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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Description	Within this report, a framework for the sustainability assessment of the SALTGAE system is established. A system model with clear inputs, outputs and system boundaries is presented together with scenarios to be evaluated. These will act as a foundation for tasks 7.2 Techno-Economic evaluation, 7.3 Environmental assessment, and 7.4 Social assessment.
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1.0	2017-03-30	Finn Englund (RISE)	

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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
AP	Algae ponds
BOD	Biochemical oxygen demand
CBA	Cost benefit analysis
CHP	Combined heat and power plant
CO_2	Carbon dioxide
COD	Chemical oxygen demand
DAF	Dissolved Air Flotation
ERD	Energy recovery device
LCA	Life cycle assessment
LCC	Life cycle costing
MCA	Multi-criteria analysis
NOx	Nitrogen oxides
PLA	Polylactic acid
SD	Sustainable development
S-LCA	Social life cycle assessment
TRL	Technology readiness level
TBL	Triple bottom line
UV	Ultraviolet
VFA	Volatile fatty acids
WWTP	Wastewater treatment plant

Table 1: Abbreviations and Acronyms

1. INTRODUCTION

The vision of the SALTGAE project is the deployment of algal ponds able to withstand and treat saline wastewater in presence of organic load while extracting value from its constituents. A circular economy approach is adopted; the external energy and resource intake will be minimized (e.g. internal production of CO_2 and methane by anaerobic digestion of sludge) and the resulting residues will be re-deployed and valorised (e.g. clean water and brine by using desalting technologies, animal feed etc. by means of biomass harvesting, refinement and transformation processes).

The SALTGAE vision will be demonstrated at three different locations - Slovenia, Italy and Israel - each treating wastewater with different physico-chemical properties. In particular, the site in Slovenia will demonstrate the treatment of tannery WW; the site in Italy will treat whey WW; the site in Israel will treat aquaculture WW. Different effluent pre-treatment methods and desalting technologies will be evaluated for the effluent valorisation. For the biomass valorisation, production of high value products (animal feed, resins, edible coatings, and material fillers) will be considered, but not implemented at each demo-site. The solids and sludge will be utilized by anaerobic digestion and the resulting digestate could be used as fertilizer. The algae species that will be used are *Spirulina* (Arava and Archimede), *Tetraselmis* (Archimede), and a mixture of naturally occurring species (KOTO).

1.1. Aim

The overall aim of work package seven is to assess the sustainability of the system developed in SALTGAE, by identifying the positive and negative impacts and implications of the system from a technical, economic, environmental and social perspective, using a life cycle approach. With these as a basis, business plans will be developed for the benefit of industrial partners and for the wider spread and adoption of the project’s results.

The aim of task 7.1 is to develop a system model that includes the necessary data and information required to implement tasks 7.2 Techno-Economic evaluation (viability study), 7.3 Environmental assessment and 7.4 Social assessment (Figure 1). The life cycle inputs and outputs as well as components of the treatment systems will be modelled and clear system boundaries and scenarios to be evaluated will be defined. Interactions and exchanges with external systems such as nature, energy systems and society will be included in the model. Benchmark systems will also be defined, which will serve as a reference to which the SALTGAE technology will be compared to in terms of performance.

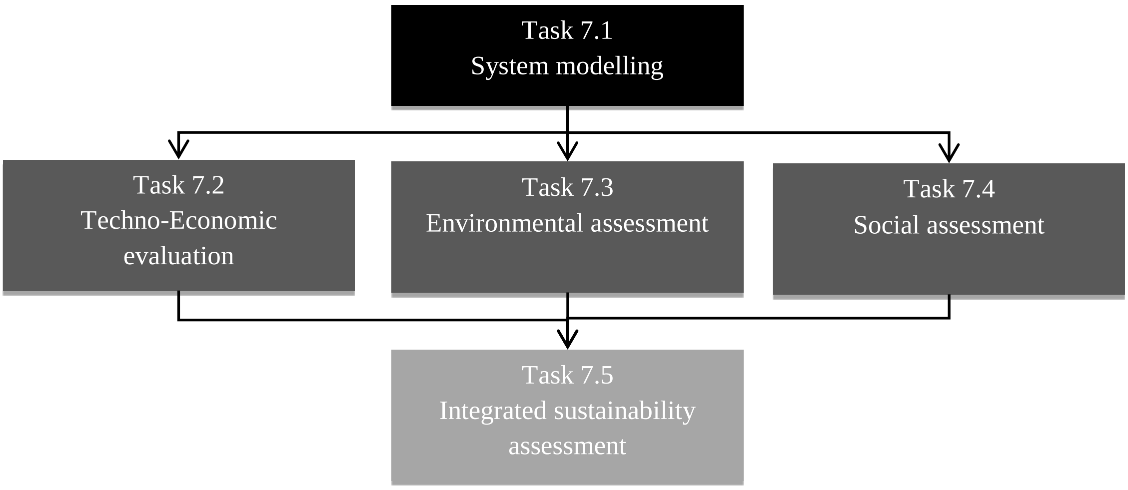

Figure 1: Schematic illustration of the links between the tasks in WP7.

2. SUSTAINABILITY ASSESSMENT

Sustainable Development (SD) first appeared as a concept in 1987 with the so-called “Brundtland Report”, by the Brundtland Commission. In their report titled “our common future”, they defined SD as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"; a definition that has fundamentally shaped sustainability science since it was established [03 – WCED (1987)]. Several different ways to define SD have been proposed since then, but in spite their differences some common ground can be found in the way these definitions establish the goals, indicators, values and practice of SD [01 – Kates, R et al. (2005)]. The well-known “Triple Bottom Line” (TBL) approach to sustainability is one of these sources of common ground.

The TBL is an approach where SD is defined as the equilibrium between the developments of three parts: society, the economy and the environment [02 – USNRC (1999)]. Many sustainability frameworks nowadays apply the TBL as a pillar for defining and monitoring SD, as well as means to measure sustainability in the context of decision-making related to processes, projects, policies or technologies. For this, several tools are available to measure the effects of these decisions in each of the three fronts of the TBL. Some common examples of these tools are: SWOT analysis, Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), Multi-Criteria Analysis (MCA), Life Cycle Costing (LCC), Cost-Benefit Analysis (CBA), etc.

2.1. Sustainability assessment within SALTGAE

In the context of SALTGAE, assessing sustainability is a crucial part of the work planned in WP7. The overall structure of WP7 adopts the TBL approach, where the impacts of the SALTGAE system on the three dimensions of SD will be evaluated using specific tools. The tools chosen to evaluate the three dimensions of SD in WP7 are LCA (environmental sustainability), techno-economic assessment (economic sustainability) and social hot-spot assessment (social sustainability). These three tools have a life cycle approach, which means that the life cycle of the SALTGAE system needs to be modelled in order to carry out all three assessments. With this in mind, the role of this deliverable as the foundation for the three assessments in WP7 is clear.

For each individual assessment (techno-economic, environmental, and social), the performance of the SALTGAE system will be compared with benchmark systems identified depending on the function(s) delivered by the system in terms of water treatment and valorised co-products. In addition, positive and negative impacts from the implementation of the SALTGAE system will be identified and measured. An integrated analysis will then be made to identify the most important hotspots and challenges related to SD. In this step, weighting factors will most likely be established for all the sustainability aspects evaluated, using a stakeholders perspective. These results will be presented as a roadmap for future development of the SALTGAE technology so it achieves its’ maximum potential in terms of contribution to SD.

3. SETTINGS AND DEFINITIONS

As mentioned in the previous section, the three assessments of the SALTGAE system that will be carried out within WP7 have a life cycle perspective. A life cycle perspective requires accounting for all processes and activities that take part during the life cycle of a product; including the extraction of raw materials, manufacturing and transport of materials, substances or energy, the SALTGAE transformation processes in itself, the processes needed for valorisation or disposal of co-products, and the following processes until all co-products from SALTGAE have reached their end-of-life. As a consequence, a model is required for these processes and activities, including their material, energy, labour and economic exchanges with other processes and with nature. This chapter gives a summary of some definitions and highly relevant methodological choices related to this model, but it should be borne in mind that they are preliminary, due to the iterative nature of life cycle studies. Further detailed information about these processes that are included within the system boundaries is given in Chapter 5.

3.1. Reference unit and comparison with other systems

The reference unit, also called functional unit, is one of the most important methodological choices in life cycle studies. It can be defined as the unit that measures the function of the studied product system, and provides a reference to which all the flows and therefore indicators in the assessment(s) can be related. The reference unit is fundamental in order to make comparative assertions; given that comparisons with benchmark product or systems can only be made in terms of the function they provide. All the studied systems (SALTGAE pilot plants and benchmarks) will be evaluated using the main reference unit **cubic meters of waste water with high salinity treated per day**. This reference unit will probably be modified in future deliverables due to refinement of the system as the project progresses, mainly in relation to the time component (daily flow treated) and to the specific meaning of "high salinity".

Establishing a reference unit for a biorefinery system such as the one studied in SALTGAE presents a special type of challenge due to the fact that the system provides several functions at the same time. Besides its main function of treating waste water with high salinity, the various co-products from the SALTGAE system will also provide other functions, i.e. produce energy carriers (biogas), fertilize crops (sludge), animal nutrition (animal feed), etc. In order to overcome this challenge, an approach known as a "basket of functions" will be applied. The basic principle of this approach is that each of the aforementioned additional functions besides the one related to the reference unit are accounted for as environmental, economic or social benefits or positive impacts based on the benchmark products they displace in the market. These benefits will be visualized separately whenever results are presented, so stakeholders can clearly observe the co-product benefits and the basket of functions that the whole system offers. However, this approach to allocate impacts and benefits among multiple co-products from a process requires what is usually referred as system expansion.

