD model are much more detailed and extensive than other processes (COD fractionation to lipid, protein and carbohydrate level) and are difficult to obtain. Capital expenditure (CAPEX) estimations are required for a range of flowrate scales from 5 – 500 m^3/d. These estimations cannot be scaled linearly as they would not capture the scale economies as commonly exhibited by other wastewater treatment systems (WWTSs). Similar scale economies have been observed for energy consumption and OPEX, and therefore, it has been necessary to ask the project partners to provide additional information that was not within the original scope.

10.3 Design

To overcome some of the challenges it was necessary to compromise between site-specificity and program complexity. The solution was to provide the SVT user with a discrete set of parameter values from which to select (Table 7). This approach eliminates the need to include complex models within the program, which allows almost instant presentation of predetermined, sub-system and process simulation results. Other site-specific parameters such as energy, chemical, water, and labour costs have been soft-coded into the program with average values from the literature provided for default. The limitations of this approach are:

- Wastewater is highly variable. Even with a large database of WW types, there will always be some level of variation in its composition. This means that the program outputs will never reflect the exact conditions at a given site.
- This approach requires large amount of simulation data for each sub-system.

Table 7. Toolkit user-input parameters

Parameter	Variation	Notes
Wastewater types	Aquaculture, brewery, corn processing, dairy, distillery (spirits), distillery (wine), meat processing, olive mill, poultry processing, tannery.	Selection of WWs was based on data availability in the literature. Additional WWs can be included where data becomes available
Wastewater strength	Low, medium and high	Describes the variation in the range of COD concentrations as reported from the demonstration sites and from literature sources
Flowrate	5, 25, 50, 100, 250, 500 m3/d	It may be uncommon to have a company that produces 500 m^3/d of WW, but with a high enough COD concentration it may be feasible to invest in a CHP plant to further realise the advantages of AD
Salinity	1, 5, 10, 20, 30, 40 g/L	
Wastewater temperature (mean)	User defined	
Ambient temperature (mean)	User defined	
pH	Based on WW characterisation data but can be changed by user	
Country	Belgium France, Ireland, Israel, Italy, Portugal, Slovenia, Spain, Sweden, U.K.,	Required for environmental profile of electricity grid-mix. Additional countries can be included by request

10.4 Output

As stated, the SVT outputs will include economic and environmental profiles for user defined scenarios. The economic profile will include a breakdown of the capital and operational costs per sub-system (Figure 30), and a system LCCA (Figure 31). This will include estimations for variations in algal species values, and sensitivity analysis for energy, water, and brine disposal costs. A system energy profile will also be included to provide transparency regarding anticipated energy consumption. Energy estimations are provided with average values and uncertainty ranges. The environmental profiles are presented as life cycle impact assessments (LCIA), with the choice of LCIA methodology (e.g. CML, EDIP, TRACI), and normalisation factors (Western, Northern, and Central Europe) (Figure 32).

Figure 30. Operational cost assessment (conceptual image only).

Figure 31. Life cycle cost analysis (conceptual image only).

