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Life Cycle Assessment of Biogas Production from Marine Macroalgae: a Latvian Scenario

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Abstract **–There is potential environmental benefit to be gained from the use of algae because of their ability to fix CO_2, no need for direct land use and utilization of bio-waste (rich in potassium, phosphate and nitrogen based compounds) as a nutrients.**

The aim of the research is to assess the impact of biogas production and the final use in a cogeneration unit system from a Life Cycle Assessment (LCA) in comparison with a similar reference system using a non-renewable source (e.g. natural gas). The paper is intended to be a preliminary study for understanding the implementation of this novel technology in a Latvian context.

Keywords **– biogas, LCA, macroalgae, CO_2 fixation, Ulva prolifera, renewable energy sources**

I. INTRODUCTION

Nowadays two sectors - power generation and transport - produce two-thirds of global CO_2. Generation of electricity and heat was the largest producer of CO_2 emissions and was responsible for 41% of the world CO_2 emissions [1], where a share of 80% is related to the use of non-renewable sources (oil, natural gas, coal and peat) [1].

In the same way, it is also know that natural fossil reserves are rapidly decreasing, even if it is not well known when and how these resources will be completely depleted [2, 3].

In this scenario, the European Union has developed the so-called “20-20-20” [4] goals implemented in the European Directive 2009/28/EC [5], which firstly aim to reduce greenhouse gas emissions by 20%, in comparison with the year 1990, and, secondly, aim to ensure 20% of end used energy to be provided by renewable sources. Thirdly, the goal is to reduce the utilization of primary energy by 20% [4]. These are the requirements included in this plan, which Latvia has also ratified.

The Directive (2009/28/EC), specifically for renewable resource development, requires Latvia to achieve 40% of renewable energy at the end usage stage by the year 2020.

According to the statistics of Eurostat [6], energy in Latvia that was produced from renewable resources in the end usage phase in 2008 reached 29.9%. Nowadays, this level approximately equals to 34% [7], although national experts say that the number is lower [8]. An urgent need for renewable resources usage intensification and development, in order to fulfil the targets, is necessary.

In the 2009/28/EC Directive, it has been highlighted that biogas is one of the most promising substitutes for fossil-based energy, since it reduces the potential of greenhouse gases, at the same time developing autonomous systems in the rural areas [5, 6].

Thanks to the European Union supporting mechanisms, the amount of produced energy from biogas in Latvia has increased over three times since the year 2001 [8]. Nonetheless, in the terms of substrates, more research is needed in order to gather all possible bioresources. One of the possible feedstock for the production of biomass is algae.

Algae have a biomass potential higher than terrestrial plants [9], moreover, the photosynthetic efficiency of aquatic biomass results is much higher (6– 8%, average) than that of terrestrial plants (1.8–2.2%, average) [9]. This makes it possible to enhance CO_2 fixation with the consequence to afford a high biomass production. Moreover, aquatic biomass presents an easy adaptability for growth under different conditions, either in fresh- or marine-waters, or in a wide enough range of pH [9].

The recent report of the Food and Agriculture Organisation of the United Nations [10] also underlines the need to focus on ‘non-food’ energy crops for the production of 2nd generation biofuels and to develop cost-efficient solutions which pay more attention to the importance of biofuel production. In fact, currently, the production of biogas is principally carried out through the anaerobic fermentation of (mixed) cereal crops [10].

The needed nutrients for algae growing are mostly the main eutrophication agents: nitrogen and phosphate. Meanwhile, the direct use of CO_2 (from external industrial) is becoming a large factor for increasing the daily growing rate of algae. That means that macro algae represent a capacity to transform the negative eutrophication potential of such biowaste into a benefit for algae growth.

The aim of this paper is to assess the environmental benefits and impacts of a biogas production system which is adopted for Latvian conditions from a cradle to grave perspective using marine macro algae and waste water treatment plant (WWTP) sludge as a substrate for the production of biogas. The final use is planned in a small combined heat and power (CHP) unit (40kW). The analysis will be performed in the light of comparison with a reference fossil-based system using natural gas as the fuel for the cogeneration unit under study.