3.2. System expansion and co-product allocation

The SALTGAE pilot plants are multi-functional processes, as they generate more than one product with different functions. Multi-functional processes present one of the biggest challenges in life cycle studies since there is still no consensus regarding how to deal with these processes, more specifically how to allocate impacts (positive or negative) among them. One possible way to deal with these is to split the impacts between co-products based on a specific characteristic, which can be either physical (i.e. energy content or mass) or economic (market value). The other way which was mentioned in the previous section is system expansion; where the full impacts of the multi-functional process is accounted for but each of the co-products are accounted for as an avoided impact, depending on which product (or mix of products) they displace in the market.

System expansion requires several assumptions concerning the displaced products and their characteristics, which can also be challenging.

The impacts from the multi-functional process of the SALTGAE pilot plants will be allocated using the system expansion approach, as was explained in the previous section. The required assumptions for the displaced products will be made based on internal knowledge within the consortium, especially from those partners in charge of valorisation of biomass. Moreover, in case high uncertainties are found and the range of possible products to displace is too large, sensitivity analysis with different displacement scenarios will be carried out. Finally, other allocation approaches may be used for less relevant upstream and downstream processes, depending on the allocation procedures used for the original data source. The lesser relevance of such processes is due to their low influence on the overall result and to the lower level of control over them for future developments.

3.3. Temporal, geographical and technological boundaries

Both geographical location and time can have significant influence on the modelling of product life cycle systems. One example is the electricity mix for energy intensive processes, as the cost and environmental impacts could vary significantly with time and depending on location. Given that three pilot plants with different locations are implemented in the project, the assessment will focus on three locations: Slovenia, Israel, and Italy. The assessments will thus be representative for these countries, and not necessarily for other geographical areas. The technology readiness level (TRL) of the SALTGAE system is described in Table 2. The TRL target level in the end of the project in June 2019 is 6/7. Therefore, it seems realistic that the techniques are going to be relatively mature around 2020, which is set as the time frame. To increase the benefits of the results, ratios of the main inputs and outputs (e.g. energy) will be presented, thus enabling discussions and rough estimations regarding the performance in other countries as well as with other time frames.

Technologies	Current TRL	Current state	Target TRL
Primary treatment	4	Already deployed for non-saline wastewater treatment. Salinity, organic and non-biodegradable content all pose technological challenges	6/7
Pre-treatment and conditioning (DAF)	5	Already deployed for non-saline wastewater treatment	6/7
Anaerobic digestion using anaerobic granular sludge	4	Initially tested at laboratory scale for saline sludge to address the limitations of granules strength and structural stability in saline environments	6/7
Selection & cultivation of halotolerant algae/bacteria inoculums	4	Halotolerant Technology validated at lab scale.	6/7
HRAP design and optimization	5/6	Initial tests in relevant environment. Huge photosynthetic surfaces. No optimal removal of nutrients.	6/7
HRAP Effluent - desalination pre-treatment technologies	5	Already deployed in other industrial applications	6/7
Desalination by ED	5	Already deployed for brackish and seawater desalination. Not yet deployed in presence of saline WW from F&B industry.	6/7
Novel pump and Energy Recovery Device	5	Already undergone testing in relevant environments (e.g. irrigation and air conditioning)	6/7
Biomass harvesting by filtration and low shear centrifugation	5	Technologies already deployed independently (single approach) for other biological processes	6/7
Biomass refinement	4	Technologies already deployed at lab scale. Used with mixotrophic culturing of algae obtained from fermentation in a controlled environment.	6/7
Biomass valorisation into biochemical, animal feed products and fillers/pastes	4	Technologies and chemistries already tested at lab scale	6/7

Table 2: Readiness levels of the SALTGAE technologies[1].

[1] Source: SALTGAE proposal template

4. PROCESS DESCRIPTION

The waste water treatment with biomass valorisation system to be developed in SALTGAE is composed of several individual processes. Some of these processes are sequential, while others are only present in certain scenarios or pilots. Still, before starting with descriptions and scenarios at the system level, it is necessary to introduce the process involved. This chapter presents a short description of every relevant process present in the studied system and its scenarios, with focus on an early screening of key sustainability issues and the inputs and outputs for each process. Each section presents one process, including a short outline of the process plus a graphic representation. It shall be noted that even as construction material inputs are accounted for, they are not included in the process descriptions for simplification.

4.1. Primary treatment

The goal of the primary treatment is to remove the solids and reduce the BOD in the waste water inlet that could cause operative problems downstream; especially for the microalgae. It consists of a pre-treatment, a second stage that could be a two-step anaerobic digester or dissolved air flotation, and anaerobic digestion of the solids.

4.1.1. Pre- treatment

The pre-treatment includes a pumping station in all pilots, with anti-clogging systems adapted to the nature of the inlet. This pumping station requires energy input and maintenance activities. The primary treatment in all pilots will most probably consist of rotary screen sieves, with varying slot depending of the characterisation of the waste water inlet in each pilot. Some degree of maintenance will be required, mainly for cleaning of the sieves. For the cleaning, scrapers is used which have to be changed around once per year. Regarding the outputs of the process; the solids removed will be sent to anaerobic digestion and the effluent will be pumped to either two-stage anaerobic digestion or dissolved air flotation, depending on the pilot. Figure 2 shows the graphic description of the primary treatment.

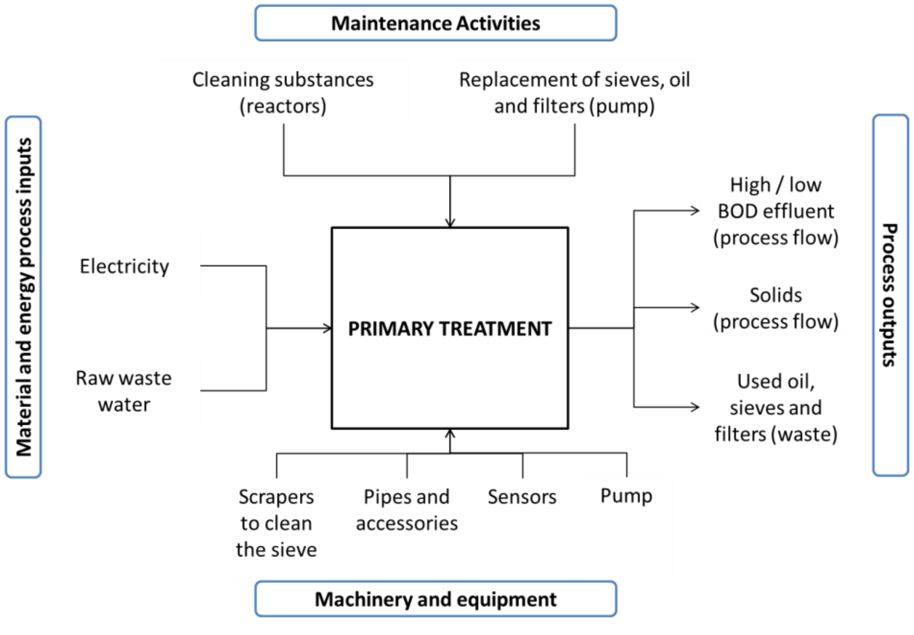

Figure 2: Graphic description of the primary treatment.

4.1.2. Anaerobic digesters

The first of two possible primary treatments in the SALTGAE system is anaerobic digestion in a two-stage anaerobic digester before the waste water enters the algae ponds system. A buffer tank is needed prior to the two-step anaerobic digester featuring a mixing system and sensors. Both steps of the two-step digester include a recirculation pump and a heat exchanger. Regarding the process outputs, the main effluent of the two-step digester will continue to the algae ponds system. On the other hand, carbon dioxide and methane will be produced in both reactors, which will be re-used in the system. The CO_2 will serve as flue gas for the algae culture and as input in the buffer system to adjust pH, while the methane will be used for electricity and heat generation in a biogas reactor to off-set some of the energy requirements of the whole system. In this process there might be some emissions of volatile fatty acids (VFA). However, these are most likely small, if at all present, since the VFA emissions should be dissolved quickly in water and used in heterotrophic processes. The same most likely also applies for emissions of NO_x.

In the SALTGAE system there are also a small digester meant to treat solids from the pre-treatment and sludge from different processes. The idea is to treat the outputs (methane and carbon dioxide) from this digester the same way as described above, and use the digestate as fertilizer. However, at the demonstration sites the fractions of solids and sludge are quite small, and at two of the sites larger biogas plants are located nearby. Thus, the solids and sludge from the demo-sites will be sent to existing biogas plants. Figure 3 and Figure 4 show a description of the anaerobic digesters.

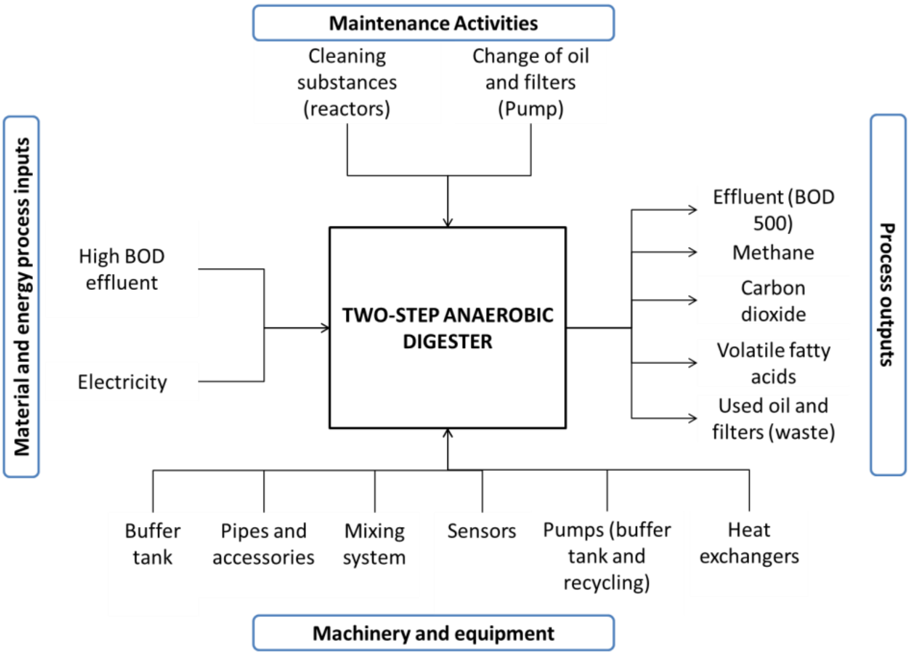

Figure 3: Graphic description of the two-step anaerobic digester.