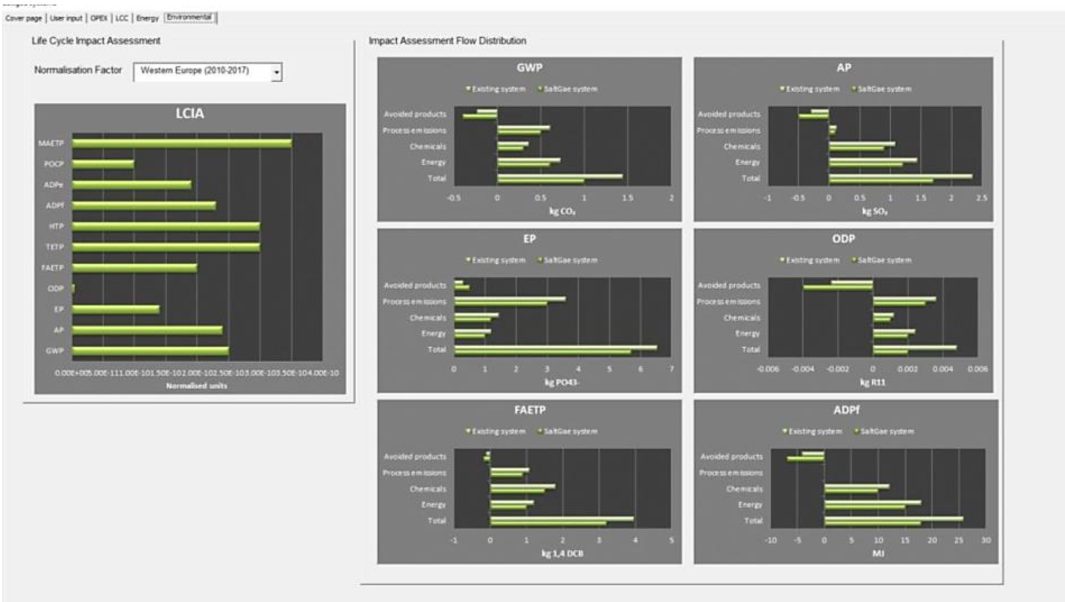

Figure 32. Life cycle impact assessment (conceptual image only).

10.5 Progress

The program architecture is nearing the end of its construction phase. Energy modelling for most of the sub-systems is completed. However, there are still some significant discrepancies between the model outputs and the empirical data collected from site. It is expected that the problem areas will be identified during the visit to Camporosso in October. All of the reverse osmosis simulations are complete and testing of the RO rig has begun in DCU which will provide validation data. There are some valorization data still to be obtained – market values for variations in algae species. Capital expenditure estimations for variations in flowrate scale are still required for the pre-treatment processes. However, Biboaqua have stated that they will assist with this when the demonstration units are installed and operating. Similarly, DCU are compiling estimations for scale variations in the RO system. Earlier delays in the program development were due to uncertainties related to data availability. It was unclear initially as to what level of data would eventually be produced and this was a determining factor in how the program would be designed, operated, and what the outputs would be. However, this has not affected the timeline for completion. Testing and validation is still scheduled for mid to the end of November, with roll-out planned for January.