The analyzed system is partly based on the pilot project “Biowalk4biofules”, which is implemented in Augusta, Italy [11].

The life cycle assessment method defined within the standards ISO 14040 and ISO 14044 [12, 13] has been chosen as the most appropriate method for analysis. The method is implemented in the LCA software SimaPro version 7.3 [14].

The results gained in the study are useful for decision makers in the sphere of energy planning and researches. Moreover, the final intention of the research is to identify environmental indicators and a benchmarking threshold within the specific technology analyzed.

II. PLANT DESCRIPTION

The following section will describe the biogas production system which is assumed to be located in Riga, Latvia. The site is assumed to be near the Baltic Sea and in the territory of the waste water treatment plant (WWTP) "Daugavgrīva". The plant site is equipped with: four separate algae growth open ponds, anaerobic digesters (two stage processes) and one cogeneration unit.

The algae growth process is ensured by providing appropriate conditions (see table III and Figure 3). In order to control the cultivation process, the open ponds are separated from the surrounding waters. The pond area and the internal walls are made in ethylene propylene diene Monomer (EPDM) rubber. The ponds are filled with water from the Baltic Sea. Inlet flows of air - together with water and CO_2 - and nutrients are foreseen. More specifically, a half of the nutrients are recirculated from the biodigestor and another half are supplied directly from the sludge of the WWTP process. Based on the literature data, a volume of 1500 μl CO_2 per one litre of air insufflate in the open pond has been assumed (see Table III, [15]).

Algae need carbon (CO_2) and nutrients for optimal growth and artificial increase of the CO_2 concentration in the growth media (e.g. from industrial external sources) increases the algae growth rates by a factor 1.2-1.8 [16 - 19]. In this work, the reuse of CO_2 of exhaust gas from the combustion processes of the cogeneration unit is planned.

Initially there are supposed to be 200 kg of algal biomass (taken from a protoplast incubator, but not taken into account in the LCA model) in the ponds. When the biomass reaches the level necessary for production, the planned biogas is harvested. As the harvesting is done, there is new water added which replaces the volume.

In the next step, the prepared algal biomass, together with sludge (from the WWTP), is pumped into the anaerobic digester for biogas generation.

The system is cantered on a two-stage bioreactor for production of biogas through anaerobic digestion. The acidification phase will be carried out at 38° C. After this first phase, the effluent is clarified: the solid part is then recycled to complete the hydrolysis, while the liquid part will pass through the second phase for methanization. The second phase of the anaerobic digestion uses biomass patented rotors, "Archimedes Rotors", to maintain a high concentration of bacterial methanogenic flora and optimize the production of biogas.

The outflows from the digestion phase are separated. The solid part is removed from the liquid in order to obtain fertilizers after drying. The liquid fraction is reused in the system – in the open ponds for algae growing. This is a good way to use the co-products of biogas production with a consequential increase of the total environmental benefit of the plant.

In the final stage, biogas is sent to the cogeneration unit where electrical and thermal energy are produced.

The conceptual scheme of the plant is described in Fig. 1 where the main flows, end products and co-products are shown.

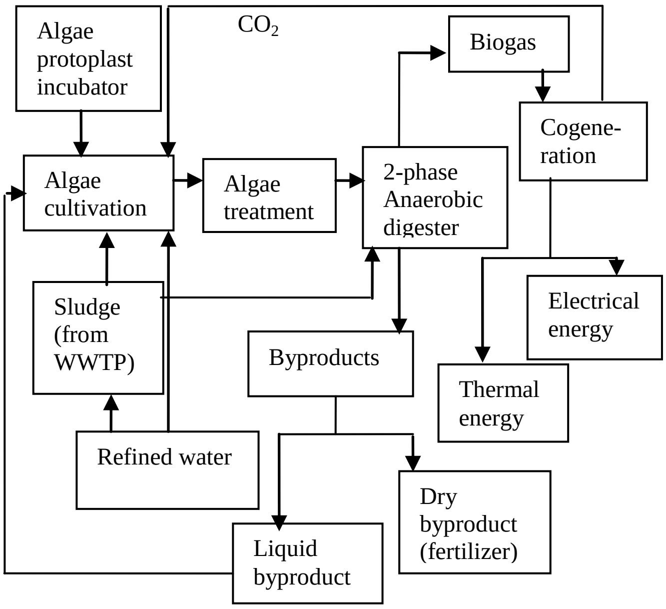

Fig. 1. Scheme of the production system.