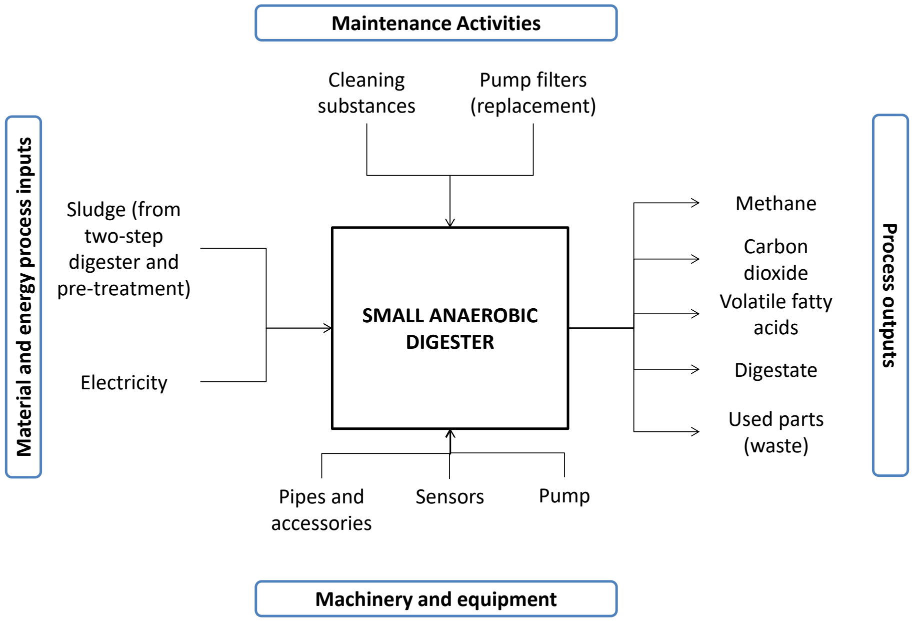

Figure 4: Graphic description of the small anaerobic digester.

4.1.3. Dissolved air flotation

The second alternative for primary treatment in the SALTGAE system is Dissolved Air Flotation (DAF). After this step, a reduction of 25-30% of the effluent COD is expected. The process includes chemical flocculation and mixing, and requires industrial services such as compressed air and pumping. In general, there is a need to add flocculants and coagulants to reach the target COD/BOD removal. However, it might not be needed in all cases and the algae production might benefit from exclusion of such chemicals. This means that there is a possible balance between obtaining an effluent with low enough COD/BOD content by adding mentioned chemicals and obtaining a high quality biomass for valorisation by excluding such chemicals. Thus, the need for chemical input to obtain a good quality of the resulting effluent will be tested within the SALTGAE project and the effects on the algae production will be evaluated. Figure 5 presents an outline of the inputs and outputs for the DAF.

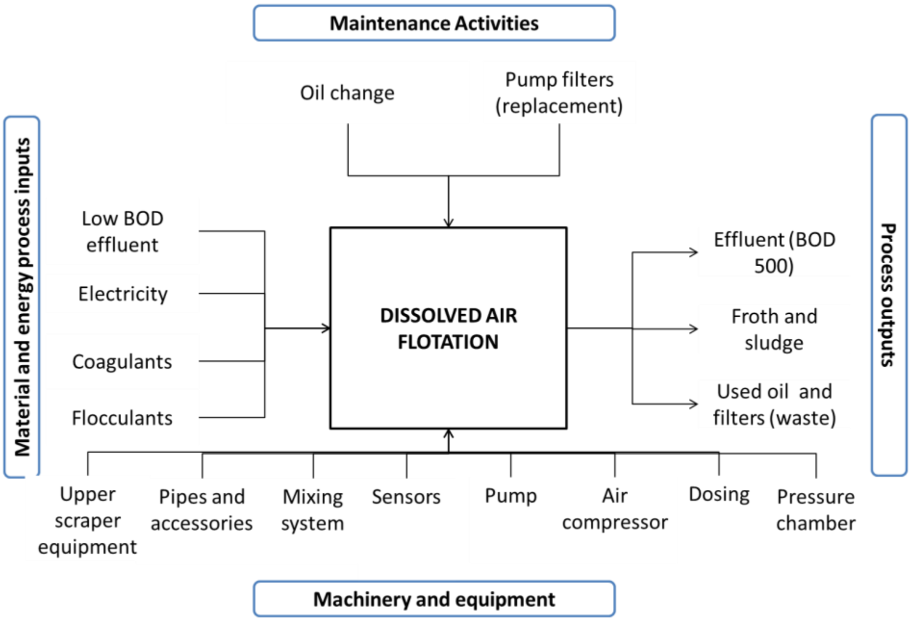

Figure 5: Graphic description of the dissolved air flotation.

4.2. Biogas reactor

One of the main co-products of the anaerobic digesters is methane, which has a significant heating value and therefore can be used for energy generation. The reactor receives methane from the two-stage anaerobic digester (and from the small anaerobic digester if such is used) and uses it to generate heat and electricity. It is possible that due to shortages of biogas in colder months when extra heat is needed in the plant, alternative energy sources such as natural gas and electricity are required. Some emissions to the atmosphere from biogas incineration are expected, mainly carbon dioxide, carbon monoxide, nitrogen oxides and unburned hydrocarbons. In Figure 6, a graphic description of the process is presented.

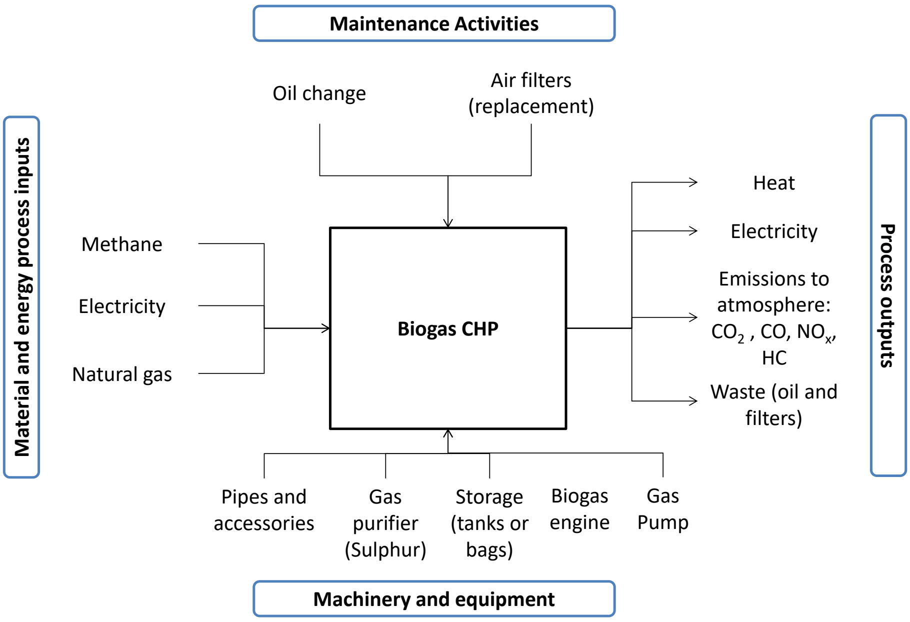

Figure 6: Graphic description of the biogas CHP.

4.3. Algae ponds system

The algae ponds system features two stages; a pre-treatment buffer system and the algae ponds.

4.3.1. Buffer system

After the primary treatment the BOD in the waste water has been reduced to acceptable levels for the algae ponds treatment. Nevertheless, before entering the algae ponds, some monitoring and homogenisation of the affluent is required to prevent problems caused by flow variation, which is why a buffer system is needed featuring certain monitoring systems. One of these systems is UV oxidation to degrade colour-absorbing compounds, which requires UV-lamps that require maintenance and generate electronic waste. Another is an ammonia scrubber to regulate ammonia concentration, a system that requires sulphuric acid and generates ammonia salt as waste. A pH monitoring system can also be implemented using carbon dioxide, e.g. recirculated from the anaerobic digester(s). If there is a need to control the salinity and the nutrient content in the effluent before entering the algae ponds, recycled desalination products can be used. Finally, cyanobacterial mats may be used to adsorb heavy metals. Which of these systems are implemented can vary between the sites. Figure 7 presents an outline of the buffer system.

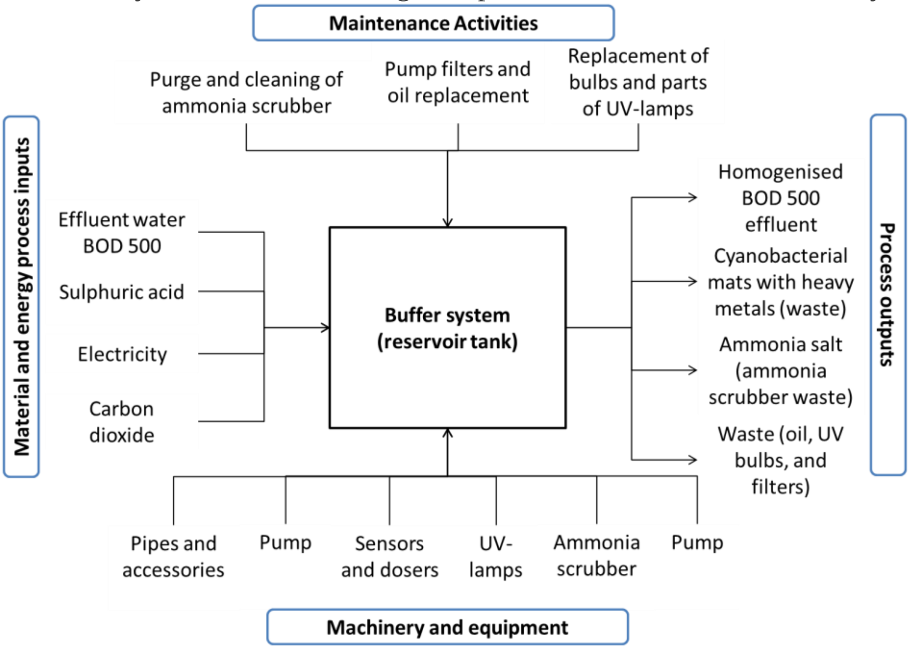

Figure 7: Graphic description of the buffer system.