REFERENCES

Table 8. References

1	Acién, F.G., Fernández, J.M., Magán, J.J., Molina, E. (2012). Production cost of a real microalgae production plant and strategies to reduce it. Biotechnology Advances, Volume 30, Issue 6. pp. 1344-1353
2	Baumann, H., Tillmann, A.M. (2004). The hitchhiker's guide to LCA. Studentlitteratur, Edition 1:3.
3	Bernesson. S. (2004). Life cycle assessment of rapeseed oil, rape methyl ester and ethanol as fuels- a comparison between large- and small-scale production. SLU Institutionen för biometri och Teknik. Uppsala 2004.
4	Bradley, T., Maga, D., Antón, S. (2015). Unified approach to Life Cycle Assessment between three unique algae biofuel facilities. Applied Energy 154 (2015), 1052-1061.
5	Cucurachi, S., van der Giesen, C., Guinée, J. (2018). Ex-ante LCA of emerging technologies. 25th CIRP Life Cycle Engineering (LCE) Conference, 30 April – 2 May 2018, Copenhagen, Denmark. Procedia CIRP 69 (2018) 463 – 468.
6	De Menna, F., Loubiere, M., Dietershagen, J., Vittuari, M., Unger, N. (2016). Methodology for evaluating LCC. REFRESH Deliverable 5.2, ISBN: 9789462577220.
7	Deng, Y., M.J. Achten, W., Van Acker, K., Duflou, J. (2013). Life cycle assessment of wheat gluten powder and derived packaging film. Biofuel, Bioproducts & Biorefining (2013), 429-458.
8	Estrada, J. M., Kraakman, N. J. R., Muñoz, R., Lebrero, R. (2001). A Comparative Analysis of Odour Treatment Technologies in Wastewater Treatment Plants. Environmental Science & Technology 2011 45 (3), 1100-1106. DOI: 10.1021/es103478j
9	Eurostat electricity prices. (2017). Electricity prices by type of user. Access: <https://ec.europa.eu/eurostat/tgm/refreshTableAction.do;jsessionid=05bnUJ1X2PkOtou8RGd23jctVw4uZe88sYLGt6hqNMMa-58BvntU!1290106958?tab=table&plugin=1&pcode=ten00117&language=en> 2018-09-03
10	Eurostat Labour prices (2017). Labour costs in the EU. Access: <https://ec.europa.eu/eurostat/documents/2995521/7968159/3-06042017-AP-EN.pdf/6e303587-baf8-44ca-b4ef-7c891c3a7517> 2018-09-03
11	Financial administration Ministry of Slovenia. (2018) Environmental taxes. Available at: http://www.fu.gov.si/en/taxes_and_other_duties/areas_of_work/environmental_taxes/
12	Global water intel. (2016) The Italian water sector. https://www.globalwaterintel.com/static_file_containers/36
13	Guinée, J.B. (2002). Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, Dordrecht, 2002, 692 pp.
14	Heck, N., Paytan, A., Potts, D., Haddad, B. (2016). Predictors of local support for a seawater desalination plant in a small coastal community. Environmental Science & Policy, Volume 66, 2016, 101-111.DOI: 10.1016/j.envsci.2016.08.009.
15	Hermansson, F. (2013). Environmental evaluation of bio-composites using LCA. Master Thesis. Chalmers University of Technology. Sweden. 2013.
16	Hoekstra, A. Y., Chapagain A. K., Aldaya M. M., and Mekonnen M. M. (2011). The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan, London, UK.
17	Hunkeler, D., Lichtenvort, K., Rebitzer, G. ed. (2008). Environmental Life Cycle Costing. Pensacola, CRC Press, ISBN 9781420054705.
18	IEC (2017). Dependability management – Part 3-3: Application guide – Life cycle costing (IEC 60300-3-3:2017).
19	Kleinegris, D. et al. (2013). FUEL4ME – Public final report. Available at: https://cordis.europa.eu/docs/results/308/308983/final1-fuel4me-finalreporting-whole-project-final.pdf
20	Kraakman, N. J. R., Estrada, J. M., Lebrero, R., Cesca, J., Muñoz, R. (2014). Evaluating odour control technologies using reliability and sustainability criteria – a case study for water treatment plants. Water Sci Technol 1 April 2014; 69 (7), 1426–1433. DOI:10.2166/wst.2014.036

21	Malcata, X. (2011). Microalgae and biofuels: A promising partnership? Trends in Biotechnology, Volume 29, Issue 11, November 2011, pp 542-549.
22	Mondal, S., et al. (2017). A socio-economic study along with impact assessment for laterite-based technology demonstration for arsenic mitigation. Science of The Total Environment, Volume 583, 2017, 142-152. DOI: 10.1016/j.scitotenv.2017.01.042
23	Montagne, X., Porot. P., Aymard, C., Querleu, C., Bouter, A., Lorne, D., Cadoret, J., Lombaert-Valot, I. and Petillon. O. (2013). Algogroup: Towards a Shared Vision of the Possible Deployment of Algae to Biofuels. Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, Vol. 68 (2013), No. 5, pp. 875-898.
24	Peñaloza, D., Keller, H. (2018). Using the social hotspots database to assess the social risks of prospective value chains: The case of D-Factory. Proceedings of the 6th Social Life Cycle Assessment Conference - 2018, Pescara, Italy.
25	Primas, A. (2007). Life cycle Inventories of new CHP systems. Ecoinvent V2.0. Dubendorf and Zurich, december 2007.
26	Reyck, B. D., Degraeve, Z., Vandenborre, R. (2004). Project options valuation with net present value and decision tree analysis. European Journal of Operational Research, vol. 184, pp. 341–355
27	Tredici, M., Rodolfi, L., Biondi, N., Bassi, N., Sampietro, G. (2016). Techno-economic analysis of microalgal biomass production in a 1-ha Green Wall Panel (GWP®) plant. Algal Research. Volume 19. pp. 253-263

