AlgaeBioGas

Algal treatment of biogas digestate and feedstock production

D4.3

LCI, LCA of the case study instalation

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1 Summary

Life cycle assessment is a multi-step procedure for calculating lifetime environmental impact of a service or a product. In our case, we have set up AlgaBioGas Demonstration centre for algal treatment of biogase digestate and the following report describes LCA of AlgaeBioGas system. Environmental impacts of Algaebiogas system were assessed using Simapro software and ecoinvent database; 18 impact categories were used. Impact categories for 3 different scenarios were assessed and compared.

Editorial note

Deliverables in AlgaeBioGas project necessary build on and refer to previous deliverables. Our aim is to make them self-contained readable documents which necessary involves some replication of contents of previous deliverables, either as verbatim or summarized quotes. We are aware that such text is annoying to someone reading deliverables in series, so we have decided to set such text in lighter colour.

Thus, if you are reading just this text, please find contextual and reference information in lightly set sections; if you are acquainted with the project context (like a reviewer), please ignore the text set in light typeface.

Previous deliverables (partially) quoted in this document:

DoW	Description of work (Annex I of the Grant Agreement)
D4.1	Case study operation assessment

2 Project Abstract

AlgaeBioGas project is focused to market introduction of algal-bacterial treatment of biogas digestate. Using algae we can recycle CO2 emissions and nutrients contained in the biogas digestate. Excess heat can also be productively used. Treated digestate is of such quality that it can be reused or released to the environment. Resulting biomass can be used as biogas substrate, possibly after extraction of specific components in biorefinery.

Classical biological (bacterial) waste water treatment successfully reduces the quantities of organic substances at the cost of significant CO2 emissions and significant energy consumption for aeration. Mineral nutrients, flushed with the liquid phase of digestate, are lost in the bacterial sludge which is frequently deposited, incinerated or discharged to the environment.

Algae hold a great potential because of their high growth rate, easy production, better utilization of sunlight compared to conventional plants, shorter lifecycles and independence from fertile agricultural land. Biogas plants are rich sources of mineral nutrients, CO2 and heat. By algal recycling we can close material cycles, provide feedstock for bio-refining various high value products and decrease competition between biogas and food use of agricultural crops.

The project aims to set-up the first application as a demonstration centre and prepare all prefabricated technology, organization and marketing tools to market replication projects. The technology demonstration centre is not only be able to demonstrate the technology in full size at a demanding customers site, but also provides on-site support for customer's testing, analysis, evaluation, training and other activities required as part of a complex project.

3 Task Description and Objectives

The objective of this deliverable is to evaluate environmental impact of microalgal treatment of liquid phase of biogas digestate and comparison with environmental impacts of biogas digestate application as a fertiliser to agricultural land. To our knowledge, AlgaeBioGas demonstration centre is the only installation for biogas digestate treatment connected to biogas plant in EU up until April 2016. Moreover, no LCA analysis has been published for this technology so far.

From DoW (task 4.3 Preparation of LCI and LCA for he demonstration centre)

Existing Life Cycle Assessment is based on theoretical and small scale pilot data. Operation of the demo centre will make a large set of real world data available to be incorporated into the future assessments.

A software tool for LCA and a database of LCI data will be selected and our data will be contributed to the knowledge base.

A detailed LCA will be done for the demonstration centre operation in several operating modes. This will be used for both assessing the real impact of the centre to the environment, but above all as a marketing tool: LCA estimates for potential new installations have almost become a must. So we have to be able to show an accurate assessment as an example of future work for the customer in repeated market applications.

4 Introduction

4.1 Biogas sector in Europe

The number of biogas plants in Europe is rising and has reached 17240 biogas plants by the end of 2014 (EBA, 2015). This number shows great potential of the technology where organic material is transformed into biogas, a sustainable source of energy, through the process of anaerobic fermentation. Biogas presents important renewable source of energy in Europe decreasing dependency of fossil resources and contributing to achieve the target approved by the renewable energy directive (2009/28/EC) of 20% of final energy consumption based on renewable sources by 2020. In most cases biogas is used for production of electricity, rarer in combined heat and power units to produce electricity and heat, or for transport use.

4.2 Digestate and its challenges for biogas operators

Beside biogas, biogas plants are generating large amounts of biogas digestate daily. For example 1 MW biogas plant produces approximately 160 m^3 of biogas digestate per day and its processing presents an important issue for biogas plant operator resulting in high costs and environmental impact (Fuchs & Drosg, 2013).

Biogas digestate is a mixture of undigested substrates, microbial biomass, and metabolic products. Its composition depends on input biomass and the process of anaerobic digestion. Digestate consists of water (90% – 95%), high concentration of mineral nutrients, heavy metals, small percentage of organic matter and other undefined substances (Xia & Murphy, 2016).

4.2.1 Digestate treatment technologies and its drawbacks

Other digestate treatment technologies, such as centrifugation and evaporation, can efficiently concentrate the nutrients; however, they require high energy input.

Different technologies are available for biogas digestate treatment, from simple application of digestate to agricultural land as a fertilizer to mechanical drying, thermal vaporization, physical–chemical treatment (separation, ultra-filtration, reverse osmosis, ionic exchanger) (Rehl & Müller, 2011). Those techniques require high energy input and most common practice in many biogas plants is separation of biogas digestate to solid and liquid phase and simple application of the digestate to agriculture land as a fertiliser. Solid phase presents approx. 10-20% by mass and its use as a fertiliser is not problematic. Liquid phase of biogas digestate is more difficult to process due to its big quantity 80-90% by mass and its composition. Simple spreading of liquid digestate can lead to nutrient loss due to NH_3 volatilization and draining of the nutrients (N, P) to nearby waters causing eutrophication. Liquid phase can contain contaminants like heavy metals, pathogen organisms or plastic particles, which can reduce soil productivity (Lukehurst et al., 2010; Xia & Murphy, 2016). High concentration of cations, especially K+ ions, reduces ion-excange capacity of soil causing decreased fertility of soil (Unterfrauner et al., 2010).

Another important factor is that land application of liquid biogas digestate depends on the type of the soil, planted crops, crop growth stage and time of year. Liquid digestate cannot be applied in winter months or in bad weather and meanwhile digestate needs to be stored. During storage biogas digestate can emit greenhouse gases (e.g., CH4, N2O) and other substances due to present volatile solids. Transport of biogas digestate to agricultural area causes logistical problems and high costs, since transported biogas digestate consists mostly of water. Biogas digestate has to be transported to adequate agricultural area to prevent over fertilization of soils and to avoid negative effects on the soil or loss of the nutrients (Fuchs & Drosg, 2013; Lukehurst et al., 2010; Xia & Murphy, 2016).

4.3 Microalgae and biogas digestate treatment

To avoid abovementioned problems and to optimize biogas plant process, alternative techniques for biogas digestate treatment are needed. Microalgae hold great potential for wastewater treatment and present alternative option for biogas digestate treatment (Whitton et al., 2015; Xia & Murphy, 2016). Microalgae use dissolved mineral nutrients from biogas digestate, CO_2 and organic matter for their growth and produce O_2 and valuable biomass. This results in reduction of concentration of mineral nutrients in biogas digestate, contributes to CO_2 sequestration and oxygenation of biogas digestate. Microalgae also contribute to heavy metals removal (Kaplan et al., 2013), organic pollutants like hormone disruptors removal (Matamoros et al., 2015) and pathogen bacteria removal (Abdel-Raouf et al., 2012). Produced microalgal biomass can be used for several applications, for example biogas (Passos et al., 2014; Razzak et al., 2013), biofuels (Razzak et al., 2013), feed (Markou and Georgakakis, 2011), bioplastics, protein production and others.

Microalgae need sunlight for their growth. For that reason, microalgae cultivation systems are designed as a shallow raceway ponds which require large area, which doesn't have to be agricultural land. Biogas digestate has dark colour, which can additionally reduce the penetration of light into raceway ponds. Another factor that can inhibit microalgae growth is high ammonia concentration in biogas digestate. This can be avoided with higher retention times of biogas digestate in the treatment system or by larger area needed for digestate treatment.

4.4 Benefits of microalgal treatment of digestat

There are several benefits that can be reached by using algae for biogas digestate treatment:

- production of algal biomass that is returned to the anaerobic process as additional biogas substrate;
- production of algal biomass as a fertilizer (as an alternative to composting),biological;
- production of algal biomass that is used in biorefinery to extract useful products (lipids for biodiesel, protein for animal food, special ingredients like polyunsaturated fatty acids, antioxidants, and similar); the remaining biomass is returned to biogas production as substrate;
- treatment of liquid digestate to remove organic residuals and all mineral nutrients; treated water can then be released to the environment or re-used in the process; such treatment is best done with algal bacterial culture; resulting biomass is again recycled to the biogas production;
- use of nutrient rich substrate for production of algal biomass for other purposes (e.g. edible products, animal feed products, nutriceuticals); provided that the substrates for the biogas production are of organic / ecological origin, the resulting product may receive ecological status and be certified as organic product;
- quick pre-treatment of digestate by attached cyanobacteria to remove heavy metals and/or endocrine disruptors and then using the treated digestate for any of the above purposes.

5 LCA and microalgae

All mentioned technologies for biogas digestate treatment have certain environmental impacts. The most accepted method for assessment of these impacts is life cycle assessment (LCA). The objective of this deliverable is to evaluate environmental impact of microalgal treatment of liquid phase of biogas digestate and comparison with environmental impacts of biogas digestate application as a fertiliser to agricultural land. To our knowledge AlgaeBioGas demonstration centre is the only installation for biogas digestate treatment connected to biogas plant in EU, up to April 2016. Moreover, no LCA analysis has been published for this technology. Most published LCA studies refer to energetic use of microalgae. The best approximation of LCA for AlgaeBioGas technology was published by Collet et al. (2011) and covers methane production from microalgal biomass as a biofuel. The article is based on lab scale and pilot scale data which can differ significantly from real scale application.

LCA study of biogas processing techniques has been published by Rehl and Muller (2011) which included one conventional digestate management option (storage and application of untreated manure on agricultural land), one stabilization process (composting), three mechanical drying options (belt dryer, drum dryer and solar dryer), one option using thermal vaporization (concentration) and one physical–chemical treatment (combination of separation, ultra-filtration, reverse osmosis and ionic exchanger); but no microalgae technology was included.

We have to mention that comparison between different published LCA studies is complicated due to the differences in LCA methodologies, system boundaries and life cycle inventory data (Bradley et al., 2015). Bradley et al. (2015) have published guidelines for unified approach to LCA for algae biofuel facilities. In LCA of micro-algal biogas digestate treatment we tried to consider the proposed guidelines, but we couldn't avoid modifications due to different system and methodology.

6 Demonstration centre overview

The concept and the technology of microalgal treatment of biogas digestate has been successfully tested and proven within AlgaeBioGas project in demonstration centre for microalgal-bacterial treatment of biogas digestate. Demonstration centre consist of 0,5 MW thermophilic biogas plant and 100 m^2 high rate algal pond (HRAP) covered with greenhouse. Liquid phase of biogas digestate is treated with mixed community of microalgae and bacteria in HRAP, where microalgae use mineral nutrients and CO_2 from fuel gases and bacteria during growth and produce O_2 and microalgal biomass. O_2 and remaining organic matter is used by bacteria, which produce CO_2. Excess heat is used for maintenance of optimal temeprature in colder months. Produced algal biomass is returned to the biogas plant as additional biogas substrate. Within this process biogas digestate is processed directly on site. By algal and algae-bacterial recycling of nutrients we can close material cycles, provide feedstock for bio-refining various high value products and decrease competition between biogas and food use of agricultural crops. We can also prevent local shortages of digestible feedstocks, which occasionally limit biogas productivity, especially in larger biogas power plants (>1 MWe). Algal production can fully use nutrients from anaerobic digestate, CO_2 that is otherwise emitted to the atmosphere and some of the excess heat from the biogas operation.

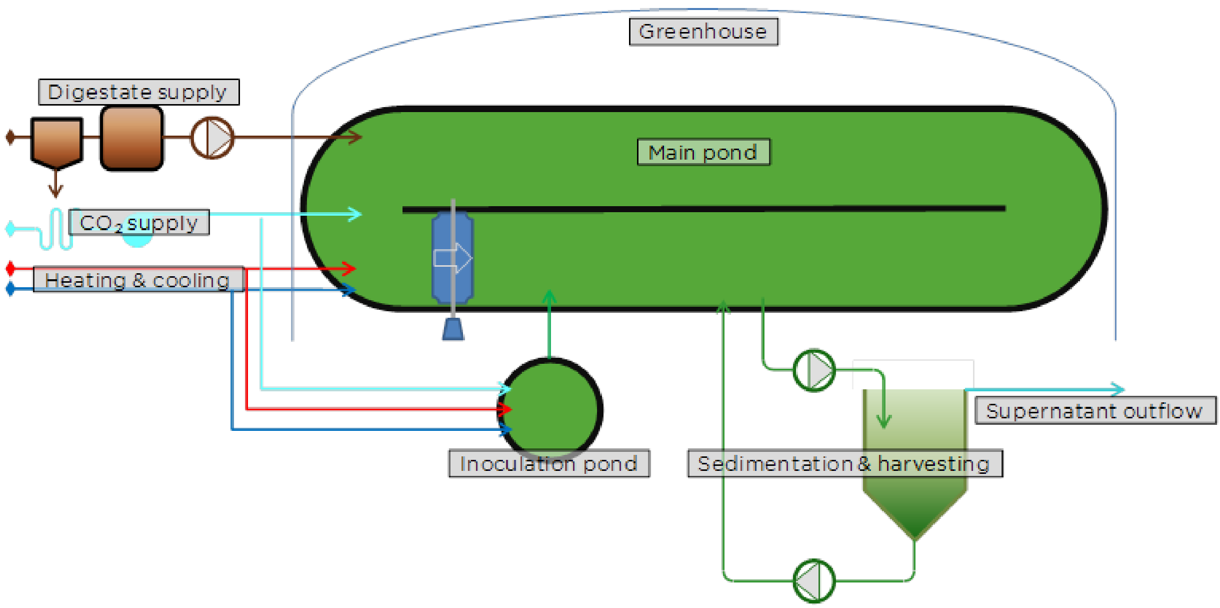

Figure 1 Demonstration centre subsystems

7 LCA of microalgal-bacterial biogas digestate treatment technology

7.1 Goal and scope definition

The goal of this study is to evaluate environmental impacts of AlgaeBioGas system for microalgal - bacterial biogas digestate treatment. Environmental impacts of ABG system are compared to environmental impacts of application of biogas digestate to agricultural land. Three scenarios were determined (Figure 2):

Scenario A: includes all material and energy flows of the system (cradle to grave). Produced microalgal biomass presents new sustainable energy (electricity) which is released into electrical network and replaces electricity production from other types of power plants.

Scenario B: includes all material and energy flows of the system (cradle to grave) where produced microalgal biomass presents new free feedstock for biogas plant, resulting in additional production of electricity and increased nominal power of biogas plant. Electricity production increases for 15%.