4.3.2. Algal Ponds

The Algal Ponds (AP) are the main feature of the SALTGAE system, a process whose goal is to remove the remaining BOD of the waste water while generating the microalgae biomass that will be harvested for valorisation. The process receives the homogenised effluent from the buffer system, and its main output is the BOD-treated waste water rich in biomass. Heat and cooling are needed to regulate the optimal temperature for the algae mainly during colder months, while electricity powers the equipment. If a biogas reactor is implemented, the energy will be provided by the reactor and additional external sources depending on the supply/demand, if not, external energy sources will be used. Carbon dioxide will also be added for bacterial activity, and will be provided by the anaerobic digester(s) if such are in place and external sources when required. In order to protect the pond integrity linings and coverings will be installed, but the specific type and materials of these will vary depending on location and costs, and therefore is not yet well defined. Besides the pump and pipe required in all stages, the AP will feature a mixing system that will most likely consist of paddle wheels, but other systems such as turbines could be implemented depending on the damage they cause to the algae. The mixing system will be developed and optimised during the project and therefore its specifications are not yet well defined. Introduction of nutrients to improve performance will also be considered, another material input for the process. Besides from the waste from maintenance activities, another output of the process is evapotranspiration to the atmosphere, which will be estimated for WP7. A graphic representation of the AP process is shown in Figure 8.

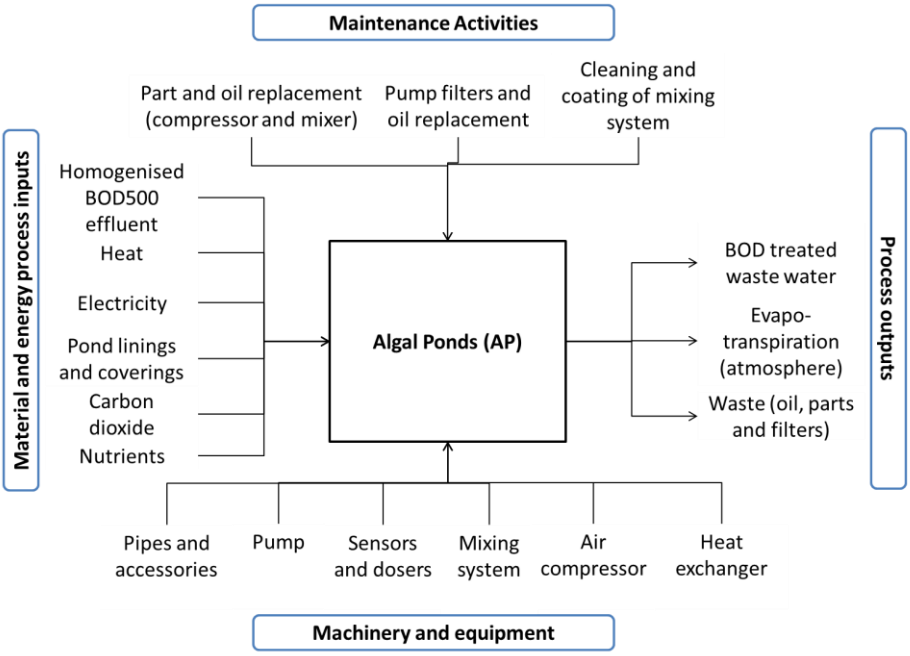

Figure 8: Graphic description of the algal ponds.

4.4. Biomass harvesting

After the wastewater is treated in the algae ponds system, the algal biomass needs to be separated from the wastewater so it can be refined and transformed into value products. In this stage of the project, the final design of the harvesting is not yet decided. However, two alternatives are considered that minimize cell damage and at the same time minimize costs; membrane ultrafiltration and low shear centrifugation. It is still uncertain if the membrane ultrafiltration and the low-shear centrifugation will be implemented at all sites. Further, some additional steps might be needed before the membrane ultrafiltration, such as sedimentation and DAF.

4.4.1. Membrane ultrafiltration

An ultrafiltration system with optimal flux conditions will be implemented. The process receives the effluent from the algae ponds system, and delivers a pre-concentrated feed separated from the rest of the effluent. Filtration modules with membrane filters are required, and the specifications of these filters such as pore size and material are yet to be defined. Still, the membrane filters need to be replaced, requiring additional materials and generating waste from maintenance activities. Figure 9 outlines the process.

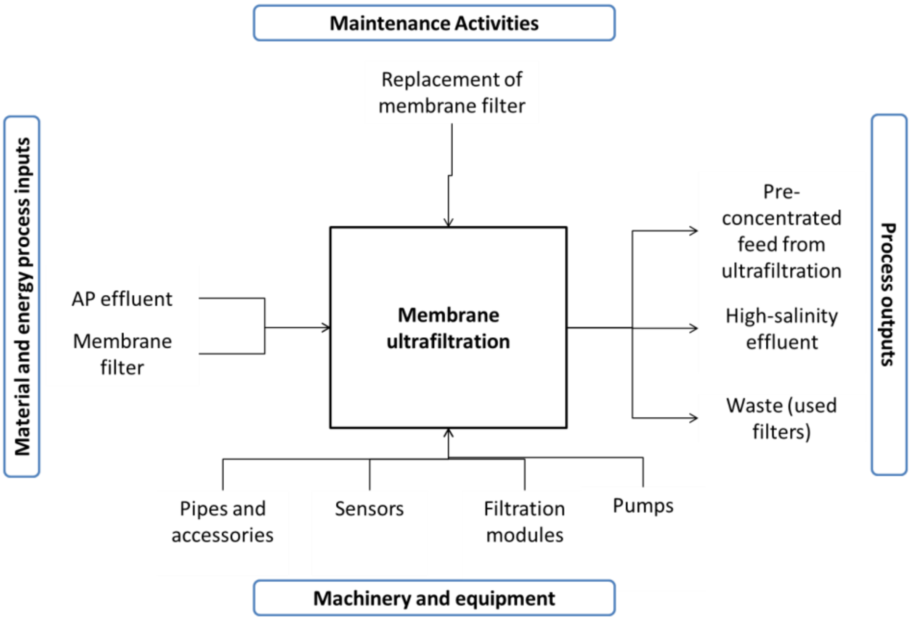

Figure 9: Graphic description of the membrane ultrafiltration.

4.4.2. Low-shear centrifugation

A centrifuge prototype with lower shear pressure will be tested as part of the project for biomass harvesting. The centrifuge will receive the pre-concentrated feed from the ultrafiltration and will separate the algal biomass from the rest of the effluent. Only the centrifuge is required, including maintenance activities such as cleaning. The process is described in Figure 10.

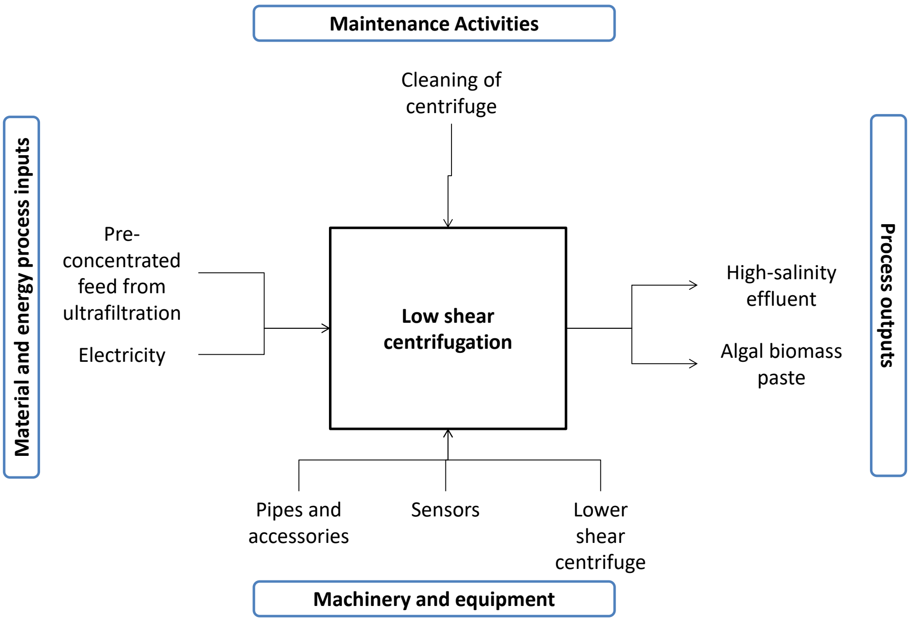

Figure 10: Graphic description of the low shear centrifugation.

4.5. Biomass refinement

After the biomass is separated from the rest of the effluent, it will be refined and extracted into final products. This stage is divided in three processes; pre-treatment, three-stage separation and spray-drying. Not all of these steps will be implemented at the each demonstration site. At present, it is uncertain whether the three-stage separation will be implemented at the site in Slovenia and the drying-step is not planned to be implemented at that site.

4.5.1. Pre-treatment

The main goal of this stage is to characterise the initial and final products of the refinement process under different conditions. For this step, mainly characterisation equipment will be needed, mainly an ultrasonic device. A high-pressure homogeniser will also be tested in this stage. A graphic representation of this process is shown in Figure 11.