ANNEX I. Pumps in KOTO

Unit name	Electricity use per day (kWh / d)	Type of data
Pump station 1	0.55	Estimations based on pump capacity installed on demo site and hours operated.
Pump station 2	0.55	
Dosing PH adjust Raw water	4.32	
Feed pump to AD1	13.2	
Feed pump to AD2	13.2	
Recirculation pump AD1	13.2	
Recirculation pump AD2	13.2	
Water supply recirculation pump	6.24	
Diluting pump to AD1	8.88	
Diluting pump to AD2	8.88	
Dosing alkaline pump 1	4.32	
Dosing alkaline pump 2	4.32	
Pretreated water mix pump	3.74	
Digestate feed pump	0.01	
HRAP effluent pump	0.04	Estimation by Algen based on literature (i.e. pool operations)
RAS line pump	0.04	
Algae discharge pump	0.01	
Electricity circulation pump	0.02	

ANNEX II. Pumps in Archimede

Unit name	Electricity use per day (kWh / d)	Type of data
Pump from truck to tank 1	0.314	Estimations based on pump capacity installed on demo site and hours operated, as well as power and flow factor.
Pump to Roto-screener	1.191	
Pump to DAF	1.310	
DAF main pump	2.680	
Dosing pump pH adj	0.179	
Coagulant pump	0.071	
Flocculant preparation and dosing pump	2.716	
DAF sludge discharge (fat) pump	0.168	
Pump to Buffer Tank	1.310	
2*PBR circulation pump	34.848	
RWP-A circulation pump	17.424	
RWP-B circulation pump	17.424	
RWP cooling tower pump (1/2)	12.395	
PBR heating pump (1/2)	1.650	
RWP heating pump (1/2)	4.125	

ANNEX III. Construction phase KOTO

Material	Lifetime (years)	Quantity		Classification
Pump (pumping station 1)	10	1	pieces	1. Roto-screener pumps
Pump (pumping station 2)	10	1	pieces	
Dosing pH adjust Raw wastewater	10	1	pieces	
PVC (sewage pipe)	30	5.8174	kg	2. Distribution system 2-AD
Feed pump to AD 1	10	1	pieces	
Recirculation pump AD 1	10	1	pieces	
Feed pump to AD 2	10	1	pieces	
Recirculation pump AD 2	10	1	pieces	
UV lamp	5	6	pieces	
Diluting pump for AD2	10	1	pieces	
Diluting pump for AD1	10	1	pieces	
Dosing alkaline pump 1	10	1	pieces	
Dosing alkaline pump 2	10	1	pieces	
Pretreated water mix pump	10	1	pieces	
Water supply recirculation pump	10	1	pieces	
Transport tank (IBC)	10	1	pieces	3. Tanks
Buffer tank--Raw wastewater	15	1	pieces	
Intermediate tank	15	1	pieces	
Buffer tank-- Pre-treated water	15	1	pieces	
Storage tank--Treated water	15	1	pieces	
Harvested algae tank (IBC)	10	1	pieces	
Galvanised sheet metal	30	27.1277	kg	4. Greenhouse system
Steel	30	308.9539	kg	
Aluminium foil	10	24.9876	kg	
Geo textile	30	13.5186	kg	
Rubber foil for pond	30	114.4184	kg	
Concrete	30	4.1897	m^3	
Electric cables	30	3.1649	m	
HDPE (mixer blades)	30	30.1418	kg	
Stainless steel (mixer)	30	3.3910	kg	
Steel (for electric motor)	30	0.0410	kg	
Aluminium (for electric motor)	30	0.0310	kg	
Copper (for electric motor)	30	0.0140	kg	
Medium carbon steel (for electric motor)	30	0.0055	kg	
Coating and insulation (for electric motor)	30	0.0040	kg	