Scenario X: includes storage of biogas digestate in storage containers, its daily transportation to farms and application of the digestate to agricultural land. Transportation from biogas plant to farms includes average distance 50 km (one way) and capacity of transport trucks 20 m^3. Application of biogas digestate to agriculture land is provided by farm tractors on average distance 10 km (two way).

The scenarios are schematically presented in Figure 2. The biogas plant is not included in the LCA due to different types of anaerobic digestion process (mezo- and thermo-philic process) and different substrates used by biogas plants. The process of microalgal – bacterial treatment of biogas digestate is presented in Figure 3. Microalgal-bacterial biogas digestate treatment process takes place in shallow raceway ponds, covered with simple greenhouse to provide optimal conditions for microalgal – bacterial culture in all weather conditions and to prevent contamination and introduction of algae eating organisms. Microalgal biomass is concentrated in sedimenter and then returned to biogas plant. Input parameters to ABG system are biogas digestate, CO_2, heat and electricity. Important environmental factor is smell of biogas digestate, which is hard to evaluate numerically due to unknown concentration of substances causing bad smell. Output of the algaebiogas system is algal-bacterial biomass, which can be returned directly to anaerobic digestion process, and effluent water. Effluent water can be partly reused in the system for replacement water loses due to evaporation.

Algaebiogas system is located in southern central Europe in Ljubljana, Slovenia. All data for LCI were obtained from algaebiogas demonstration centre and extrapolated for the system with biogas digestate treatment capacity from 1 MW thermophilic biogas plant. The required area for the system is 5,1 Ha Functional unit is determined as MWh of energy produced in biogas plant per year.

The inventory includes extraction of resources, production of materials and parts used in the system, production of energy, construction of parts of the system, construction process, use of material and dismantling and disposal of material. Final mounting of each system components, e.g. greenhouses, is excluded from LCA. Life span of infrastructure is 30 years. Life span of electrical equipment is 15 years.

LCA follows the standard LCA guidelines according to ISO 14000 and ISO 14040. Software program SimaPro 8.0.5 and ReCiPe methodology was used for preparation of LCA. The Excel template "ReCiPe Mid/Endpoint method, version 1.08 December 2012" (Goedkoop et al., 2013b) was used as a base document for further work. Environmental impacts were assessed using databases Ecoinvent, Agri-Footprint LCI, European reference Life Cycle Database, Franklin US LCI 98, European Life Cycle Data, US Input Output library, EU and Danish Input Output library, Swiss Input Output, LCA Food, U.S. Life Cycle.

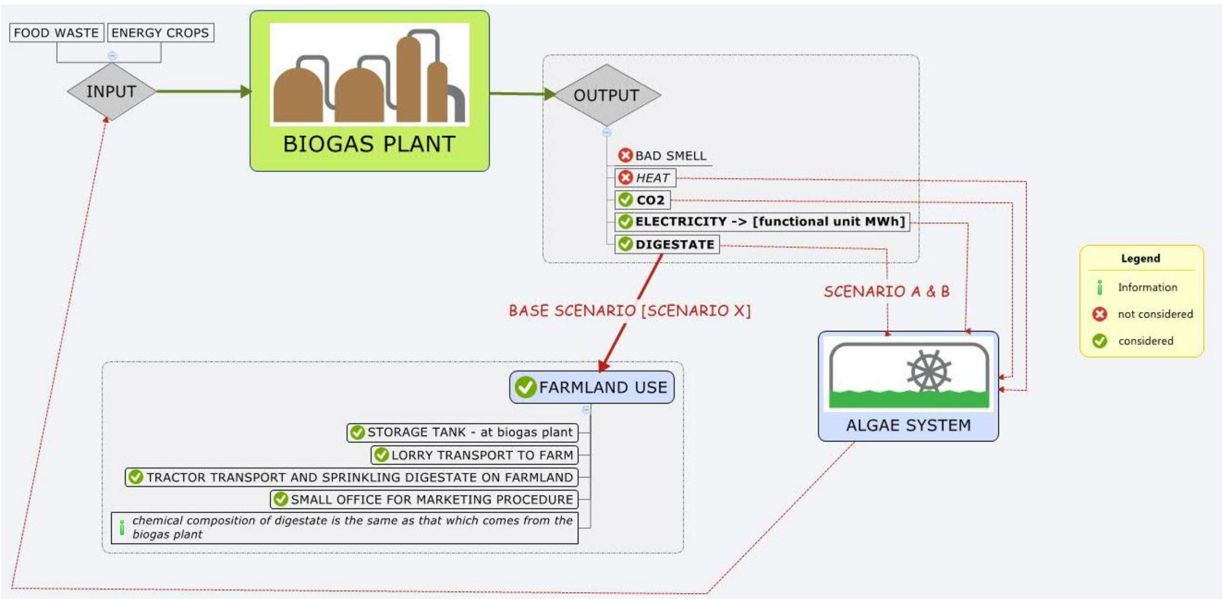

Figure 2 Overview of the system, scenario A, B and X.

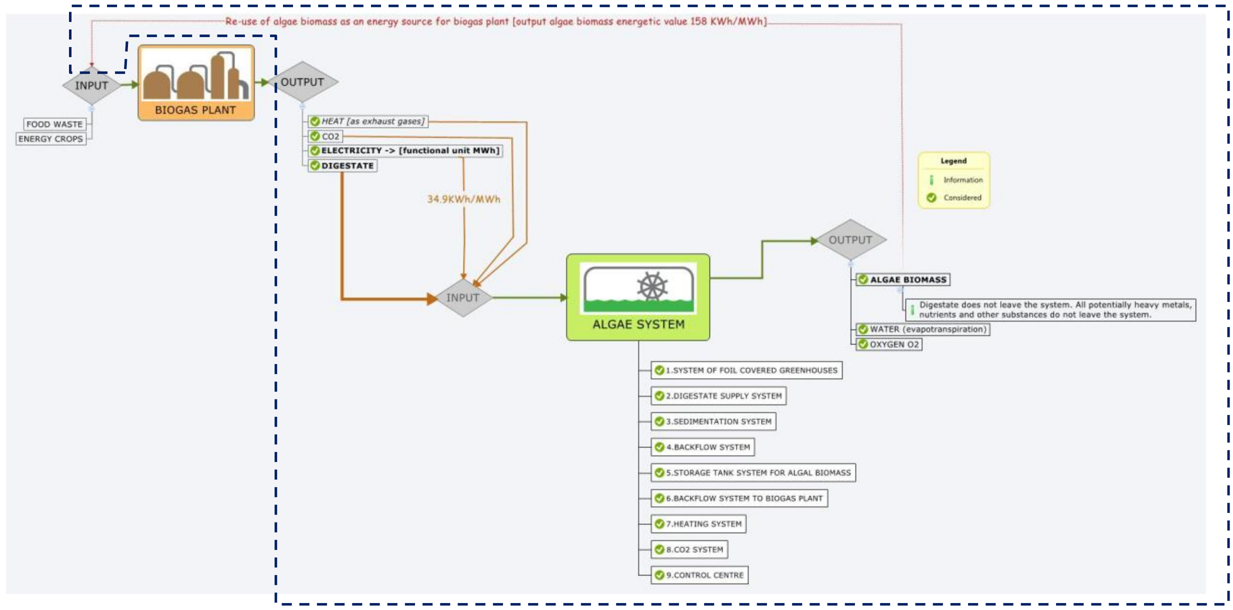

Figure 3 Overview of the microalgal – bacterial biogas digestate treatment process. Dotted line shows system boundary for LCA.

7.2 Life cycle inventory (LCI) and impact assessment

Detailed calculations of LCI are presented in Appendix I.

7.2.1 LCI for microalgal-bacterial treatment of biogas digestate technology

7.2.1.1 Pond system

Algaebiogas system for treatment of biogas digestate is design as modular system, consisting of modular units. Each unit consist of 500 m^2 raceway pond and 64 m^2 area for maintenance of the system. The depth of raceway ponds is 30 cm. Each algal pond is covered with greenhouse. Determined distance between greenhouses is 50 cm.

Number of algaebiogas units is calculated based on the data of algaebiogas system, which can process 300 L of biogas digestate per 100 m^2 of raceway ponds per day. Daily amount of biogas digestate from 1 MW biogas plant is 137,49 m^3. Based on that number required area is 45,83 ha, which requires 92 modular units. Here we have to add additional area required for maintenance, operation process, harvesting of biomass and area needed for control system with control room. Total area needed is 6,5 Ha.

Each raceway pond base is made of concrete (27,8 m^3) and cowered with geotextile (89,7 kg) and rubber foil (4503 kg). Mixing is provided with paddlewheel (200 kg of HDPE and 22,5 kg steel) and 250W motor. Total electricity consumption for mixing is 3750 kW/year for 92 units.

Cooling in summer months is provided with ventilators. Each unit has 2 1,1 kW ventilators. Operating time is calculated in warmer months May-September for 7 h/day. Average operating time of ventilators is 1050 h/year and total electricity consumption for algaebiogas system is 21300 kWh/year.

The average measured growth rate of algal bacterial biomass in the system is 20 $g/m^2/day$, which is equal to 10 kg/ algaebiogas system unit.

7.2.1.2 Biogas digestate supply from biogas plant to microalgal ponds

Biogas digestate is pumped into system units with 750W electric pump. Operating time for pumps are 6 minutes/day for each unit. Total electricity consumption for pumps 10100 kWh/year for 92 units. Ordinary pipes DN 160 mm are used for digestate manipulation. Biogas digestate is pretreated with 200W UV lamp before entering to algal ponds. UV lamp removes potential pathogenic bacteria present in biogas digestate and improves the quality of the produced microalgal biomass and effluent. Total electricity consumption of UV light for 92 units is 1010 kWh/year. Electromagnetic valves are used to regulate input flow of biogas digestate.

7.2.1.3 Sedimentation process

Microalgal bacterial biomass is pumped from raceway ponds to sedimenter, where biomass settles down and concentrates at the bottom of the sedimenter. 750W electric pump is used for pumping of biomass with operational time 20 min/day. El. consumption for pumping is 8640 kWh/year/92 units.

Sedimenter is metal container with conical bottom. V of the sedimenter has to be 2 m^3 for 100 m^2 of ponds. This means the total V at least 920 m^3 per 92 units. Sedimenter has installed very slow mixer (1 kW) to prevent attachment of biomass to the walls of the sedimenter. Estimated el. consumption for mixer is 8400 kWh/year/92 units.

7.2.1.4 Reverse flow system

Reverse flow system ensures that part of the content of sedimenter is returned back to the microalgal ponds. In sedimenter biomass is sedimented and part of the supernatant and biomass is returned to the ponds to maintain optimal volume in the microalgal ponds and to replace water losses due to evapotranspiration. Other part is released out of the system. Reverse flow is provided by pumping with el. pump 750W and operating time 20 min/day. System is controlled with electromagnetic valves and standard pipes DN160 are used. Total el. consumption for pumping is 8640 kWh/year/92 units.

7.2.1.5 Biomass storage

Biomass from sedimenter can be stored in container for short period. This is optional and this is operational in algaebiogas demonstration centre. Storage container should have capacity of 92 m^3 of harvested biomass per day (before drying). Biomass storage unit consist of 750W electric pump, electromagnetic valves, pipes and sensor. Operating time for pump is 0,1h/day per unit and total el. consumption for pumping is 1680 kWh/year/92 units.

7.2.1.6 Biomass transporting system to biogas plant

Produced biomass from algaebiogas system can be directly used in biogas plant. For anaerobic digestion wet biomass can be used. For this reason biomass from the sedimenter or from storage unit can be simple transferred to biogas plant with electrical pump 750W. Besides pump, transport system consist of pipes 160DN, flow sensor and eland data cables. Operating time for pump is 0,1 h/unit what requires 1680 kWh electricity/year/92 units.

7.2.1.7 Heating system

Heating system has to be installed in climates with colder winters. The optimal temperature for microalgal biogas digestate treatment is around 25 – 30 °C. A simple radiator immersed in raceway ponds is used for heating. The source of heat is exhaust gases which goes through heat exchanger. Hot water from heat exchanger is pumped through isolated pipes to radiators with 25W electric pump. Total electricity consumption for pumping is 4970 kWh per year/92 units.

7.2.1.8 CO_2 introduction system

Exhaust gases from biogas engines are used as a source of CO_2. Part of CO_2 comes from bacteria in the system and small amount is introduced by dissolving of CO_2 from air. CO_2 introduction is regulated with pH of the microalgal bacterial culture which is set to 6,5. If pH raises to 7, CO_2 is introduced through simple aerator immersed in the microalgal pond. Total length of the CO_2 introduction pipe is 1092 m^2 per 92 units.

7.2.1.9 Control system

Control system of algaebiogas system is placed in a mobile unit – office container with control room, including hardware and software systems, and electrical unit for control system. Main electric consumers are air condition for heating- 4 months/year and 8 hours/day and cooling- 90 days and 8h/day for the control room. El. consumption for heating and cooling is 2400 kWh/year. El. consumption for PC (150W) is 2630 kwh/year and for lights 876 kWh/year. Mini PC units of control system in each module require 3050 kWh/year.

7.2.1.10 Parameters and substances released from biogas plant entering the algaebiogas system

Parameters and substances from biogas plant which enter the algaebiogas system are CO_2, biogas digestate, heat and electrical energy (Figure 3). Detailed calculations of all parameters are presented in Appendix I.

CO2: 1 MW biogas plant produces 32 g CO_2 / kWh.

Biogas digestate: 300 L of biogas digestate can be treated per 100 m^2 of algaebiogas ponds per day. Each 500 m^2 unit of algaebiogas system can process 1500 L of biogas digestate daily. Biogas composition is shown in Table 1. In LCA an assumption was made that all chemical nutrients are used by microalgae, which are used as a substrate in biogas plant for biogas production. With this assumption, no chemical elements are released out of the system. In real algaebiogas system this assumption would cause accumulation of heavy metals, especially Cr, and non-digestible matter in the system, which could decrease efficiency of biogas digestate treatment process in the long term. Due to this reason, part of biomass should be removed out of the system and could be used as a fertiliser, for biogas production etc.

Table 1 Chemical composition of biogas digestate

PARAMETER	(mg/kg)
Nitrogen total (N)	1938.0000
Ammonium Nitrogen (NH4-N)	1421.8800
Nitrate as nitrogen (NO3-N)	0.5712
Nitrite nitrogen (NO2-N)	0.3060
Phosphate phosphorus (PO4-P)	427.3800
Phosphorus total (P)	1691.1600
Potassium (K)	137.7000
Calcium (Ca)	178.5000
Magnesium (Mg)	74.4600
Sodium (Na)	8155.9200
Arsenic	1.0000
Zinc	2.0000
Mercury	0.0200
Nickel	1.0000
Cooper	1.0000
Chromium	1.0000
Cadmium	0.0300
Lead	1.0000
Cobalt	1.0000
Selenium	0.3000
Chromium	3.0000

Heat: Heat is by-product of the biogas plant, therefore it is not deliberately produced and used for algaebiogas system. Due to this reason heat is not included in LCI and LCA.