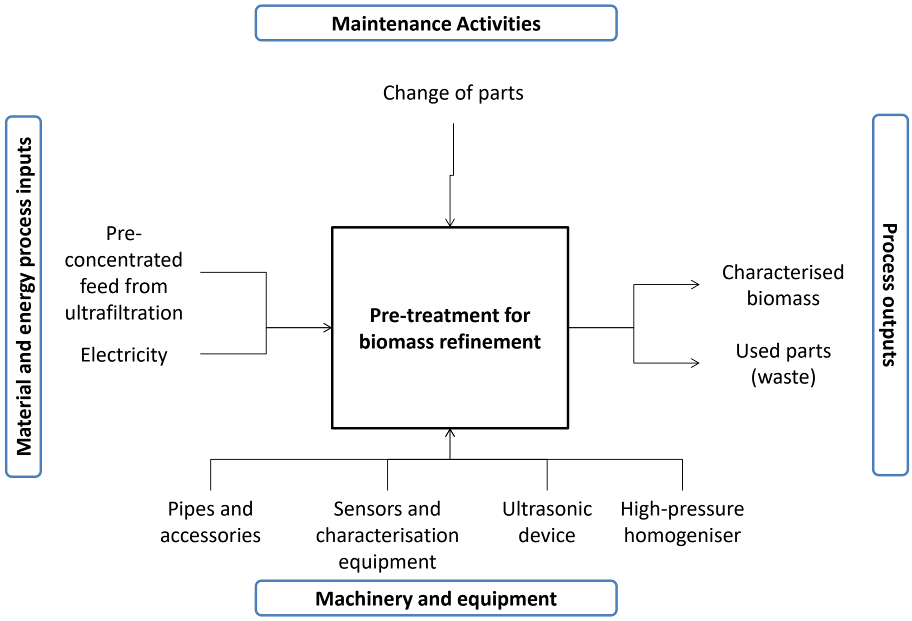

Figure 11: Graphic description of the pre-treatment for biomass refinement.

4.5.2. Three-stage separation

The second step of the biomass refinement is the three-stage separation using a three-phase decanter where the biomass feed will be separated in three phases; an oily phase with high-value betacarotene, a water phase with minerals and proteins and a sludge phase with the remaining cell debris. While the last two phases will be spray-dried, the oily phase will go directly to valorisation. The three-phase decanter includes a pump, and requires maintenance and replacement of parts. The process is summarised in Figure 12.

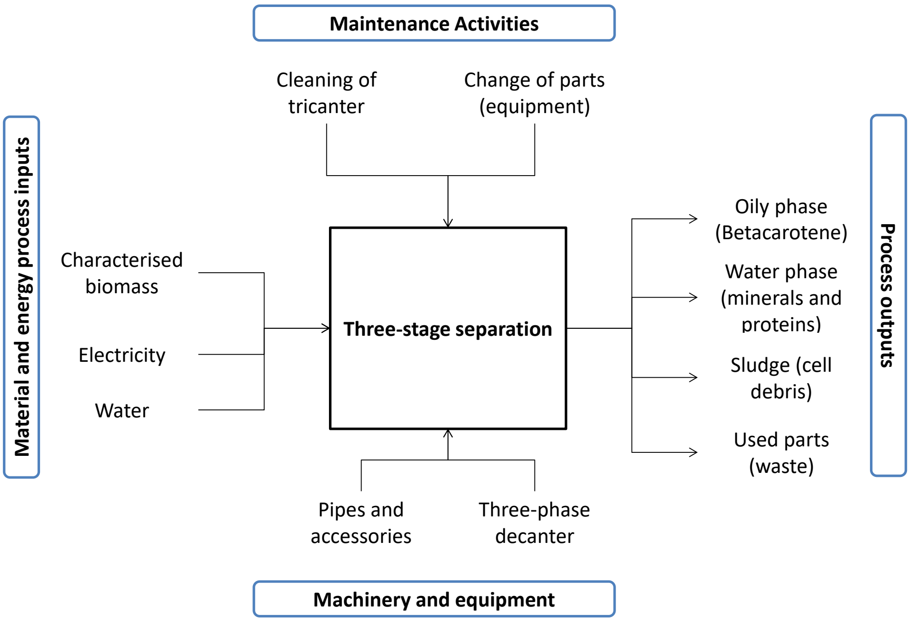

Figure 12: Graphic description of the three-stage separation.

4.5.3. Spray drying

After separation, the water and sludge phases will most likely be spray dried. The spray drier includes pumps, a cyclone separator and a filter. There might be some further process steps needed before the drying, e.g. filtering, pressing and/or washing. The exact layout of the system will be developed during the course of the project. However, at some sites other options are also under consideration, e.g. sun ovens and lyophilisation (freeze-drying). The process outline is shown in Figure 13.

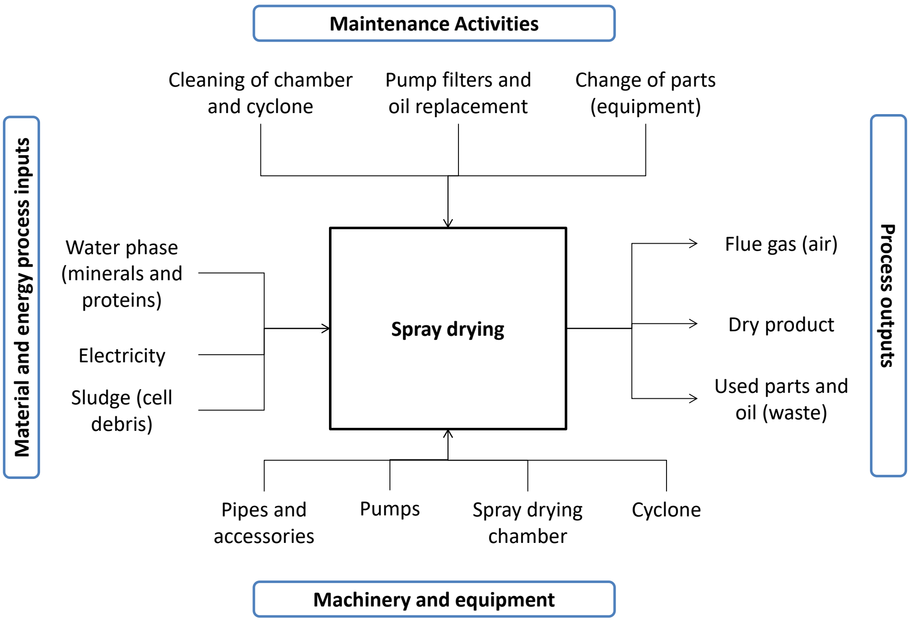

Figure 13: Graphic description of the spray drying.

4.6. Effluent valorisation

The waste water effluents resulting from the biomass harvesting need treatment before they are recycled in the process or used for other purposes such as irrigation (depending on pilot). For this, a pre-treatment and a subsequent desalination process are needed, which could be electro-dialysis or reverse osmosis. If the water is to be used as irrigation, additional treatment such as pH-adjustment might be needed.

4.6.1. Pre-treatment

Three alternative pre-treatment processes will be evaluated in the project, each with specific inputs and outputs besides those related to pumps. The first is ultrafiltration, which requires membrane filters with specifications regarding material and pore size yet to be defined, similarly to the need for chemical maintenance. The second is activated carbon adsorption, where an activated carbon medium and its subsequent replacements would be needed and potentially further addition of activated carbon particles. The third is direct photolysis using UV lamps, which must be replaced at some point. In all three cases some waste would be generated; used membrane filters, used activated carbon medium or replaced UV lamps. Figure 14, Figure 15, and Figure 16 displays the three processes described.

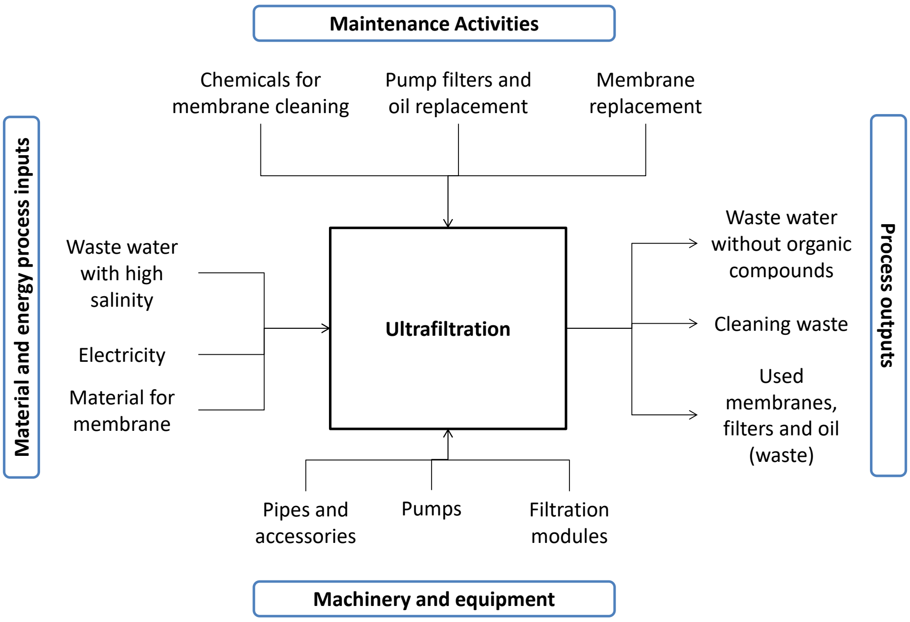

Figure 14: Graphic description of the ultrafiltration.