Stainless steel (for electric motor)	30	0.0020	kg	
NdFeb (motor magnet)	30	0.0025	kg	
Stainless steel	15	2.8032	kg	5. Pond heating system
PE 80 CEV (insulation)	30	3.1649	m	
Pump	10	1	unit	
Data cable	15	8.2890	m	
Cyclic powder (filter for CO_2)	30	0.0016	pieces	6. CO2 addition system
PE 80 CEV (pressure tube for CO_2)	30	0.2065	kg	
Data cable	15	8.2890	m	
Steel	30	5.4193	kg	7. Control centre
Air conditioning	15	1	pieces	
Data cable	15	3.1649	m	
Mini PC + PC	15	1	pieces	
Lamps	5	4	pieces	
Electric cables	30	0.3276	m	

Annex IV. KOTO and Archimede operational specifications

Site	Parameter	Input	Unit	Type of data
KOTO	Algae pond operational	330	days / year	Demo site data
	Mechanical systems	220	days / year	Demo site data
	Pond size	85	m²	Demo site data
Archimede	Algae pond operational	330	days / year	Demo site data
	Mechanical systems	220	days / year	Demo site data
	Pond size	1 810	m²	Demo site data

Annex V. Gluten and Rubber composite formulation and LCI sources

Raw materials & Energy	Gluten composites			LCI data source
	Algae-based (high algae content)	Algae-based (low algae content)	Benchmark	
Octanoic Acid	25 %	32 %	35 %	The environmental impact of production of octanoic acid was approximated using Eco-invent V3.3 data for production of fatty acid production, from vegetable oil.
Gluten	46 %	59 %	65 %	The environmental impact of gluten production was obtained from Deng et al. 2013 [7].
Algae	29 %	9 %	0 %	All environmental impact is allocated to the algae high value fraction. This low value fraction carries no environmental burden.
Electricity grinding	0.12 MJ / kg grinded*			The amount of electricity and heat used was approximated using Eco-invent V3.3 process for milling limestone at industrial scale.
Heat grinding	0.09 MJ / kg grinded*			Thinkstep LCI for heat production with natural gas in EU with 100 % efficiency was used. Italy has more than 60 % of its thermal energy produced from natural gas. Thinkstep LCI for electricity production based on Italian grid mix was used.
Electricity mixing	0.60 MJ / kg mixed*			The amount of electricity and heat used was approximated using Eco-invent V3.3 process for alkyd paint production at industrial scale.
Heat mixing	8.76 MJ / kg mixed*			The LCI for heat and electricity as the same as stated for grinding.
Electricity hot pressing	16.2 MJ / kg hot pressed*			The amount of energy was approximated using compound moulding energy from Hermansson (2013) [15]. The LCI for heat and electricity as the same as stated for grinding.
Waste	0.05 kg/kg			Overall yield of 95 % provided by Polimi. Eco-invent V3.3. LCI for paint waste incineration emulsion paint was used to approximate the impact from waste treatment.

* Not including yield loss.

Raw materials & Energy	Rubber composites				LCI data source
	Algae-based (high algae content)	Benchmark (high carbon black content)	Algae-based (low algae content)	Benchmark (low carbon black content)	
Rubber (Latex)	67 %	67 %	83 %	83 %	Thinkstep LCI for latex concentrate (100%) production was used. The production takes place in Germany.
Mercapto-benzothiazole	1 %	1 %	1 %	1 %	The production of Mercaptobenzothiazole is represented with Eco-invent V3.3 LCI for the production of benzene (precursor) in Europe.
Stearic acid	1%	1%	2%	2%	The environmental impact of stearic acid production is represented using the Eco-invent V3.3. LCI for tallow fatty acid production in Europe.