7.2.1.11 Output parameters release from algaebiogas system to technosphere

Output parameters include algal biomass, oxygen and water. Detailed calculations of all parameters are presented in Appendix I.

Water: water losses due to evapotranspiration are 100 L/100 m^2/day. Evapotranspiration is needed for cooling of the algaebiogas system in the summer months.

Oxygen: Oxygen is end product of the photosynthesis process. For each kg of produced microalgal biomass, 1 kg of O_2 is released. Major part of O_2 is used by bacteria in algaebiogas system and for chemical oxidation of different chemical substances. For example substances causing bad smell are immediately oxidised in algaebiogas system resulting in elimination of bad smell.

Algae biomass: 20 g/m^2 algal bacterial biomass is produced daily in algaebiogas system. For LCA caloric value of microalgae biomass is presented for easier interpretation and to provide right functional unit. Caloric value of microalgal biomass is 3580 kcal/kg DW. This equals to 4,16 KWh/kg DW microalgae biomass. Based on presented assumptions produced microalgal biomass equals to 1,08 x 10^6 kWh energy each year.

7.2.2 LCI for application of biogas digestate to agricultural land

7.2.2.1 Output parameters from biogas plant

Output parameters from biogas plat for application to agricultural land include biogas digestate and CO_2. Composition of biogas digestate is presented in Table 1. Total amount of 137,49 m^3 biogas digestate is produced from 1 MW biogas plant each day. The same amount has to be stored and transported to agricultural land.

Produced CO_2 is released to the environment.

7.2.2.2 Parameters included in transport of biogas digestate to farms and its application

137,5 tons of biogas digestate has to be transported daily to farms. Assumed average distance of farms is 50 km. Digestate is transported by trucks with capacity 20 t and euro 4 motor. Distance made by trucks is 685 km/day.

Biogas digestate is storage in storage containers with capacity 962,5 m^3. Biogas digestate application to agricultural land is carried out by tractors and farm machinery. Each application requires average distance of 10 km.

7.3 LCA results and discussion

In the following chapters, LCA results for 3 scenarios are showed and compared.

Scenario A includes all material and energy flows of the system (cradle to grave) and assumes that produced microalgal biomass presents new sustainable energy (electricity) which is released into electrical network and thus replaces electricity production from other types of power plants.

Scenario B includes all material and energy flows of the system (cradle to grave) where produced microalgal biomass presents additional feedstock for biogas plant, resulting in additional production of electricity and increased nominal power of biogas plant.

Scenario X includes application of biogas digestate to agricultural land.

The first part of the results presents midpoint damage level, focusing on negative environmental effects (e.g., terrestrial acidification, freshwater eutrophication, water depletion, etc.).The last part of the results illustrates the endpoint damage level, where indicators from the midpoint category are combined into three common denominators (damage to ecosystem quality, human health, and resource availability).

Selected midpoint impact categories are climate change, ozone depletion, terrestrial acidification, freshwater acidification, marine acidification, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land occupation, water depletion, metal depletion, fossil depletion and electricity use.

7.3.1 Climate change

Impact of scenarios A, B and X on climate change is shown in Figure 4. Algal treatment of biogas digestate (scenario A and B) has positive impact on climate change, as expected, due to the process of photosynthesis in which CO_2 is used for microalgal growth. On the contrary, scenario X – application of biogas digestate to agricultural land has negative impact on climate change, since more than 100 kg of CO_2 equivalent is released to the environment per MWh of energy produced in biogas plant. Based on the results, algaebiogas technology contributes to CO_2 sequestration.

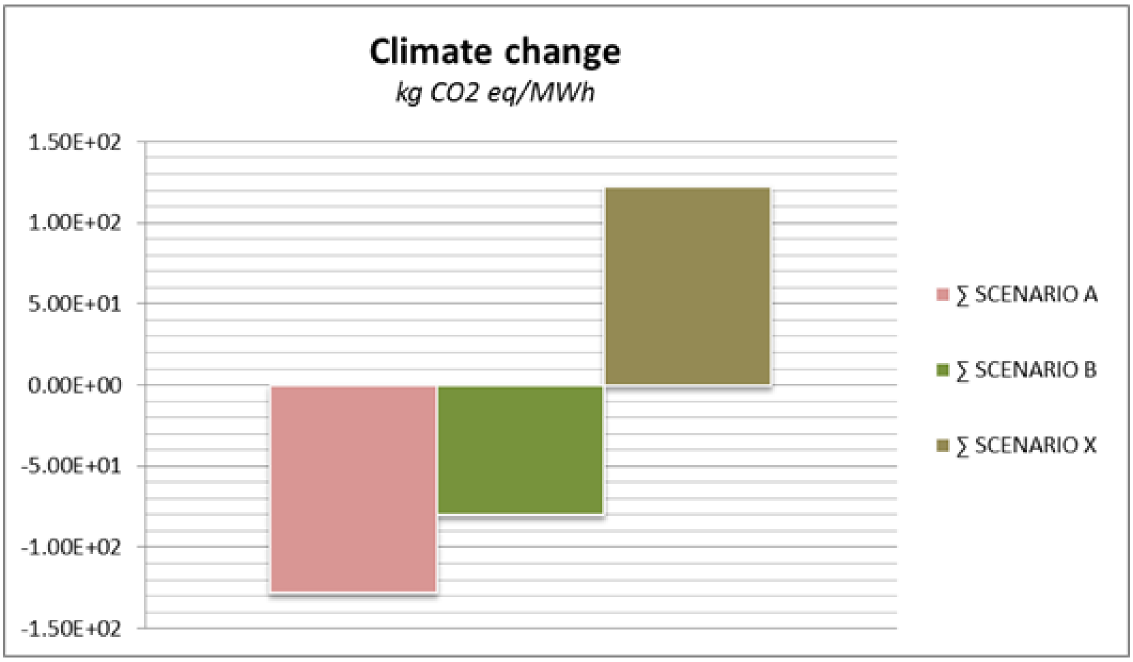

Figure 4 Climate change impact category for scenarios A, B and X.

7.3.2 Ozone depletion

Impact of scenarios A, B and X on ozone depletion is shown in Figure 5. Microalgae technology scenario A and B has minimal impact on ozone depletion. Comparison of scenarios B and X shows 3,2 times lower environmental impact on ozone depletion of scenario B, compared to scenario X.

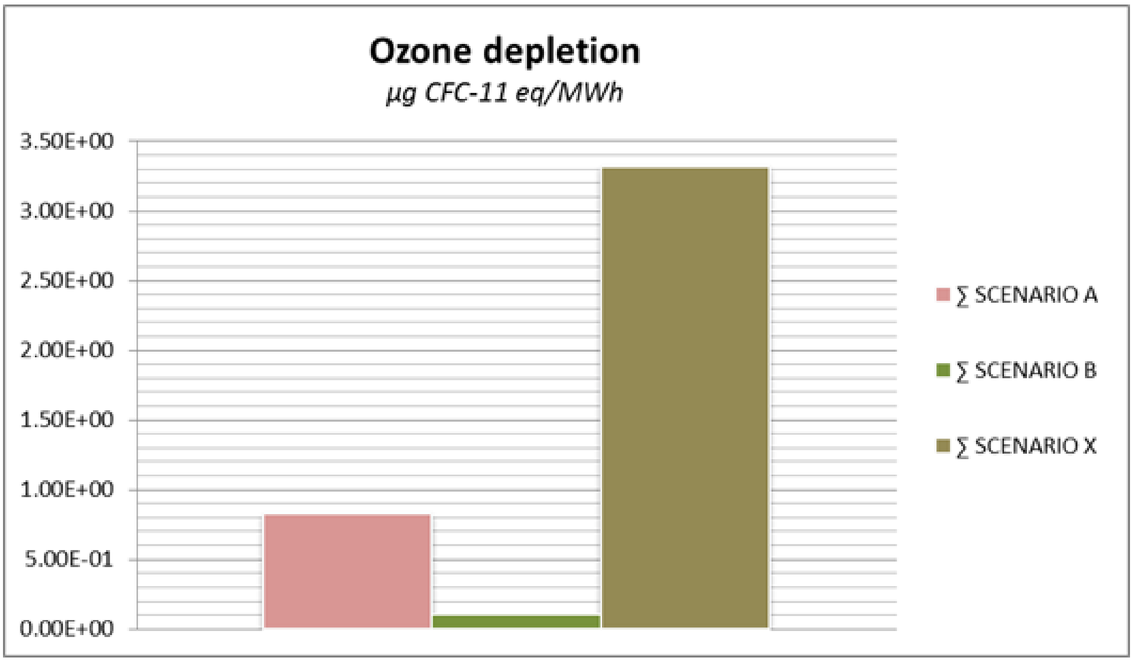

Figure 5 Impacts of scenarios A, B and X on ozone depletion.

7.3.3 Terrestrial acidification

Impact of scenarios A, B and X on terrestrial acidification is shown in Figure 6. Results show minimal impact on terrestrial acidification for microalgal systems (scenario A and B). Scenario X has negative impact on terrestrial acidification expressed as 540 g SO_2 equivalent per MWh energy, compared to 20 g SO_2 equivalent per MWh in scenario A. Scenario B has no impact on terrestrial acidification.

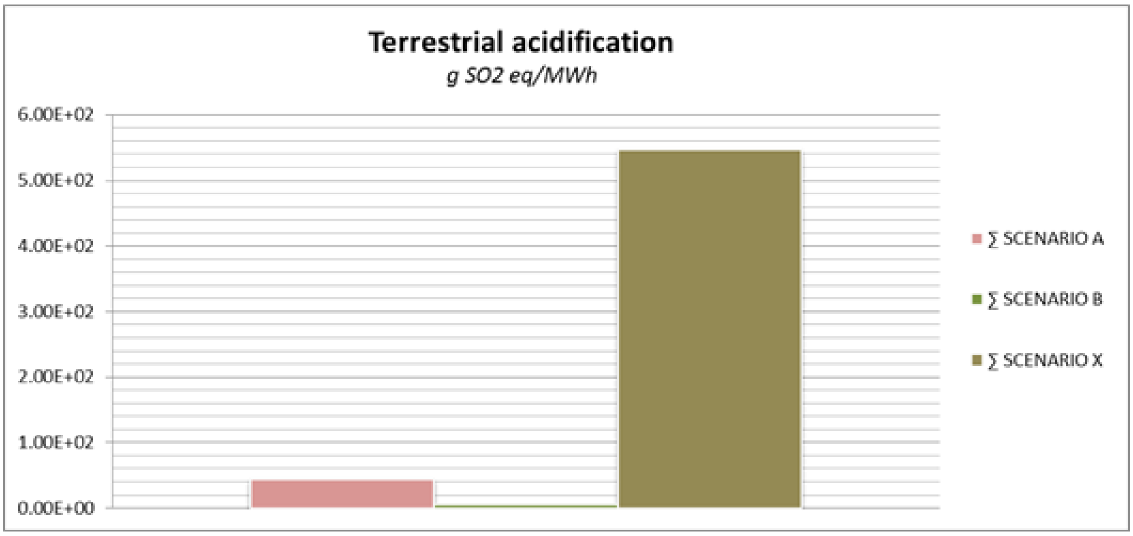

Figure 6 : Impact of scenarios A, B and X on terrestrial acidification.

7.3.4 Freshwater eutrophication

Impact of scenarios A, B and X on freshwater eutrophication is shown in Figure 7. Results show no impact on freshwater eutrophication for microalgae technology (scenario A and B). Those results are expected due to the assumption that all mineral nutrients are used by microalge and are later returned to biogas plant. However, on the long period, some of the microalgae biomass will have to be removed out of the algaebiogas system due to accumulation of heavy metals and other substances which can inhibit microalgae growth.

Results show big impact on freshwater eutrophication equal to 13 kg of P per MWh. Reason for those high values is transportation of biogas digestate to agricultural land.

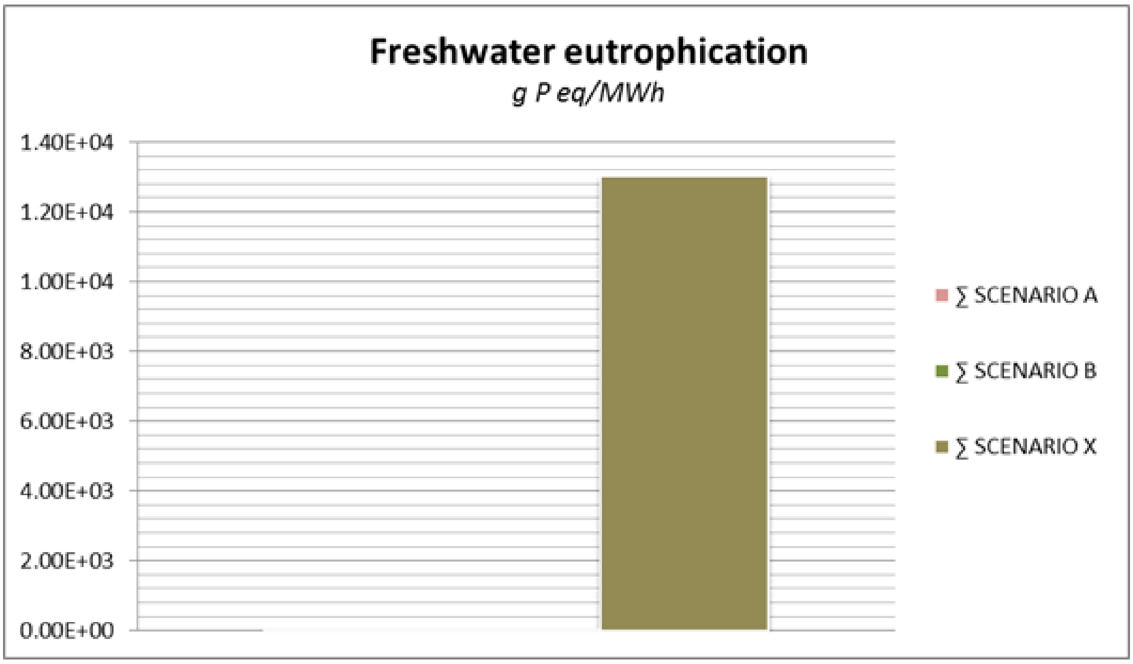

Figure 7 Impact of scenarios A, B and X on freshwater eutrophication.

7.3.5 Marine eutrophication

Impact of scenarios A, B and X on marine eutrophication is shown in Figure 8. Results shows minimal impact of scenarios A and B to marine eutrophication compared to scenario X.