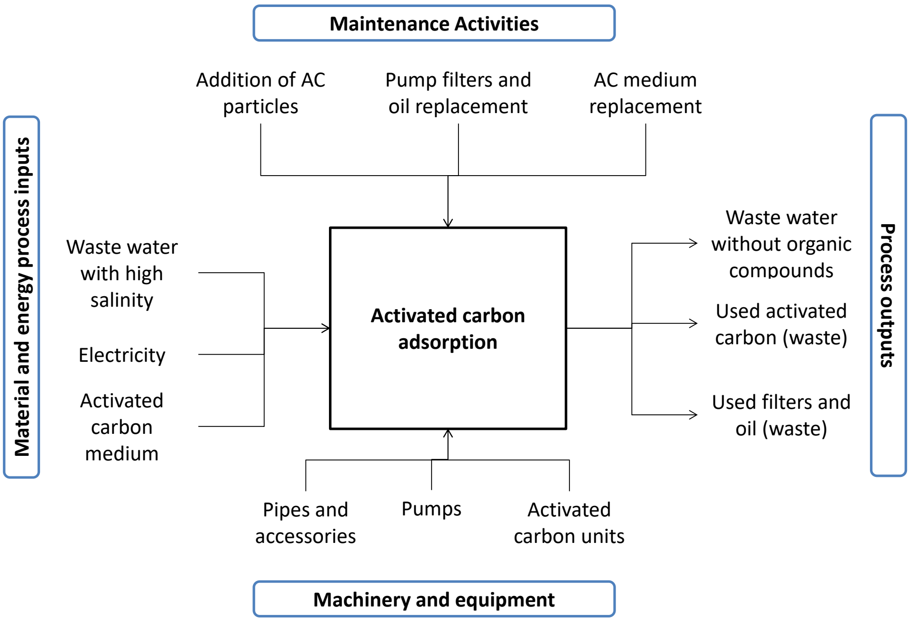

Figure 15: Graphic description of the activated carbon adsorption.

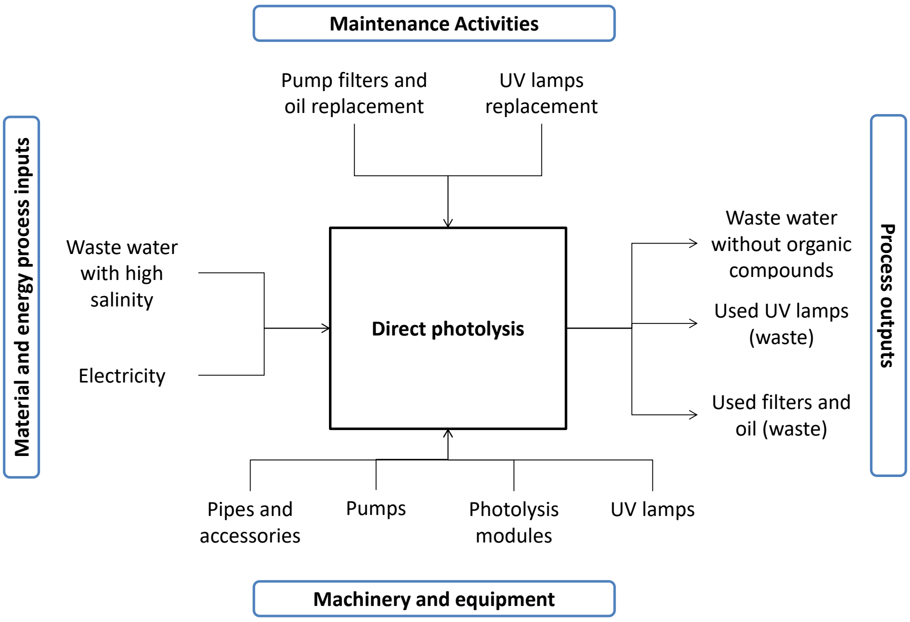

Figure 16: Graphic description of the direct photolysis.

4.6.2. Electro-dialysis

Electro-dialysis is a technique to remove ions and demineralise waste water with high salinity, so it is safe for certain uses depending on the yield. The process requires a unit with chambers separated by ion exchange membranes to separate the ions from the waste water, as well as anodic and cathodic solutions that are constantly recirculated. Eventually the solutions and the membranes need to be replaced and require maintenance, generating waste outputs. Platinum electrodes are also needed, which require a direct electricity feed. The treated water will leave the system as a product, while brine with high ion concentration can be recirculated to the buffer system before the algae ponds. An outline of the process inputs and outputs is presented in Figure 17.

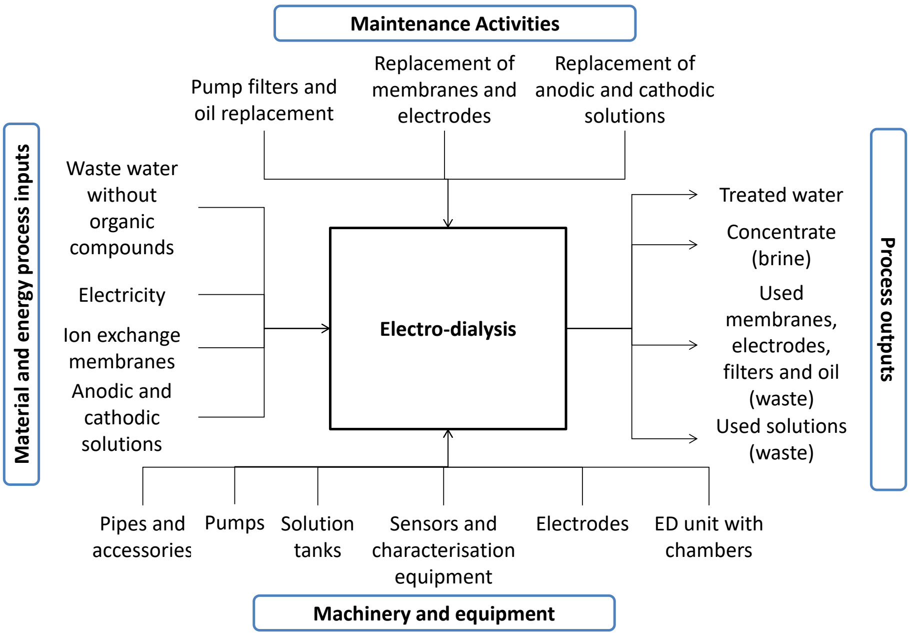

Figure 17: Graphic description of the electro-dialysis.

4.6.3. Reverse osmosis

Reverse osmosis is a more traditional desalination process. However, a novel pumping system for reverse osmosis will be tested aiming to increase energy efficiency since the majority of energy demand from the process is attributed to pumps. This will be achieved by implementing an energy recovery device (ERD), which will also be part of the system. The main component of the system is a filter membrane, whose specifications are yet to be defined. Besides common pump maintenance, the replacement of the filter membrane and other equipment are included, subsequently generating waste flows. Similarly to the electro-dialysis case, both the treated water and the brine may be allocated to different uses depending on the location, including irrigation or a recirculation in part. Figure 18 shows a graphic description of the process.

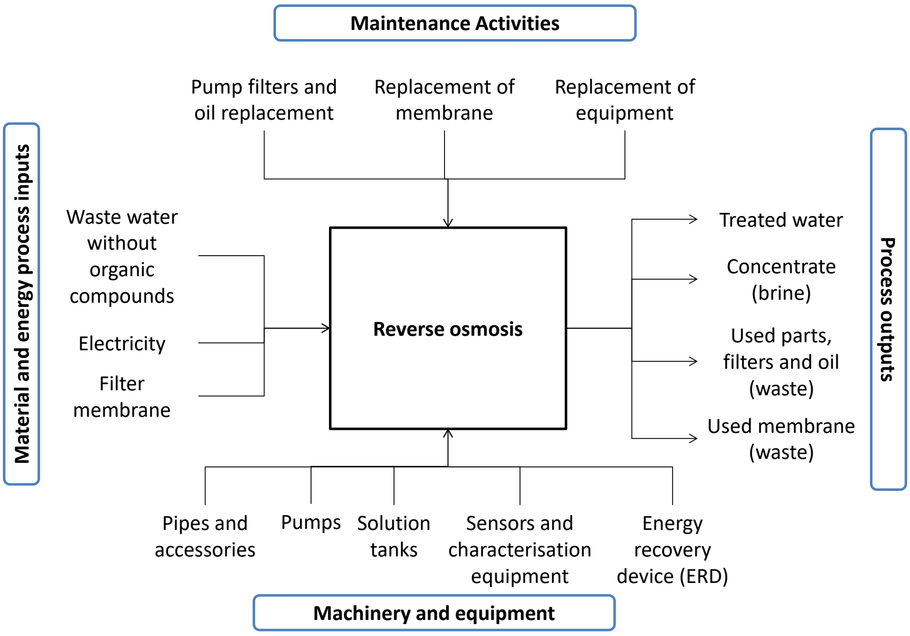

Figure 18: Graphic description of the reverse osmosis.

4.7. Biomass valorisation

Finally, the harvested biomass will be converted to valuable products through different techniques. The processes will be designed in WP6 and presented later on in the project.

4.7.1. Animal feed

The algae biomass has high protein content and thus has potential as feedstock in animal feed. Many species of microalgae also contain valuable fatty acids which mean that there is potential for higher value feeds. In the SALTGAE system, algae proteins and fatty acids from refinement of the harvested biomass will be used in the production of animal feeds.

4.7.2. Resins and edible coatings

Edible coatings can both protect the food from spoiling and enhance the nutritional value of the product. In the SALTGAE system, polysaccharides, proteins, and lipids from refinement of the harvested biomass will be used to produce edible coatings. In the production of resins, lipids and sugars will be utilized. Synthesis methodology of algae derived monomers will be used in the production of both edible coatings and in the production of adhesives and water-based coatings.