Sulphur	2 %	2 %	2 %	2 %	Eco-invent V3.3 LCI for Sulphur production was used. The LCI represents average od the global production.
Zinc Oxide	3 %	3 %	4 %	4 %	Eco-invent V3.3 LCI for Zinc Oxide production was used. The production takes place in Europe.
Algae	27 %		8 %		All environmental impact is allocated to the algae high value fraction. This low value fraction carries no environmental burden.
Carbon black		27 %		8 %	Thinkstep LCI for carbon black production was used. The production takes place in Germany.
Electricity grinding	0.12 MJ / kg grinded*				The amount of electricity and heat used was approximated using Eco-invent V3.3 process for milling limestone at industrial scale. Thinkstep LCI for heat production with natural gas in EU with 100 % efficiency was used. Italy has more than 60 % of its thermal energy produced from natural gas. Thinkstep LCI for electricity production based on Italian grid mix was used.
Heat grinding	0.09 MJ / kg grinded*				
Electricity mixing	0.60 MJ / kg mixed*				The amount of electricity and heat used was approximated using Eco-invent V3.3 process for alkyd paint production at industrial scale. The LCI for heat and electricity as the same as stated for grinding.
Heat mixing	8.76 MJ / kg mixed*				
Electricity hot pressing	16.2 MJ / kg hot pressed*				The amount of energy was approximated using compound moulding energy from Hermansson (2013) [15]. The LCI for heat and electricity as the same as stated for grinding.
Waste	0.05 kg/kg				Overall yield of 95 % provided by Polimi. Eco-invent V3.3. LCI for paint waste incineration emulsion paint was used to approximate the impact from waste treatment.

* Not including yield loss.

ANNEX VI. Animal feed formulation and LCI sources

Raw materials	**Animal feed**			**LCI data source**
	Algae-based (high algae content)	Algae-based (low algae content)	Benchmark	
Fish meal	2.5 %	3.75 %	5 %	LCI from AGRIBALYSE for production of fish meal with wastewater treatment, from Norway was used. Notice that the fish is purposely caught fish for animal feed.
Algae	2.5 %	1.25 %		Environmental impact of algae production, harvesting, drying is assumed to be from Archimede. All environmental impact is allocated to biomass production.
Other feedstuff	95 %	95 %	95 %	Not included in the analysis since it is equal for all cases.

ANNEX VII. Valorization phase LCCA data assumptions

Parameter	Input	Unit	Type of data
Algae biomass cost	4 900	euro / ton	Literature data.
Energy cost (Italy)	0,08	euro / kWh	Literature data
Carbon black	900	euro / ton	Literature data
Rubber (latex)	1 400	euro / ton	Literature data
Fish meal	1 279	euro / ton	Literature data

ANNEX VIII. LCI KOTO Operational phase.

Raw Material & Energy	Description	Data source and LCI data
Roto screener energy	Electricity from adjacent biogas combined heat and power to remove solids bigger than 0,15 mm.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Buffer tank mixing energy	Electricity from adjacent biogas combined heat and power to mix the water in buffer tank.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Two step AD system- KCl	Potassium chloride added to the two step AD system.	LCI from Eco-invent V3.3. Process name "Potassium chloride production" in Europe.
Two step AD system- Fresh water	Fresh water used in the two step AD system	Water for both KCl dilution and raw wastewater dilution. LCI from ThinkStep. Process name "Tap water". Environmental impact includes filtration, disinfection, ion. Surface water.
Two step AD system- Energy	Heat used in the two step AD system in winter time by heat exchanger.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Two step AD system- Avoided heat and electricity	Avoided heat and electricity from biogas CHP plant due to the production of biogas in the Two step AD system.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Conditioning tank mixing energy	Electricity from adjacent biogas combined heat and power to mix the water in conditioning tank.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Pond - Fresh water	Freshwater used in the pond to compensate for evapotranspiration.	LCI from ThinkStep. Process name "Tap water". Environmental impact includes filtration, disinfection, ion . Surface water.
Pond- Electricity	Electricity used in pond mainly for pumps and fan. Electricity sourced from adjacent CHp biogas plant.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit