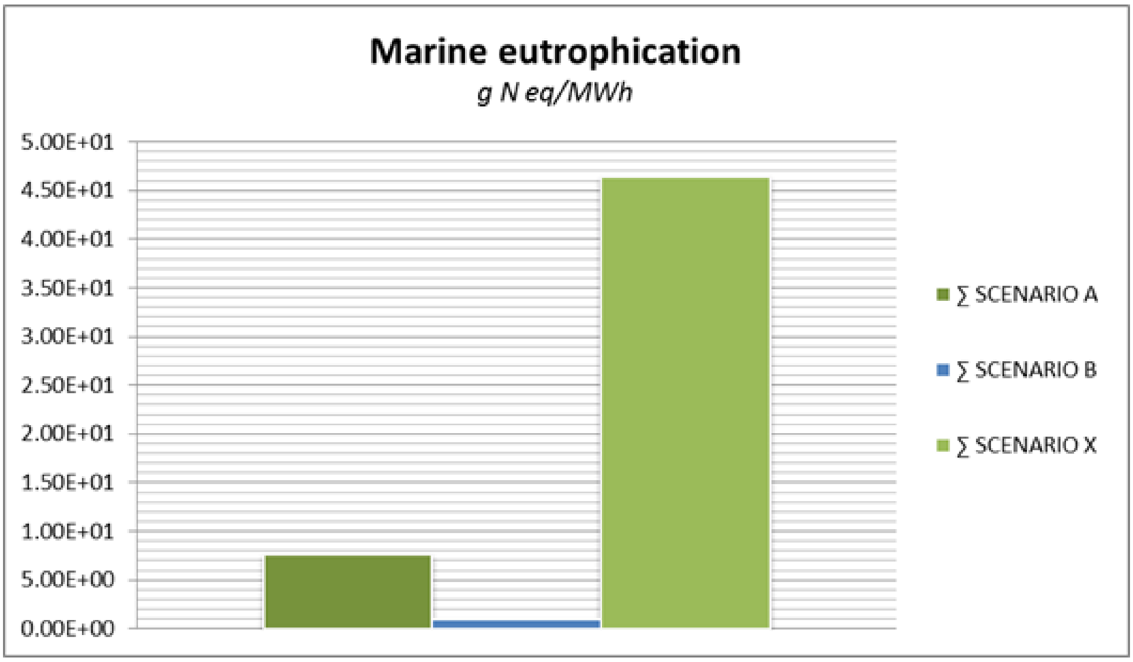

Figure 8 Impact of scenarios A, B and X on marine eutrophication.

7.3.6 Human toxicity

Impact of scenarios A, B and X on human toxicity is shown in Figure 9. Scenario B has minimal impact on human toxicity compared to scenario A and scenario X.

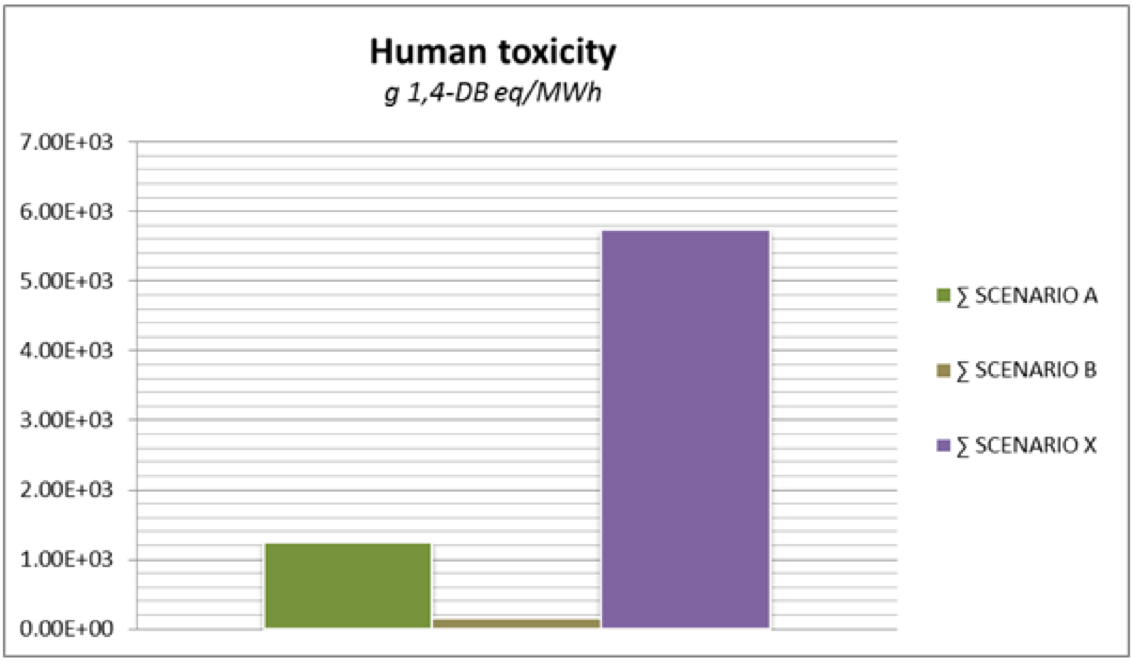

Figure 9 Impact of scenarios A, B and X on human toxicity.

7.3.7 Photochemical oxidant formation

Impact of scenarios A, B and X on photochemical oxidant formation is shown in Figure 10. Scenario X has most negative impact on photochemical oxidant formation, 9500 g NMVOC/MWh. Scenario B has no impact on human toxicity while scenario A has minimal negative impact compared to scenario X.

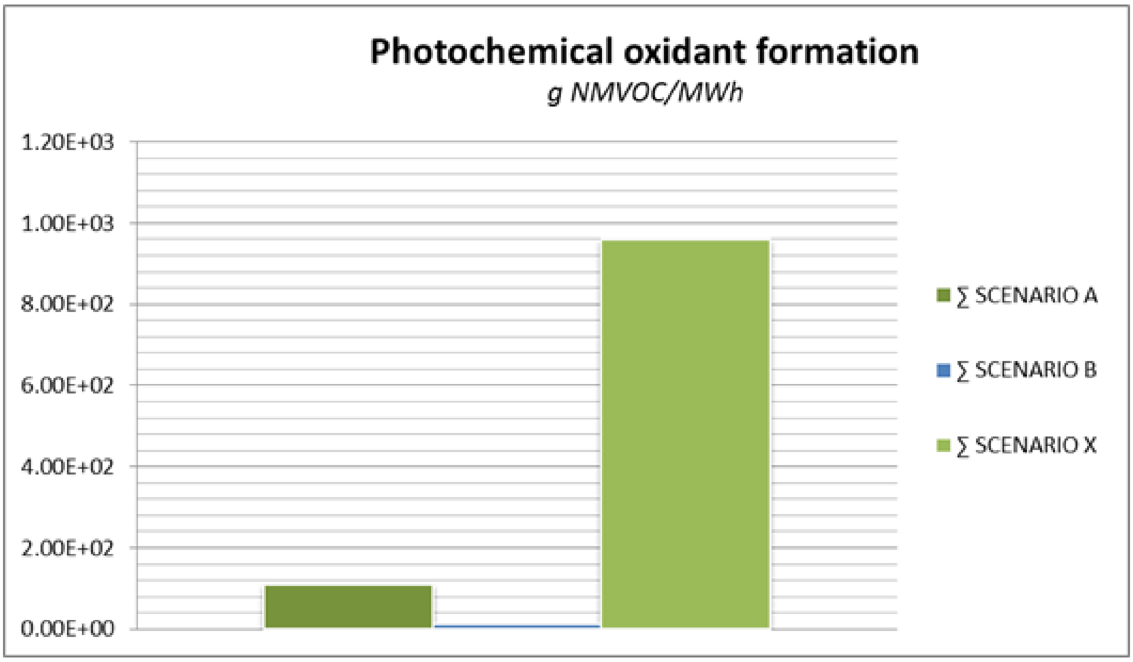

Figure 10 Impact of scenarios A, B and X on photochemical oxidant formation.

7.3.8 Particulate matter formation

Impact of scenarios A, B and X on particulate matter formation is shown in Figure 11. In case of scenario B, no impact on particulate matter formation is seen, whereas only minimal impact is seen in case of scenario A. Scenario X has negative impact on terrestrial acidification, which is expressed as 250 g PM10 equivalent per MWh energy.

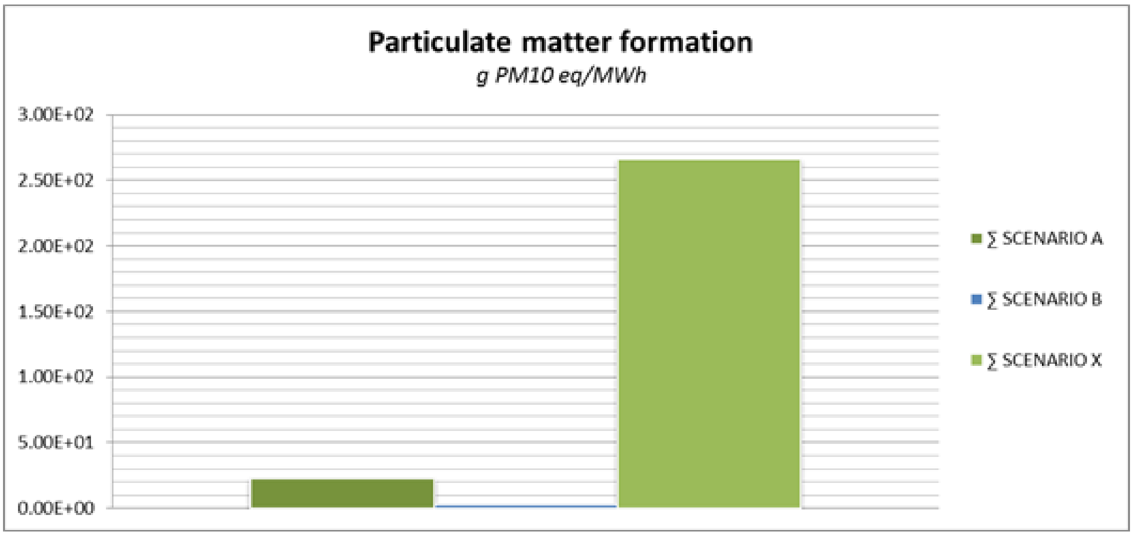

Figure 11 Impact of scenarios A, B and X on particular matter formation.

7.3.9 Terrestrial ecotoxicity

Impact of scenarios A, B and X on Terrestrial ecotoxicity is shown in Figure 12. Scenario A and B have no negative impact on terrestrial ecotoxicity, while scenario X has high negative impact, equal to 300 1,4-DB eq/MWh.

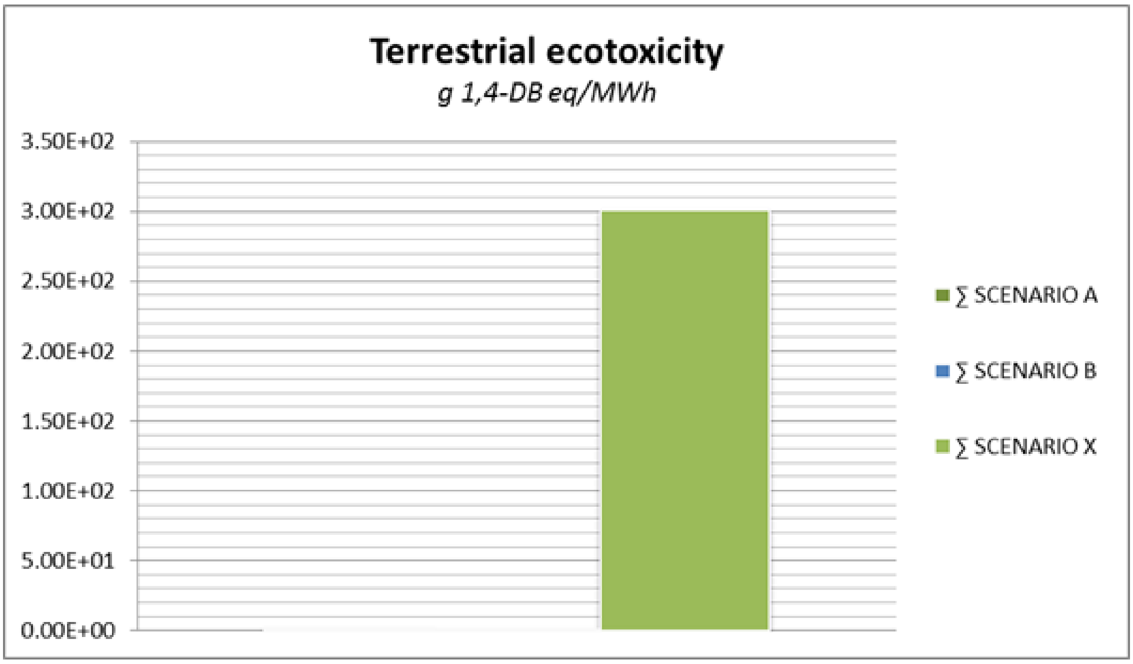

Figure 12 Impact of scenarios A, B and X on terrestrial ecotoxicity.

7.3.10 Freshwater ecotoxicity

Impact of scenarios A, B and X on freshwater ecotoxicity is shown in Figure 13. Scenario A and B have positive impact on freshwater toxicity while X have negative impact on freshwater toxicity.

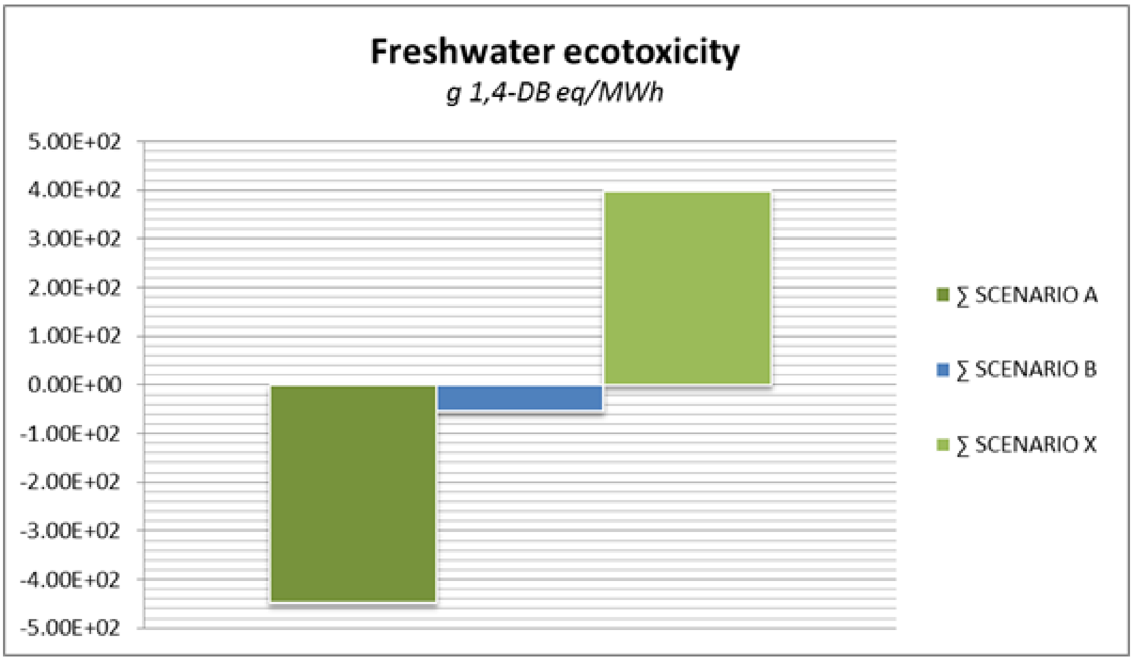

Figure 13 Impact of scenarios A, B and X on freshwater ecotoxicity.