4.7.3. Material fillers and pastes

The resulting algae residues after refinement of the harvested biomass mainly consist of partially degraded cell fractions and carbohydrates. At present, this biomass fraction is usually burnt or used as fertilizer. Within SALTGAE, this fraction will instead be used as fillers for bio-composites and/or 3D-printing pastes. For use in bio-composites and rubber compounds, the biomass will be processed into a solid powder e.g. by the following operations: drying, grinding, ultra-sonication, and sieving. The polymers that will be used in the bio-composites will be biodegradable or natural polymers (e.g. PLA, other polyesters or natural rubber). For 3D-printing, the algae residues will be used as functional fillers in liquid pastes (clays, geopolymers, and polymeric resins).

5. SCENARIOS

Within SALTGAE, each of the three demo sites represents a basic scenario which will be compared with benchmark systems. Within each basic scenario, a number of variations are possible based on 1) selected process for effluent pre-treatment (three options), 2) desalination method (two options), and 3) resulting product(s) in the biomass valorisation (3 options). In Table 3, the basic scenarios and the possible variations are presented, each with an index. The purpose with the indexes is to be able to easily describe which scenario is under consideration. E.g. KO-III-RO-1 means KOTO basic scenario with direct photolysis as effluent pre-treatment, reverse osmosis for desalination, and that the end product after the biomass valorisation is animal feed. Except the products presented in the table, fertilizers are produced in the first basic scenario (KO) and material fillers and pastes are produced in all three scenarios.

Table 3. Overview of basic scenarios, possible variations within the scenarios, and their indexes.

Basic scenario (site)		Effluent pre-treatment		Desalination		Product	
KO	KOTO	I	Direct ultrafiltration/ nanofiltration of the supernatant	ED	Electro-dialysis	1	Animal feed
AV	Arava	II	Activated carbon adsorption and retention of its particles by micro/ultrafiltration	RO	Reverse osmosis	2	Edible coatings
AM	Archimede	III	Direct photolysis			3	Resins

5.1. Basic scenarios

The SALTGAE system will not be fully implemented at any of the sites. In order to assess the sustainability of the whole system, theoretical data will be used for the parts not implemented at the demo sites. The process flows and system boundaries in each basic scenario are presented in Figure 19-Figure 21. In these figures it is also possible to see which processes will be part of the respective demo. Machinery and other equipment as well as energy, materials and wastes connected to maintenance are also included in the scenarios. For detailed information of these inputs and outputs, see Chapter 4.

5.1.1. KOTO

At the Slovenian demonstration site, the SALTGAE-system will be implemented for tannery wastewater (high BOD and high salinity). A two-stage anaerobic digester is used as the second step in the primary treatment. The carbon dioxide from the anaerobic digestion is sent to the buffer system and the algae ponds. All three possible effluent pre-treatments and products (see Table 3) will be considered, and for desalination reverse osmosis will be used. The small aerobic digester will not be implemented at the demo site since the major part of the solids received is non-digestible (sand and dirt). Further, anaerobic digestion is a classical process and if needed, any digestible solids received could be sent to the large biogas plant already existing on the site. For the parts of the SALTGAE system not implemented, theoretical data will be used. An overview of the system is presented in Figure 19.

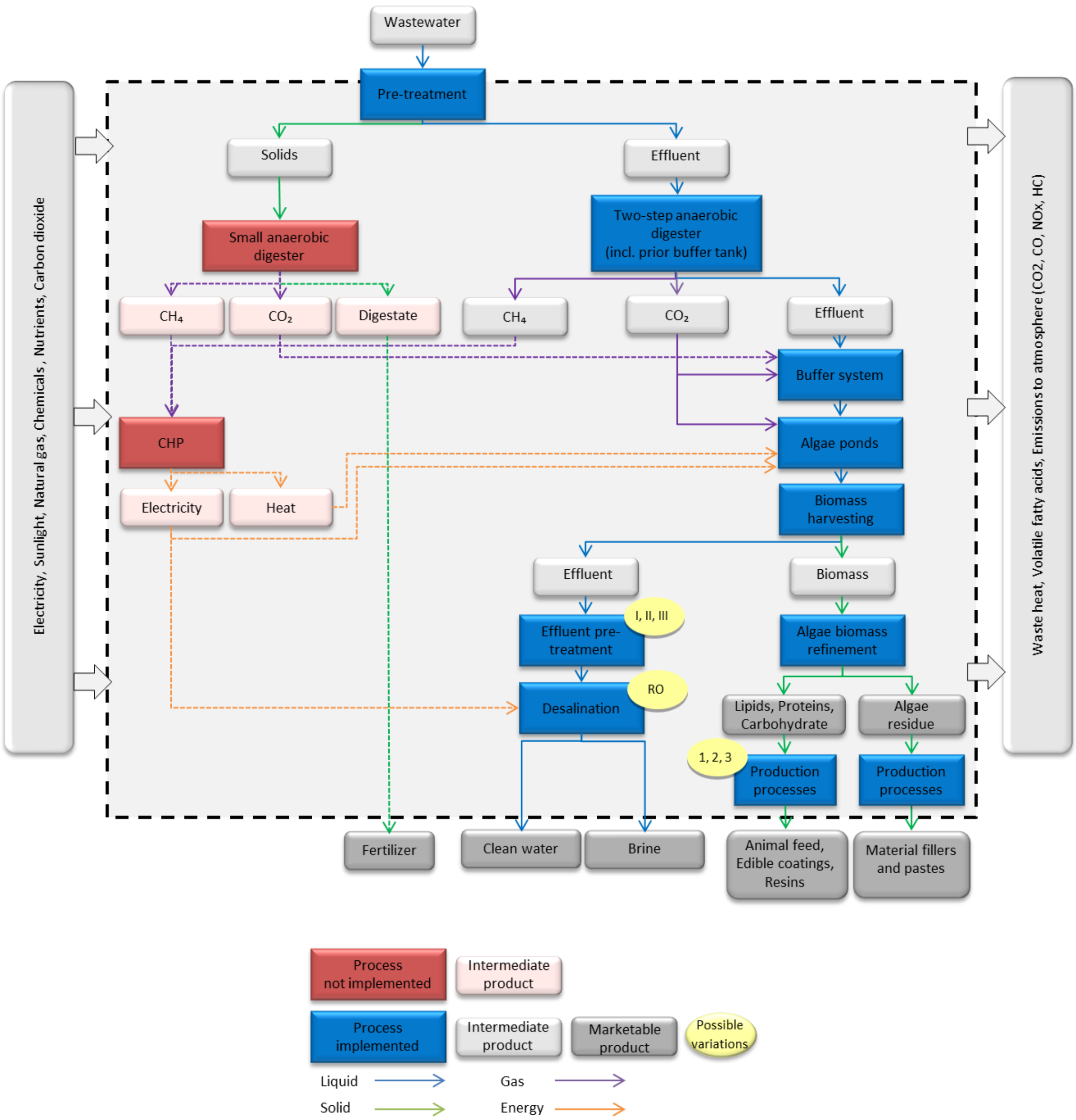

Figure 19: Schematic illustration of the KOTO basic scenario.

5.1.3. Arava

At the demonstration site in Israel, the SALTGAE-system will be implemented for aquaculture wastewater (low BOD and low salinity). DAF is used in the second step in the primary treatment. Most likely, no flocculants will be used. Some chemicals will be used for pH-adjustments and cleaning, and some might be used for nutrient balancing. All three possible effluent pre-treatments and products (see Table 3) will be considered, and for desalination electro-dialysis and reverse osmosis will be considered. At this site, there will be no need for heat-input to the algae ponds in general. If needed, e.g. during night, one option is to implement a large water storage for equalization. However, for the drying, some heat might be required. As in the previous basic scenario, the small anaerobic digester and the CHP will not be implemented (see Figure 20). Instead the solids from the pre-treatment will be used directly as fertilizers or be discarded. The treated water will be tested for irrigation of crops.