Pond-Heat	Heat used in the pond.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Pond-CO_2	The carbon dioxide used in the pond for algae growth. Sourced from the adjacent biogas plant.	Since the CO2 is sourced from the adjacent biogas plant it carries no environmental burden. Ideally some environmental burden regarding the separation of the CO2 from CH4 should be calculated, but this is expected to be small.
Harvesting DAF - Flocculant	Flocculant used for DAF harvesting. Commercial name Superflocc C-62091 from Kemira Oyj	LCI estimated based on MSDS with 40 % polyacrylamide production LCI from Eco-invent V3.3. Then, 60 % is water. LCI from ThinkStep. Process name "Tap water".
Harvesting DAF - Electricity	Electricity used for DAF harvesting. Electricity source adjacent CHP plant.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.
Pumps-Electricity	Electricity used for all pumps in the whole system (except for pond pumps). Disaggregated electricity per pump available in Annex I. Electricity source is adjacent CHP plant.	LCI from Eco-invent V3.3. Process name "Heat and power co-generation, biogas, gas engine" in Slovenia. The dataset is representative of a 160kWel biogas (from biowaste) cogeneration unit.

ANNEX IX. LCI Archimede

Raw Material & Energy	Description	Data source and LCI data
Roto screener energy	Electricity from Italian grid mix. Electricity used in drum.	LCI from ThinkStep, process name "Electricity grid mix" from Italy. About 33.54 % from natural gas and 15.23 % from hard coal.
Transfer tank-Phosphoric Acid	Phosphoric Acid used added in transfer tank.	LCI from Ecoinvent V3.3. Process name "phosphoric acid, industrial grade, without water, in 85 % solution state" average of European production.
DAF pre-treatment-Electricity	Electricity used for DAF belt and DAF sludge.	LCI from ThinkStep, process name "Electricity grid mix" from Italy.
DAF pre-treatment-Sludge	Sludge produced was assumed to be treated by anaerobic digestion.	LCI from Eco-invent V3.3. Process name "treatment of sewage sludge by anaerobic digestion" in Switzerland.
Buffer tank - Electricity	Electricity used in the buffer tank	LCI from ThinkStep, process name "Electricity grid mix" from Italy.
Pond-Electricity	Electricity use in for two PBRs and RWP paddle wheel and cooling tower.	LCI from ThinkStep, process name "Electricity grid mix" from Italy.
Pond-Heat	Heat used in the ponds. Source is adjacent vegetable oil CHP plant.	This heat is waste heat from the adjacent vegetable oil CHP plant, the heat has low temperate. This heat carries no upstream environmental burden.
Pond-Micro-nutrients	Micro-nutrients used for algae growth.	Micro-nutrients used are based confidential recipe, thereby LCI selection specification are excluded from this public deliverable.
Pond-Carbon dioxide	Carbon dioxide used in the pond for algae growth assumed in gaseous state.	LCI from ThinkStep for carbon dioxide produced in gaseous state through the Haber- Bosch process, from natural gas in Germany.
Pond-Fresh water	Fresh water added to the pond to compensate evapotranspiration.	LCI from ThinkStep for Tap water production including ion removal. Sourced from surface water.
Harvesting UF & CF-electricity	Electricity used for harvesting through centrifugation and ultrafiltration. Electricity source Italian grid mix.	LCI from ThinkStep, process name "Electricity grid mix" from Italy.
Spray drying-electricity	Electricity used for Spray drier. Electricity source Italian grid mix.	LCI from ThinkStep, process name "Electricity grid mix from Italy."
Spray drying-Heat	Heat used for spray drier. Heat from natural gas.	Calorific value natural gas of 41 MJ/kg and standard volume 1.19 Nm3/kg = 34.45 MJ /Nm3. LCI from ThinkStep, process name "Thermal energy from natural gas" production in Italy.
Pumps-Electricity	Electricity used for all pumps in the whole system (except for pond pumps). Disaggregated electricity per pump available in Annex II. Electricity source is adjacent CHP plant.	LCI from ThinkStep, process name "Electricity grid mix" from Italy.