7.3.11 Marine ecotoxicity

Impact of scenarios A, B and X on marine ecotoxicity is shown in Figure 14. Results are comparable to freshwater ecotoxicity impact. Scenario A and B have positive impact on marinewater toxicity, while scenario X has negative impact.

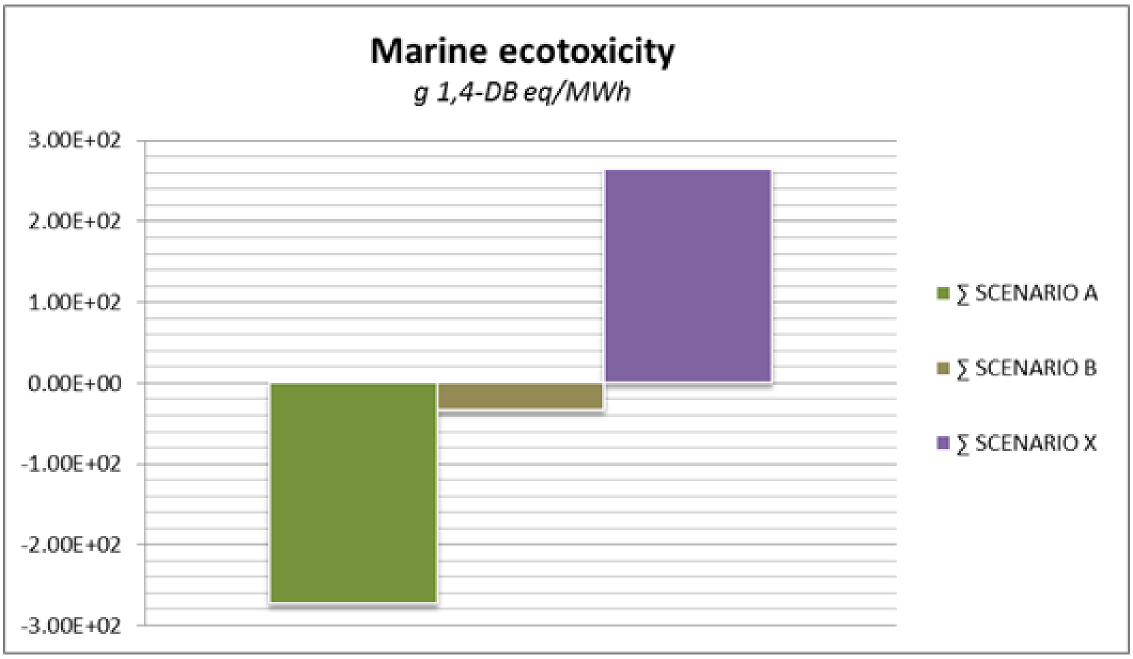

Figure 14 Impact of scenarios A, B and X on marine ecotoxicity.

7.3.12 Ionising radiation

Impact of scenarios A, B and X on marine ecotoxicity is shown on Figure 15. Scenario X has the highest negative impact on ionising radiation (1000 g U235 eq/MWh), followed by scenario A (380 g U235 eq/MWh). Scenario X has minimal impact on ionising radiation.

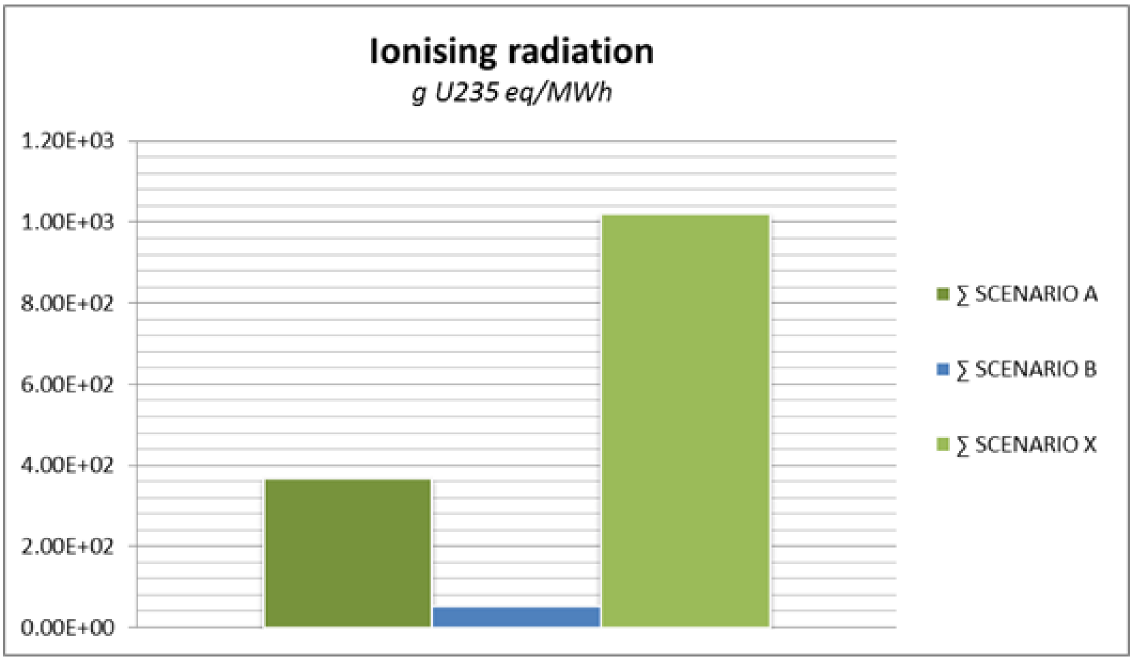

Figure 15 Impact of scenarios A, B and X on ionising radiation.

7.3.13 Agricultural land occupation

Impact of scenarios A, B and X for agricultural land occupation is shown in Figure 16. Results shows minimal impact on agricultural land occupation for all scenarios, -5 m^2/MWh for Scenario A and 2 m^2/MWh for scenario X. Only scenario X has negative impact on agricultural land occupation, while scenario A has positive impact and scenario B has no impact on agricultural land occupation.

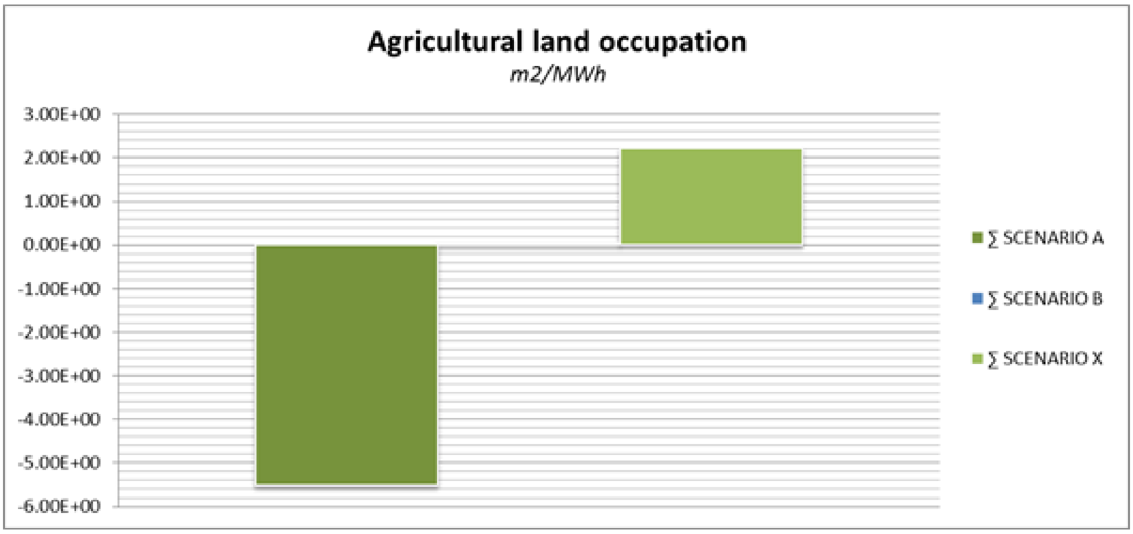

Figure 16 Impact of scenarios A, B and X on agricultural land occupation.

7.3.14 Urban land occupation

Environmental impact of scenarios A, B and X for urban land occupation are shown in Figure 17. Results show minimal negative impact on urban land occupation for all scenarios, 0,15 m^2/MWh for Scenario A, 0,05 m^2/MWh for scenario B and 0,45 m^2/MWh for scenario X.

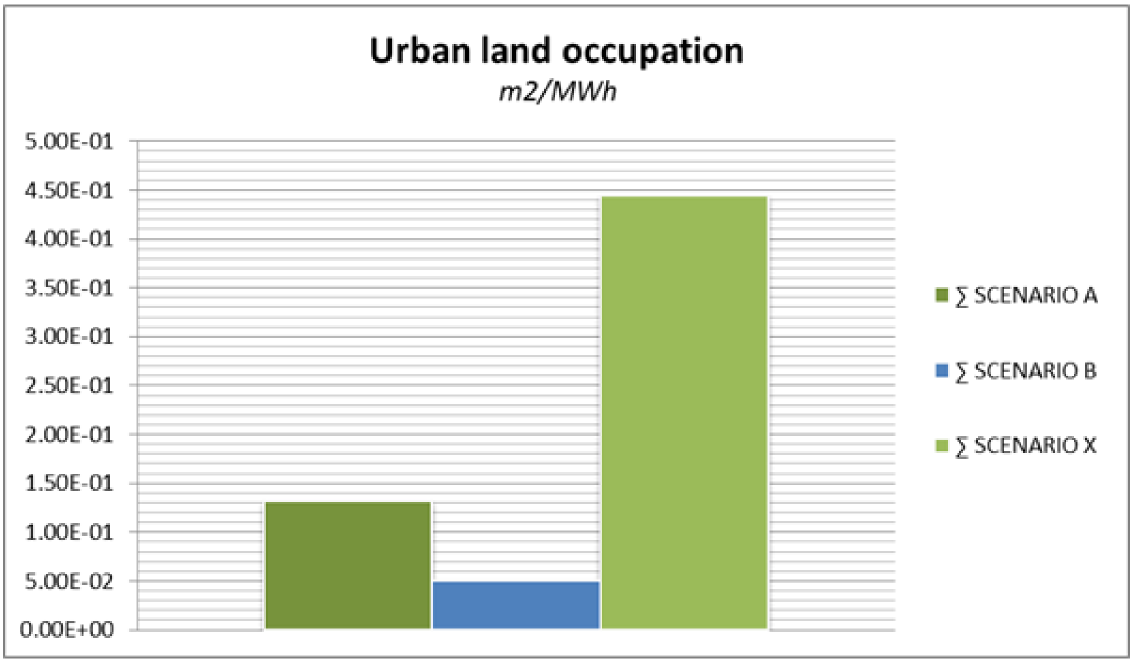

Figure 17 Impact of scenarios A, B and X on urban land occupation.

7.3.15 Natural land transformation

Environmental impact of scenarios A, B and X for natural land transformation are presented in Figure 18. Results show negative impact on natural land transformation for scenario X (0,006 m^2/MWh). Scenario A has positive impact and prevents natural land transformation (- 0,002 m^2/MWh), while results show minimal negative impact for scenario B (0,0002 m^2/MWh).

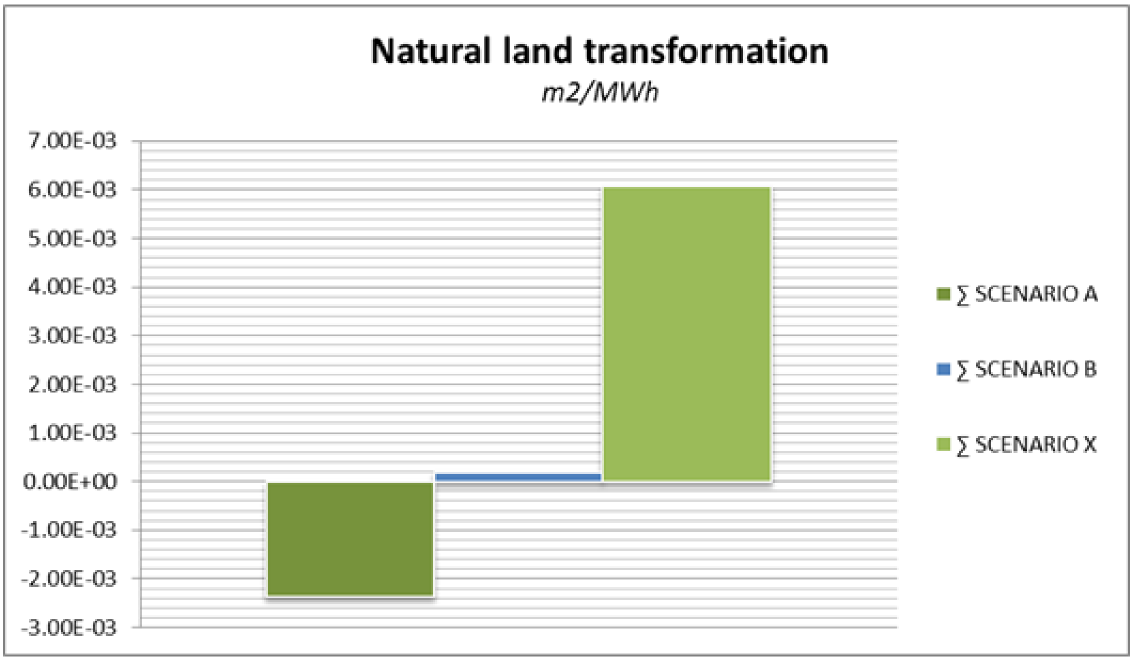

Figure 18 Impact of scenarios A, B and X for natural land transformation.

7.3.16 Metal depletion

Impact of scenarios A, B and X on metal depletion is presented in Figure 19. Results show negative impact on metal depletion for all scenarios. Scenario B has the lowest impact on metal depletion 0,8 kg Fe eq/MWh, while scenario A has the highest negative impact 5,4 kg Fe eq/MWh. Scenario X has negative impact on metal depletion, equal to 4 kg Fe eq/MWh.