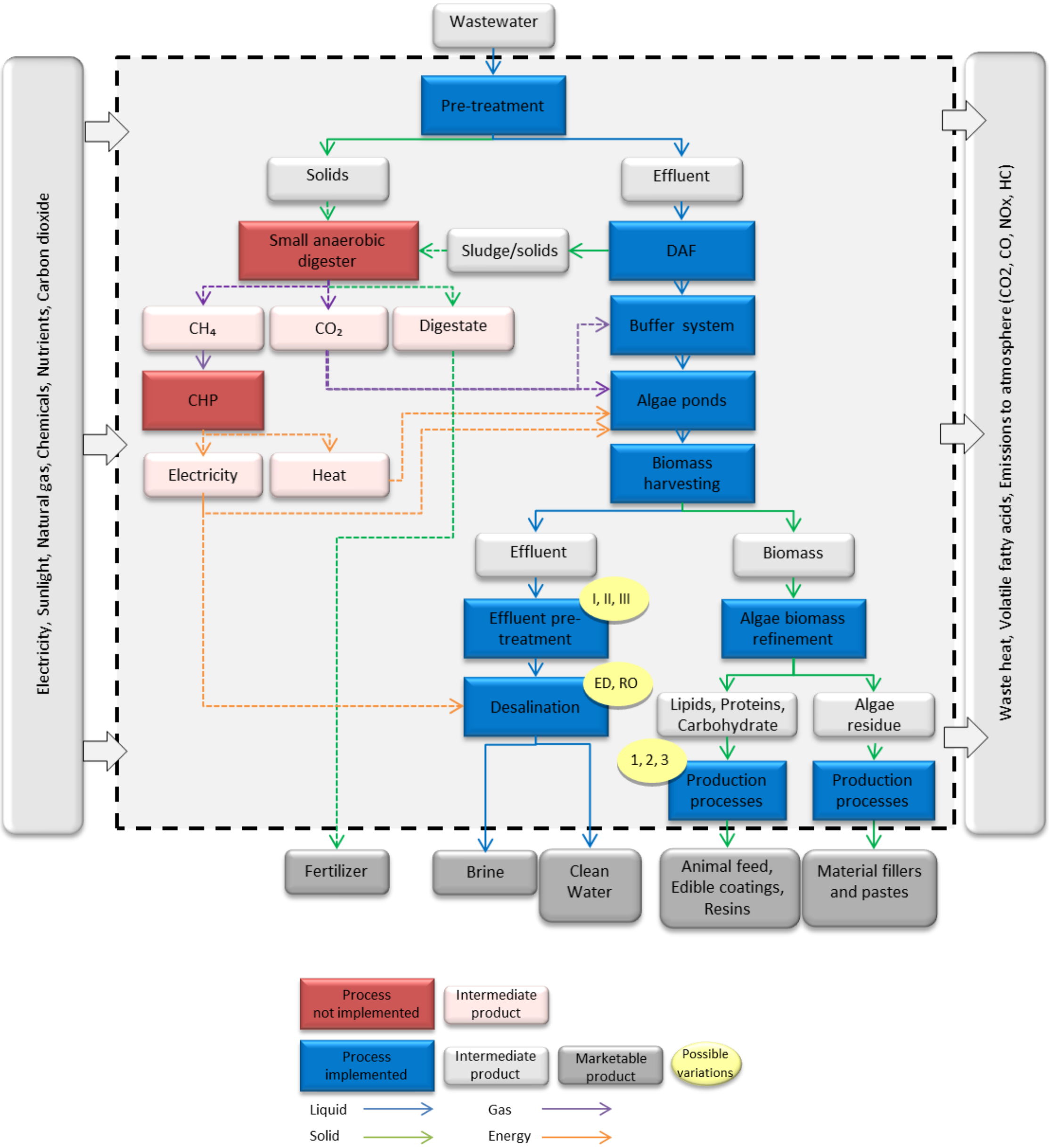

Figure 20: Schematic illustration of the Arava basic scenario.

5.1.4. Archimede

At the demonstration site in Italy, dairy wastewater (low/medium BOD and low/medium salinity) will be treated in a large scale algae multi-pond. Most likely, the primary treatment will not be done at the demo site but at the wastewater supplier (see Figure 21). At the site, a vegoil CHP is already installed and will most likely provide the CO_2 needed. DAF is used in the second step in the primary treatment. In this stage of the project, it is not yet decided how the treatment of the effluent after the biomass harvesting will be designed.

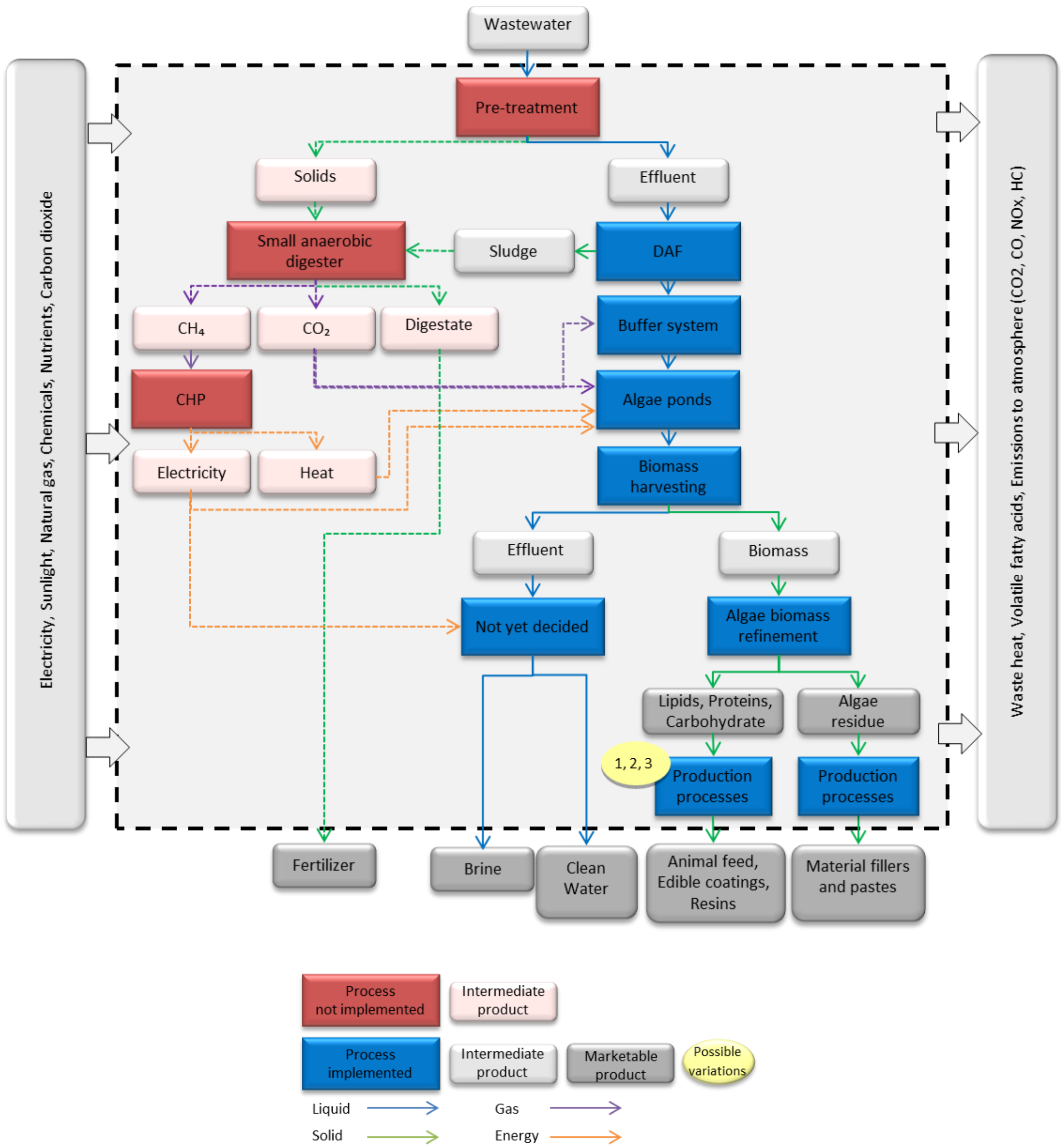

Figure 21: Schematic illustration of the Archimede basic scenario.

5.2. Benchmarks

In order to study both the positive and negative sustainability impacts of the SALTGAE system, the wastewater treatment and the resulting products need to be studied as well as the benchmark systems and products that they intend to substitute in the technosphere. In this section, the benchmark for the wastewater treatment and the products that shall be used for system expansion are briefly discussed.

5.2.1. Benchmark for wastewater treatment

There will be three benchmarks for wastewater treatment, one for each basic scenario. To make a fair comparison, it is important that the wastewater in the basic scenario and the benchmark have similar properties. Thus, it is preferable to use current practice at each demonstration site before the SALTGAE system is implemented as a benchmark system. Otherwise, a plant which treats wastewater with similar properties can be used as a benchmark. If none of these two options are feasible, a system with standard wastewater treatment can be used, where the data is adjusted with additional load factors for salinity.

At the site in Italy and Slovenia, there are already wastewater treatment plants (WWTP) in place and the demo sites will receive and treat a part of these wastewater streams. The ideal benchmark for the Archimede and KOTO basic scenario is thus the respective existing WWTP. However, at the site in Slovenia, the wastewater stream that will be sent to the KOTO demo plant will have other properties than the water treated in the existing plant. Thus, estimations must be made to compensate for these differences.

Since the wastewater treatment in place at the site in Israel only is in small scale, it seems fair to use another wastewater treatment plant as benchmark in the Arava basic scenario. A suitable benchmark system has been identified in the US. The plant treats wastewater from the shrimp industry, which is judged to be comparable with the wastewater from pisciculture, and have been in operation more than ten years. Data from this plant should be accessible and will be adjusted to facilitate a comparison. Other possible benchmarks are also under consideration and a final decision will be made later on in the project.

5.2.2. Benchmark for products

Since the project is only on an early stage, the technical specifications of the products are still unknown, as well as the viability of the final products since tests must be carried out (e.g. in-vivo trials for animal feed, performance of coatings). These technical specifications are fundamental to establish a function in the technosphere for them, and therefore key to define a benchmark equivalent that can provide the same function and thus will be substituted by each SALTGAE product. This is why instead of characterising each product system, key issues for each one will be discussed.

5.2.2.1. Animal feed

The aim of this pathway for biomass valorisation is to replace soybean-based animal feed or apply biomass (*Spirulina*) as feed supplement for its anti-inflammatory and veterinary properties.

In the first case, the percentage of replacement is not known at the moment and could vary within a wide range (5-100%), but the target is >70% replacement. Therefore, agricultural soybean feedstock is established as a preliminary benchmark product, assuming it will replace locally produced soybean or a soybean production that represents a mix of the global soybean market. In the latter case, the benchmark should be standard spirulina coming from fresh water media cultures.

5.2.2.2. Resins and edible coatings

The goal with this pathway is to use the harvested and refined algal biomass to synthesise water-based polyurethane dispersions. It is intended to synthesise only the monomer for the dispersion, before any polymerisation process. Therefore, the preliminary benchmark product is a monomer for water-based polyurethane dispersion.

5.2.2.3. Material fillers and pastes

For this pathway, the algae residue from the three-stage separation will be characterised in order to determine its suitability as filler in biocomposite materials; more specifically ceramics and liquid pastes. The preliminary goal is to substitute traditional filling materials.

5.2.2.4. Fertilizer

Finally, the digestate from anaerobic digester will be tested for use as fertilizers in agricultural crops. Since they are yet to be characterized, key parameters are still unknown such as nitrogen and phosphorus content and toxicity. Therefore, it is still unclear which kind of fertilizer could be directly substituted by this co-product. However, it can be already established that the substituted fertilizer should be organic-based.

6. CONCLUSIONS

A framework for the sustainability assessment of the SALTGAE system has been established. The benchmarks will be further developed later on when specifications of the resulting products are available. Since the techniques will be tested and further developed during the course of the project, the scenarios and settings might be refined. Some scenarios might be eliminated if they e.g. do not function as thought or proven to be too costly.

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Table 4: References