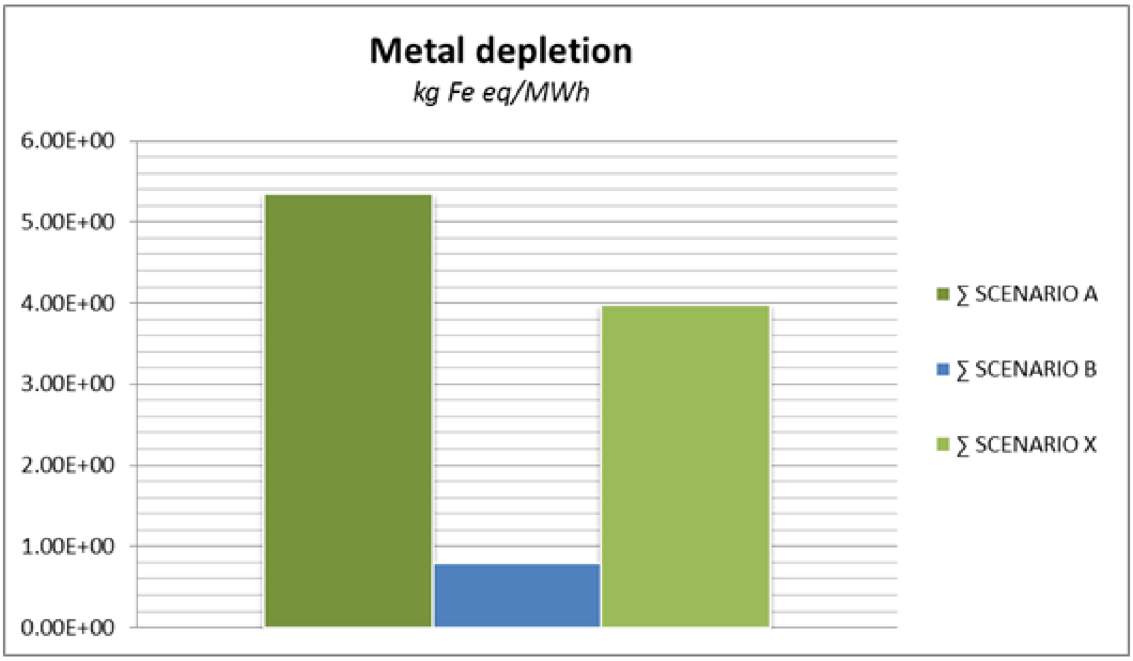

Figure 19 Impact of scenarios A, B and X on metal depletion.

7.3.17 Fossil depletion

Impact of scenarios A, B and X on fossil depletion is presented in Figure 20. Results show negative impact on fossil depletion only for scenario X with 3 t oil/MWh. Scenario A has positive impact, while scenario B has no impact on fossil depletion.

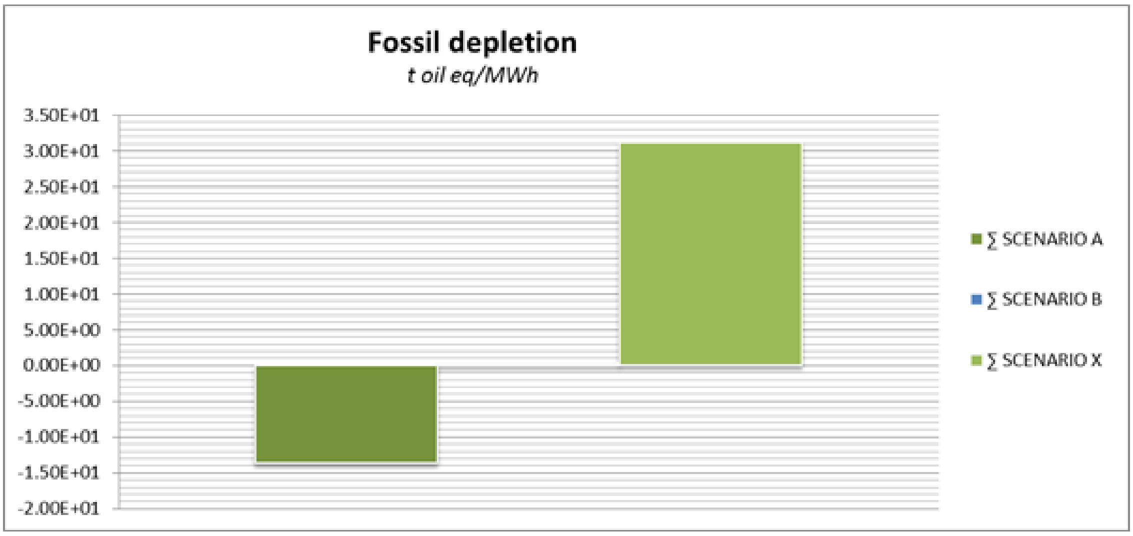

Figure 20 Impact of scenarios A, B and X on fossil depletion.

7.3.18 Electricity use

Impact of scenarios A, B and X on electricity use is presented in Figure 21. Results show positive impact on fossil depletion for scenario A and B, while scenario X has no impact on electricity use. Positive impact of scenarios A and B is expected due to production of electricity from produced microalgal biomass.

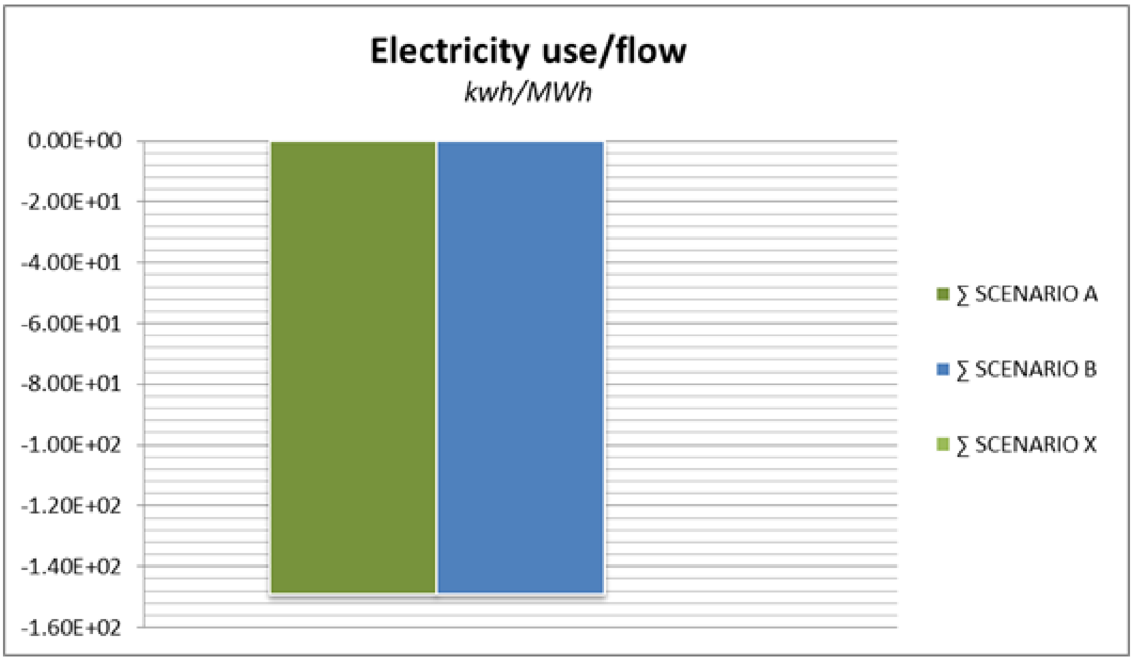

Figure 21 Impact of scenarios A, B and X on electricity use.

7.3.19 Endpoint category – combining midpoint results into three common denominators

The endpoint approach is presented in terms of damage to the ecosystem quality, human health and resource availability. More detailed information about endpoint modelling can be found at (Goedkoop et al., 2013a).

7.3.19.1 Damage to human health

Damage to human health is expressed in DALY (Disability Adjusted Life Years), which could be expressed as the number of years lost due to illness, disability or early death, or lost year of healthy life.

Impact of scenarios A, B and X on damage to human health is presented in Figure 22. Results show positive impact on human health for scenarios A and B while scenario X has negative impact on human health, 0,0022 DALY.

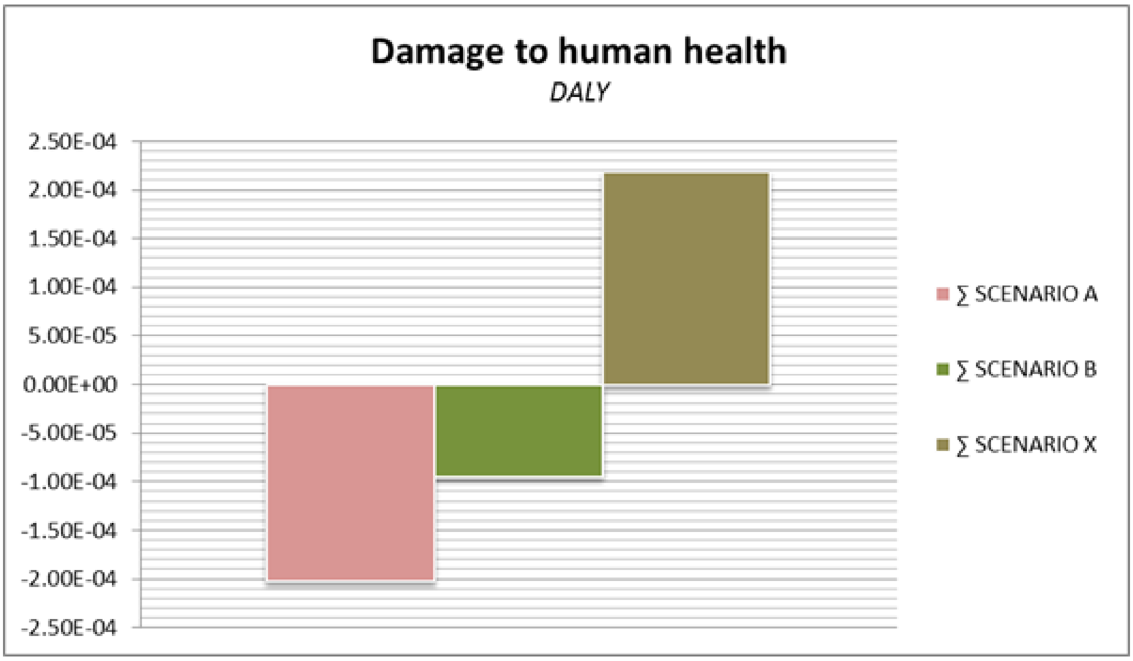

Figure 22 Impact of scenarios A, B and X on damage to human health.

7.3.19.2 Ecosystem quality

Ecosystem quality reflects the proportion of species that have disappeared in a certain area due to anthropogenic environmental pressures. Impact of scenarios A, B and X on ecosystem quality is presented in Figure 23. Results show that scenarios A and B have positive impact on ecosystem quality, while scenario X has negative impact on ecosystem quality.

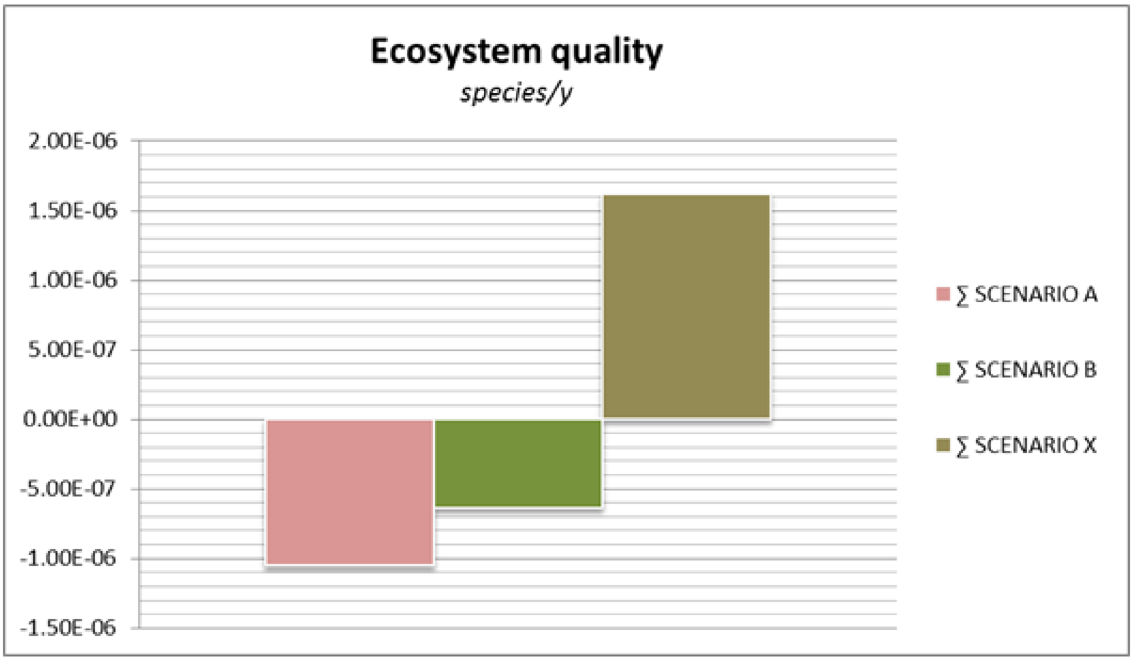

Figure 23 Impact of scenarios A, B and X on ecosystem quality.

7.3.19.3 Resource availability

Resource availability is expressed as “surplus cost” in $ or in $/kg and reflects fundamental increases in extraction costs in the future. Impact of scenarios A, B and X on resource availability is presented in Figure 24. Results show that only scenario A has positive impact on resource availability. Scenario B has minimal impact on resource availability with 0,07 $ while scenario X has higher negative impact with 1,9 $.

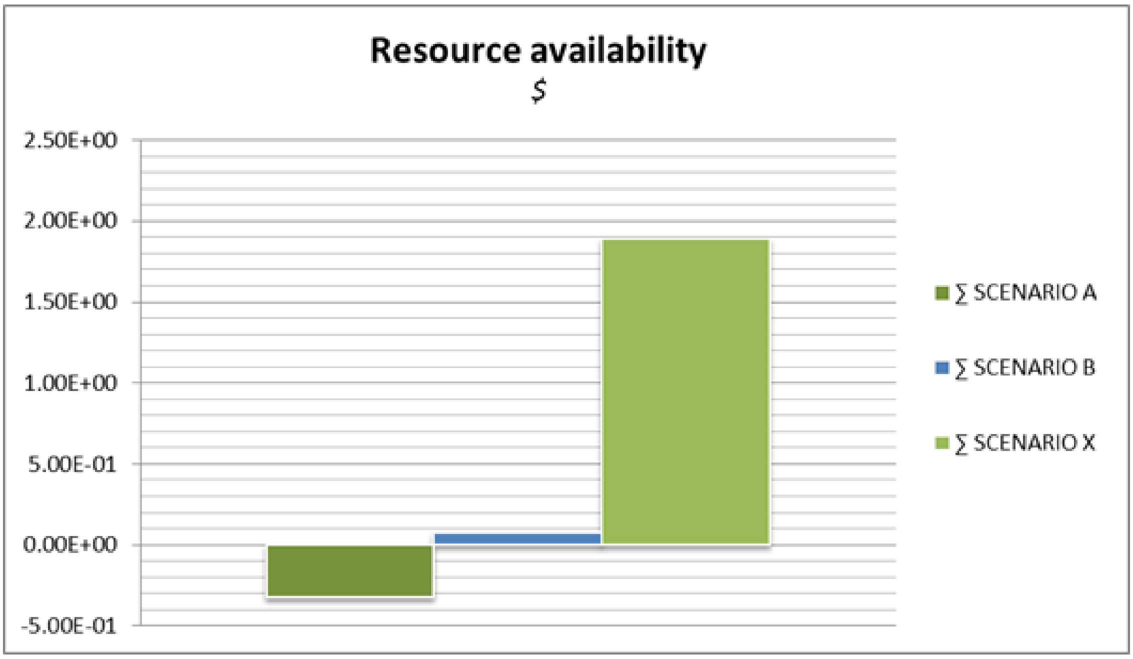

Figure 24 Impact of scenarios A, B and X on resource availability.

8 Conclusions

The aim of this deliverable was to assess the environmental impact of algaebiogas technology for treatment of biogas digestate through the LCA methodology. Microalgal technology as an alternative method for treatment of biogas digestate was compared to most common practice for biogas digestate processing - application of biogas digestate to agricultural land. Results based on three scenarios and assumption that all produced biomass is returned to biogas plant, show positive impacts of algaebiogas technology in all endpoint impact categories, damage to human health, ecosystem quality and resource availability.

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Appendix I

id	ELEMENT	DESCRIPTION	Amortisation [years]	algae weight during amortisation per m2 [kg]	Unit	Value for each pond unit (564 m^2)	Value for 1 MW biogas plant	Value per kg DW of algae	Value for 1 MW biogas plant	**ABSOLUTE VALUE** Column J divided with 8760 (hours of the year). Value per hour.	**RELATIVE VALUE** Value per MWh produced by biogas plant. 1MW biogas plant produces 7224.33MWh per year. Column J is divided with 7224.33.
						calculated per amortisation time			*calculated per year*		
1	**POND UNIT**										
1,1	pond area	Industrial area A) 500 m2 pond B) 64 m2 maintenance area (0,5 m wide area around pond)	30,000	219,00	m2	5,64E+02	5,19E+04	5,15E-03	1,73E+03	**1,97E-01**	2,39E-01
1,2	area between ponds	industrial area A) 500 m2 pond B) 64 m2 maintenance area (0,5 m wide area around pond)	30,000	219,00	m2	1,43E+02	1,31E+04	1,30E-03	4,37E+02	**4,99E-02**	6,05E-02
1,3	ventilators	el. Motor; 2 x 1.1 KW / 500m2 pond	15,000	109,50	kw	2,20E+00	2,02E+02	4,02E-05	1,35E+01	**1,54E-03**	1,87E-03
1,4	ventilators	weight of metal (90 kg per 1.1 kw ventilator)	15,000	109,50	kg	1,80E+02	1,66E+04	3,29E-03	1,10E+03	**1,26E-01**	1,53E-01
1,5	greenhouse construction	metal construction; pipes Ø51 mm, d = 2,6 mm, weight 3,12 kg/m; (middlepipes) 0,6kg/m; 33,5 (frame) x 17 frames + 90 m (middle pipes) + 155 (middle pipes)=659,5m =2,05 t	30,000	219,00	kg	2,05E+03	1,89E+05	1,87E-02	6,29E+03	**7,18E-01**	8,70E-01

1,6	greenhouse foil	Foil; mass 0,2 kg/m2; 15 m x 51 m + sides 2 x 32m2= 829 m2	10,000	73,00	kg	1,66E+02	1,53E+04	4,54E-03	1,53E+03	**1,74E-01**	2,11E-01
1,7	agrotextile	150 g/m2; 598 m2 -> 89,7 kg	30,000	219,00	kg	8,97E+01	8,25E+03	8,19E-04	2,75E+02	**3,14E-02**	3,81E-02
1,8	pond foil	Rubber; 2 mm; 7,2 kg/m^2	30,000	219,00	kg	7,59E+02	6,98E+04	6,93E-03	2,33E+03	**2,66E-01**	3,22E-01
1,9	concrete	thickness 5 cm, area 556 m2	30,000	219,00	m3	2,78E+01	2,56E+03	2,54E-04	8,53E+01	**9,73E-03**	1,18E-02
2,0	electricity for vents.	Electricity from biogas plant; May - Sept, operat-ing time 10:00 - 17:00; (1050 h/year)	1,000	7,30	kwh	2,31E+03	2,13E+05	6,33E-01	2,13E+05	**2,43E+01**	2,94E+01
2,1	cables for electric-ity	lenght: 330 m x 2 + 126m + 25 m x 46 = 1936 m; total 21 m/pond	30,000	219,00	m	2,10E+01	1,93E+03	1,92E-04	6,44E+01	**7,35E-03**	8,91E-03
2,2	paddlewheel (w=1m; l=5m) A.) HDPE (930kg/m3)	A.) 8 x 2,5m2 + 2 x 0,785 = 21,57 m2 -> 200 kg	30,000	219,00	kg	2,00E+02	1,84E+04	1,83E-03	6,13E+02	**7,00E-02**	8,49E-02
2,3	paddlewheel (w=1m; l=5m) B.) metal (fi 60,3mm, 4,5 kg/m)	B.) 5m x 4,5kg=22,5 kg	30,000	219,00	kg	2,25E+01	2,07E+03	2,05E-04	6,90E+01	**7,88E-03**	9,55E-03
2,4	paddlewheel (w=1m; l=5m) C.) El. Motor	C.) 250 W	30,000	219,00	W	2,50E+02	2,30E+04	2,28E-03	7,67E+02	**8,75E-02**	1,06E-01
2,5	electricity for paddlewheel	source is biogas plant **(literature data P.Collet in sod. (2011))** (0.035 + 0,2)/2 = 0.11175 KWh/kg Alg	0,003	0,02	kwh	1,12E+00	1,03E+02	1,12E-01	3,75E+04	**4,28E+00**	5,19E+00
2	**BIOGAS DIGESTATE SUPPLY**										
2,1	Pipes for supply of biogas digestate	Pipe DN 160; 3,195 kg/m; total lenght 92 ponds: 332 m x 2 + 126m + 7m x 46 = 1112 m; total 12,08 m/pond -> 38,6 kg /pond	30,000	219,00	kg	3,86E+01	3,55E+03	3,53E-04	1,18E+02	**1,35E-02**	1,64E-02
2,2	Pump	for digestate; (15m3/h);	15,000	109,50	KW	7,50E-01	6,90E+01	1,37E-05	4,60E+0	**5,25E-04**	6,37E-04

		750w							0		
2,3	Electricity con-sumption for pump	Daily flow for 100m2 pond is 0.3 m3/d ; 1.5m3 is pumped in 6min	0,003	0,02	kwh	7,50E-02	6,90E+00	7,50E-03	2,52E+03	**2,88E-01**	3,49E-01
2,4	UV light	UV lamp for wastewater disinfection 200 W	5,000	36,50	KW	2,00E-01	1,84E+01	1,10E-05	3,68E+00	**4,20E-04**	5,09E-04
2,5	Electricity for UV lamp	For 1m3 of digestate 200W UV lamp needs 60 min. Assumption.	0,003	0,02	kwh	3,00E-01	2,76E+01	3,00E-02	1,01E+04	**1,15E+00**	1,39E+00
2,6	Electromagnetic valves		15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
3	**SEDIMENTATION PROCESS**										
3,1	Pipes	Pipes DN 160; 3,195 kg/m; pipe lenght for 92 ponds: 315 m x 2 + 7m x 45 = 945 m; total 10,38 m/pond oz. 33,17 kg /pond	30,000	219,00	kg	3,32E+01	3,05E+03	3,03E-04	1,02E+02	**1,16E-02**	1,41E-02
3,2	Pump	for digestate; (15m3/h); 750w	15,000	109,50	KW	7,50E-01	6,90E+01	1,37E-05	4,60E+00	**5,25E-04**	6,37E-04
3,3	Electricity con-sumption	for pump; (100m2 bazen ->30m3); each 4 h (sedi-mentation time); for 5 m3 flow 15m3/h operateing time 20min/day	0,003	0,02	kwh	2,57E-01	2,37E+01	2,57E-02	8,64E+03	**9,87E-01**	1,20E+00
3,4	Electromagnetic valves		15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
3,5	Sedimenter	sainless steel; d=1,5 mm; valj h = 1,5m, r=0,75; [za 2m3/100m2 pond]/; 10.95 m2 za 100 m2; [11,7 kg/m2]	30,000	219,00	kg	6,41E+02	5,89E+04	5,85E-03	1,96E+03	**2,24E-01**	2,72E-01
3,6	Mixer in sedi-menter	stainles steel; Ocena 8 kg/100m2	15,000	109,50	kg	4,00E+01	3,68E+03	7,31E-04	2,45E+02	**2,80E-02**	3,40E-02
3,7	El. Motor for mixing	1kw	15,000	109,50	kw	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
3,8	El. Consumption	Data from literature P.Collet in sod. (2011)); 0,0252 kwh / kg SS alg	0,003	0,02	kwh	2,50E-01	2,30E+01	2,50E-02	8,40E+03	**9,58E-01**	1,16E+00
3,9	El. Cables		30,000	219,00	m	1,50E+01	1,38E+03	1,37E-04	4,60E+01	**5,25E-03**	6,37E-03

4,0	Data cable		30,000	219,00	m	1,50E+01	1,38E+03		4,60E+01	**5,25E-03**	6,37E-03
4,1	Sensor		15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
4	**REVERSE FLOW**										
4,1	Pump	(15m3/h); 750w	15,000	109,50	KW	7,50E-01	6,90E+01	1,37E-05	4,60E+00	**5,25E-04**	6,37E-04
4,2	El. Consumption for pumping	(100m2 pond ->30m3); each 4 h (sedimentation time); for 5 m3 with flowrate 15m3/h operating time 20min/day	0,003	0,02	kwh	2,57E-01	2,37E+01	2,57E-02	8,64E+03	**9,87E-01**	1,20E+00
4,3	El. Cables		30,000	219,00	m	1,50E+01	1,38E+03	1,37E-04	4,60E+01	**5,25E-03**	6,37E-03
4,4	Pipes for reverse flow	Pipe DN 160; 3,195 kg/m;lenght 92 ponds: 315 m x 2 + 7m x 45 = 945 m; total 10,38 m/pond oz. 33,17 kg /pond	30,000	219,00	kg	3,32E+01	3,05E+03	3,03E-04	1,02E+02	**1,16E-02**	1,41E-02
5	**BIOMASS STORAGE CONTAINER**										
5,1	Pipes	DN 160; 3,195 kg/m; lenght for 23 ponds = 10m -> 0.43 m/pond	30,000	219,00	kg	1,37E+00	1,26E+02	1,25E-05	4,21E+00	**4,81E-04**	5,83E-04
5,2	Electromagnetic valves	2 ventila/container	30,000	219,00	kos	8,70E-02	8,00E+00	7,94E-07	2,67E-01	**3,04E-05**	3,69E-05
5,3	Container	for 100m2 --> 200l; (input 300l/day; evapot. 100l/day); 1m3/500m2 pond; stainless steel, d=1,5 mm; P= 10.95/2 m2 / 100 m2; [11,7 kg/m2]	30,000	219,00	kg	6,41E+01	5,89E+03	5,85E-04	1,96E+02	**2,24E-02**	2,72E-02
5,4	Sensor	in container	15,000	109,50	kos	4,35E-02	4,00E+00	7,94E-07	2,67E-01	**3,04E-05**	3,69E-05
5,5	Data cable	50m/23 ponds	15,000	109,50	m	2,17E+00	2,00E+02	3,97E-05	1,33E+01	**1,52E-03**	1,85E-03
5,6	Pump	(10 m3/h);	15,000	109,50	KW	5,00E-01	4,60E+01	9,13E-06	3,07E+00	**3,50E-04**	4,24E-04
5,7	El. Cables		30,000	219,00	m	1,09E+00	1,00E+02	9,93E-06	3,33E+00	**3,81E-04**	4,61E-04

5,8	El. Consumption for pumping	(10 m3/h); (100m2 pond ->30m3); daily flow 1m3 for 500m2; operating time 0.1h/day/500m2	0,003	0,02	kwh	5,00E-02	4,60E+00	5,00E-03	1,68E+03	**1,92E-01**	2,32E-01
6	**BIOMASS TRANSPORTING SYSTEM TO BIOGAS PLANT**										
6,1	Pipes to biogas plant	Sewage pipe DN 160; 3,195 kg/m Pipe length for 23 ponds = 453m -> 19.69 m/pond	30,000	219,00	kg	1,97E+01	1,81E+03	1,80E-04	6,04E+01	**6,89E-03**	8,36E-03
6,2	Pump	Biomass from sedimentor to storage (10 m3/h);	15,000	109,50	KW	5,00E-01	4,60E+01	9,13E-06	3,07E+00	**3,50E-04**	4,24E-04
6,3	El. Cables	Ownn calculation by ArchiCad; črpalke se nahajajo pri izsopu biopli-narne	30,000	219,00	m	7,83E-01	7,20E+01	7,15E-06	2,40E+00	**2,74E-04**	3,32E-04
6,4	el. Consuption - pumping	For biomass pumping to storage unit (10 m3/h); (100m2 pond ->30m3); dnevna potreba pretoka 1m3 za 500m2; polna obremenitev crpalke 0.1h/dan/500m2	0,003	0,02	kwh	5,00E-02	4,60E+00	5,00E-03	1,68E+03	**1,92E-01**	2,32E-01
6,5	sensor	In storage unit	15,000	109,50	kos	4,35E-02	4,00E+00	7,94E-07	2,67E-01	**3,04E-05**	3,69E-05
6,6	Data cable	Connecton of sensor with central system 50m/23bazenov	15,000	109,50	m	3,04E+00	2,80E+02	5,56E-05	1,87E+01	**2,13E-03**	2,58E-03
7	**HEATING SYSTEM**										
7,1	Radiator in ponds	Metal pipes fi 25; 0,750 kg/m; area 2m2, distance between pipes 10 cm; total lenght of pipe in radiator 24,8 m	15,000	109,50	kg	1,86E+01	1,71E+03	3,40E-04	1,14E+02	**1,30E-02**	1,58E-02
7,2	Isolated pipes	PE 80 pipe d 20 x 2,0 mm; 0,116 kg/m + heat isola-tion; lenght for 92 ponds: 330 m x 2 + 126m + 25 m x 46 = 1936 m; total 21 pond	30,000	219,00	m	2,10E+01	1,93E+03	1,92E-04	6,44E+01	**7,35E-03**	8,91E-03
7,3	Bypass pump	Npr: IMP NMT 15/40 - 130 ; -> 25 W/500m2	30,000	219,00	W	2,50E+01	2,30E+03	2,28E-04	7,67E+01	**8,75E-03**	1,06E-02

7,4	El consuption for pumping	operating in winter regime Nov – Apr; operating time 12h/day (15 min intervals on/off)	1,000	7,30	kwh	5,40E+01	4,97E+03	1,48E-02	4,97E+03	**5,67E-01**	6,88E-01
7,5	Data cable	Sensor connection with central computer; 50m/23ponds	15,000	109,50	m	5,50E+01	5,06E+03	1,00E-03	3,37E+02	**3,85E-02**	4,67E-02
7,6	Sensor	1 kos/bazen	15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
7,7	Heat exchanger - exhaust gases	50 m lenght of exhaust pipes fi 400 + 10m3 water container (d=3 mm; ; [23,4 kg/m2])	30,000	219,00	kg	1,66E+01	1,53E+03	1,52E-04	5,09E+01	**5,81E-03**	7,05E-03
8	**CO2 INTRODUCTION**										
8,1	Filter	za izračun LCA predpostavil cikloski lovilec prahu moči 1MW *(*ni drugih tipov filtrov)*	30,000	219,00	kos	1,09E-02	1,00E+00	9,93E-08	3,33E-02	**3,81E-06**	4,61E-06
8,2	Pipe	PE 80 CEV d 20 x 2,0 mm; 0,116 kg/m; Dolžina cevi za 92 bazenov: 322 m x 2 + 126m + 7m x 46 =1092 m; kar znaša 11,86 m/bazen; 1,37 kg /bazen	30,000	219,00	kg	1,37E+00	1,26E+02	1,25E-05	4,20E+00	**4,80E-04**	5,82E-04
8,3	Sensor	1 kos/bazen	15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
8,4	Data cable	Povezava tipala z centralnim računalnikom; 50m/23bazenov	15,000	109,50	m	5,50E+01	5,06E+03	1,00E-03	3,37E+02	**3,85E-02**	4,67E-02
8,5	Electromagnetic valves	za dovod CO_2	15,000	109,50	kos	1,00E+00	9,20E+01	1,83E-05	6,13E+00	**7,00E-04**	8,49E-04
9	**CONTROL SYSTEM**										
9,1	Office equipment	office; 20 m2	30,000	219,00	m2	2,17E-01	2,00E+01	1,99E-06	6,67E-01	**7,61E-05**	9,23E-05
9,2	Area needed for office	industrial area	30,000	219,00	m2	2,17E-01	2,00E+01	1,99E-06	6,67E-01	**7,61E-05**	9,23E-05
9,3	Office building	office container; jeklen 165.41kg /m2	30,000	219,00	kg	3,60E+01	3,31E+03	3,28E-04	1,10E+02	**1,26E-02**	1,53E-02
9,4	Heating of the office	4 months, 8h/day	1,000	7,30	kwh	2,09E+01	1,92E+03	5,72E-03	1,92E+03	**2,19E-01**	2,66E-01
9,5	Cooling of the office	90 days/year, 8h/dan	1,000	7,30	kwh	5,22E+00	4,80E+02	1,43E-03	4,80E+02	**5,48E-02**	6,64E-02

9,6	Air condition 2kW	heating	15,000	109,50	kw	1,09E-02	1,00E+00	1,99E-07	6,67E-02	**7,61E-06**	9,23E-06
9,7	data cables	lenghtfor 92 units 330 m x 2 + 126m + 25 m x 46 = 1936 m -> total 21 pond unit	15,000	109,50	m	2,10E+01	1,93E+03	3,84E-04	1,29E+02	**1,47E-02**	1,78E-02
9,8	mini PC for unit	per unit; sensors and pump/valeves controls; 1.89 W /PC (Raspberry Pi B)	15,000	109,50	kos	2,00E+00	1,84E+02	3,65E-05	1,23E+01	**1,40E-03**	1,70E-03
9,9	PC	Osrednji 2 x; obdelava podatkov, krmilje	15,000	109,50	kos	2,17E-02	2,00E+00	3,97E-07	1,33E-01	**1,52E-05**	1,85E-05
10,0	Electric unit (omara)	Fuses	30,000	219,00	KW	4,06E-02	3,74E+00	3,71E-07	1,25E-01	**1,42E-05**	1,73E-05
10,1	El. Consumptin - Mini PC	1.89 W /PC (npr. Rasp-berry Pi B); 2 x x1.89=3,78W/24h -> 0.09072 KWh	0,003	0,02	kwh	9,07E-02	8,35E+00	9,07E-03	3,05E+03	**3,48E-01**	4,22E-01
10,2	El. consumption za PC	150 W /PC; 24/7	0,003	0,02	kwh	7,83E-02	7,20E+00	7,83E-03	2,63E+03	**3,00E-01**	3,64E-01
10,3	El. Conumption - light	operation time 24/7	0,003	0,02	kwh	2,61E-02	2,40E+00	2,61E-03	8,76E+02	**1,00E-01**	1,21E-01
10,4	Light bulbs	4 bulbs 25W T5	5,000	36,50	w	1,09E+00	1,00E+02	5,96E-05	2,00E+01	**2,28E-03**	2,77E-03
10,5	El. Cables		30,000	219,00	m	2,17E+00	2,00E+02	1,99E-05	6,67E+00	**7,61E-04**	9,23E-04
A	**FROM BIOGAS PLANT TO ALGAL POND**										
A.1	CO2	526 kW biogas plant produces 16 g CO2 / kWh	/	/	kg	/	/	/	/	**1,60E+01**	1,60E+01
A.2	*DIGESTATE 300 L of biogas digestate per 100m2 daily -> in 500m2 1500l -> 1530kg; 1 mg = 1e-6 kg*	(mg/kg)	0,003	0,02	m3	1,50E+00	1,37E+02	1,50E-01	4,98E+04	**5,69E+00**	6,90E+00
A.3	Nitrogen total (N)	1938,0000	0,003	0,02	kg	2,97E+00	2,70E+02	2,97E-01	9,85E+04	**1,12E+01**	1,36E+01
A.4	Ammonium Nitrogen (NH4-N)	1421,8800	0,003	0,02	kg	2,18E+00	2,00E+02	2,18E-01	7,31E+04	**8,34E+00**	1,01E+01
A.5	Nitrate as ni-trogen (NO3-N)	0,5712	0,003	0,02	kg	8,74E-04	8,04E-02	8,74E-05	2,93E+01	**3,35E-03**	4,06E-03
A.6	Nitrite nitro-gen (NO2-N)	0,3060	0,003	0,02	kg	4,68E-04	4,31E-02	4,68E-05	1,57E+01	**1,79E-03**	2,18E-03

A.7	Phosphate phosphorus (PO4-P)	427,3800	0,003	0,02	kg	6,54E-01	6,02E+01	6,54E-02	2,20E+04	**2,51E+00**	3,04E+00
A.8	Phosphorus total (P)	1691,1600	0,003	0,02	kg	2,59E+00	2,38E+02	2,59E-01	8,69E+04	**9,92E+00**	1,20E+01
A.9	Potassium (K)	137,7000	0,003	0,02	kg	2,11E-01	1,94E+01	2,11E-02	7,07E+03	**8,08E-01**	9,79E-01
A.10	Calcium (Ca)	178,5000	0,003	0,02	kg	2,73E-01	2,51E+01	2,73E-02	9,17E+03	**1,05E+00**	1,27E+00
A.11	Magnesium (Mg)	74,4600	0,003	0,02	kg	1,14E-01	1,05E+01	1,14E-02	3,83E+03	**4,37E-01**	5,30E-01
A.12	Sodium (Na)	8155,9200	0,003	0,02	kg	1,25E+01	1,15E+03	1,25E+00	4,19E+05	**4,78E+01**	5,80E+01
A.13	Arsenic	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.14	Zinc	2,0000	0,003	0,02	kg	3,06E-03	2,82E-01	3,06E-04	1,03E+02	**1,17E-02**	1,42E-02
A.15	Mercury	0,0200	0,003	0,02	kg	3,06E-05	2,82E-03	3,06E-06	1,03E+00	**1,17E-04**	1,42E-04
A.16	Nickel	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.17	Cooper	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.18	Chromium	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.19	Cadmium	0,0300	0,003	0,02	kg	4,59E-05	4,22E-03	4,59E-06	1,54E+00	**1,76E-04**	2,13E-04
A.20	Lead	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.21	Cobalt	1,0000	0,003	0,02	kg	1,53E-03	1,41E-01	1,53E-04	5,14E+01	**5,87E-03**	7,11E-03
A.22	Selenium	0,3000	0,003	0,02	kg	4,59E-04	4,22E-02	4,59E-05	1,54E+01	**1,76E-03**	2,13E-03
A.23	Chromium	3,0000	0,003	0,02	kg	4,59E-03	4,22E-01	4,59E-04	1,54E+02	**1,76E-02**	2,13E-02
A.24	Heat	is byproduct, not included in LCA!	/	/	/	/	/	/	/	**/**	/
A.25	El. Energy	[total el. Consuption of algae system]	0,003	0,02	kwh	9,10E+00	8,37E+02	9,10E-01	3,06E+05	**3,49E+01**	4,23E+01
B	**OUTPUT FROM ALGAE TECHNOLOGY TO TECHNOSPHERE**										
B.1	Evapotranspiration	100l /day/100m2	0,003	0,02	L	5,00E+02	4,60E+04	5,00E+01	1,68E+07	**1,92E+03**	2,32E+03

B.2	CO2	alge use 1,8 kg CO2 /kg biomass	0,003	0,02	kg	-1,80E+01	-1,66E+03	- 1,80E+00	- 6,04E+0 5	**-6,90E+01**	-8,37E+01
B.3	O2 production	algae release 20 g O2 m-2 d-1; (2kg/100m2)	0,003	0,02	kg	1,00E+01	9,20E+02	1,00E+00	3,36E+0 5	**3,83E+01**	4,65E+01
B.4	Heavy metals	accumulation in the sys-tem, not leave the system	0,000	0,00	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+0 0	**0,00E+00**	0,00E+00
B.5	Digestate	not leave the sytem	0,000	0,00	kg	0,00E+00	0,00E+00	0,00E+00	0,00E+0 0	**0,00E+00**	0,00E+00
B.6	*Algae biomass* ***[BRUTO energy]***	*Algal biomass is returned to anaerobic fermentation process.* ***Caloric value of microal-gal biomass is 3580 kcal/kg ss alg -> 4,16 KWh/kg SS alg.***	*0,003*	*0,02*	*kwh*	*4,16E+01*	*3,79E+03*	*4,16E+00*	*1,38E+0 6*	**1,58E+02**	1,91E+02

B.7	Algae biomass **[NETO energy]**	Bruto energy - energy used in operation process of the microalgae treat-ment process. V LCA je upoštevana ta vrednost	0,003	0,02	*kwh*	3,25E+01	*2,96E+03*	*3,25E+00*	*1,08E+06*	**1,23E+02**	1,49E+02
X	**BASE SCENARIO - TRANSPORT TO AGRICULTURAL LAND [X.A+X.B]**										
X.A	**TOTAL OUTPUT FROM BIOGAS PLANT**										
1	CO2	526 kW biogas plant produces 16 g CO2 / kWh	/	/	kg	/	/	/	/	**1,60E+01**	1,60E+01
	DIGESTATE 72.32m3/dan, ga 1MW 137.49 m3/day; [bulk density -> 1020kg/m3]		0,003	0,02	t	1,54E+00	1,40E+02	1,54E-01	5,12E+04	**5,84E+00**	7,09E+00
2	Nitrogen total (N)	(mg/kg) 1938,0000	0,003	0,02	kg	/	/	/	9,92E+04	**1,13E+01**	1,37E+01

3	Ammonium Nitrogen (NH4-N)	1421,8800	0,003	0,02	kg	/	/	/	7,28E+04	**8,31E+00**	1,01E+01
4	Nitrate as nitrogen (NO3-N)	0,5712	0,003	0,02	kg	/	/	/	2,92E+01	**3,34E-03**	4,05E-03
5	Nitrite nitrogen (NO2-N)	0,3060	0,003	0,02	kg	/	/	/	1,57E+01	**1,79E-03**	2,17E-03
6	Phosphate phosphorus (PO4-P)	427,3800	0,003	0,02	kg	/	/	/	2,19E+04	**2,50E+00**	3,03E+00
7	Phosphorus total (P)	1691,1600	0,003	0,02	kg	/	/	/	8,66E+04	**9,88E+00**	1,20E+01
8	Potassium (K)	137,7000	0,003	0,02	kg	/	/	/	7,05E+03	**8,05E-01**	9,76E-01
9	Calcium (Ca)	178,5000	0,003	0,02	kg	/	/	/	9,14E+03	**1,04E+00**	1,26E+00
10	Magnesium (Mg)	74,4600	0,003	0,02	kg	/	/	/	3,81E+03	**4,35E-01**	5,28E-01
11	Sodium (Na)	8155,9200	0,003	0,02	kg	/	/	/	4,18E+05	**4,77E+01**	5,78E+01
12	Arsenic	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
13	Zinc	2,0000	0,003	0,02	kg	/	/	/	1,02E+02	**1,17E-02**	1,42E-02
14	Mercury	0,0200	0,003	0,02	kg	/	/	/	1,02E+00	**1,17E-04**	1,42E-04
15	Nickel	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
16	Cooper	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
17	Chromium	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
18	Cadmium	0,0300	0,003	0,02	kg	/	/	/	1,54E+00	**1,75E-04**	2,13E-04
19	Lead	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
20	Cobalt	1,0000	0,003	0,02	kg	/	/	/	5,12E+01	**5,84E-03**	7,09E-03
21	Selenium	0,3000	0,003	0,02	kg	/	/	/	1,54E+01	**1,75E-03**	2,13E-03
22	Chromium	3,0000	0,003	0,02	kg	/	/	/	1,54E+02	**1,75E-02**	2,13E-02
X.B	**TRANSPORT OF BIOGAS DIGESTATE TO FARMS**										

1	Storage container for digestate	assumed capacity of container is 7 x137.5m3 =962.5 m3 -> Silos height 12m, width 6m; steel plates d=3mm; 23.4 kg/m2 silos površina 226m2 + 5% jekla za spone	30,000	/	kg	/	5,55E+03	/	1,85E+02	**2,11E-02**	2,56E-02
	Area used for storage and manipulation	50m2	30,000	/	m2	/	5,00E+01		1,67E+00	**1,90E-04**	2,31E-04
2	Transport of biogas digestate to farms	Daily transport; 137.5 m3/dan; [137.5 t/dan]; Average distance of farms 50 km; truck capacity 20 t EURO 4 motor; 100% full cistern; empty transport back; 6.85 transports/day po 20t distance 50km; empty truckback[distance made by trucks 6.85 x 100 km = 685 km/day]	0,003	/	tkm	/	6,87E+03	/	2,51E+06	**2,86E+02**	3,47E+02
3	Office	Office equipment 20m2	10,000	/	m2	/	1,00E+00	/	1,00E-01	**1,14E-05**	1,38E-05
4	Application of biogas digestate from farms to agricultural land	Tracto and farm machinery; one transport; total distance 10 km	0,003	/	tkm	/	1,37E+03	/	5,02E+05	**5,73E+01**	6,94E+01