In reference to the previous scheme, the main system flows are:

- protoplasts from the incubator for production of the initial algal biomass;
- refined water available from the Baltic Sea for algae growth;
- sludge - used for algae growth in order to provide the right amount of nutrients requested for the process;
- CO_2 (together with air) used to increase algae growth;
- heat and electricity from the co-generator;
- digestate from the "Archimede" rotors:
  - dry fraction to be used for fertilizers production;
  - liquid fraction of residual to be re-used as input in the algae growth ponds;

The energy demand (both thermal and electrical) necessary for the plant is supposed to be provided by the CHP unit.

III. LIFE CYCLE ASSESSMENT

The life cycle assessment method is a tool which identifies and quantifies the environmental benefits and impacts of a certain system. The LCA methodology provides the possibility to compare several scenarios on the same reference scale (functional unit). Analysis is done for a one year period and all the phases (from the material extraction until the by-product reuse) are taken into account, so it is assumed to be a cradle to grave approach. LCA is developed based on ISO 14040 and 14044 [12, 13].

The LCA object of this study has been developed through its sequential phases: goal and scope - where the aim of the studies and the aim of the results is defined -, the boundaries of the system are set, the functional unit - used as a reference unit in case of comparison -, the definition of the inventory data for the whole system. The impact assessment that has been chosen is IMPACT 2000+ [20]. In this method, there are 15 midpoint categories, and 4 end-point categories. In the paper, the results are presented at the end-point stage in relation to the category of: human health, ecosystem quality, climate change, use of non-renewable energy resources. They are expressed, respectively, in DALY, PDF m^2yr, kg CO_{2eq}, and MJ. The scores in the damage categories are further normalized based on the average impact on one person in one year in Europe.

The resulting unit is a ‘‘point’’ (Pt), where one point represents the average damage caused to one person during one year in Europe. In this way, the four damage categories can be compared to each other.

In the next paragraphs the main steps are explained in detail.

A. Goal and scope

The goal of the LCA study is to assess the environmental loads and benefits of the use of macroalage as feedstock for the production of biogas and its use in a cogeneration unit. The evaluation is also carried out through comparison with a natural gas-based system using the same functional unit.

B. Functional unit

The function of the system is to generate thermal and electrical energy. The functional unit chosen to represent the system was defined as the total energy produced in one year in the plant equal to 1.1 TJ_{el} and 2.2 TJ_{th}.

The amount of algae necessary to guarantee this production phase was set to a level of 802.91 t/year, as reported in Table IV.

All impact assessments results and different scenarios are compared based on this functional unit.

C. System boundary

The system boundaries are defined based on the biogas production system definition and inventory elaboration.

In Figure 2 there is a flow scheme of the analyzed system. As it demonstrates, the system includes the macroalgae cultivation phase, its harvesting and treatment; 2-stage anaerobic fermentation; the biogas consumption in cogeneration, as well as the by-product management expressed in terms of boundary extension. Transportation is not shown in this scheme, but it is needed for all production stages.

The model, which is implemented in the LCA software SimaPro, is shown in Figure 2 below.

Since residues from by-products – that occur during the pre-treatment and fermentation processes – still have a nutrient factor, a beneficial credit was applied for fertilizer use in the agricultural sector. This means that a certain amount of fertilizer cannot be considered as produced, because it could be replaced by the by-products of biogas production (substitution LCA approach).

The energy costs and environmental loads of certain capital equipment (buildings, roads), as well as the production of the protoplast, were excluded. The impact of plant construction has been taken into account, with a lifespan of 25 years. Basically, only the inputs and outputs directly associated with the production and use of biogas were identified and quantified. Impacts, such as noise and odour, were excluded in this study, because there are no characterisation methods to assess these impacts. The geographical boundary for this study is Europe: raw materials are assumed to be produced there.

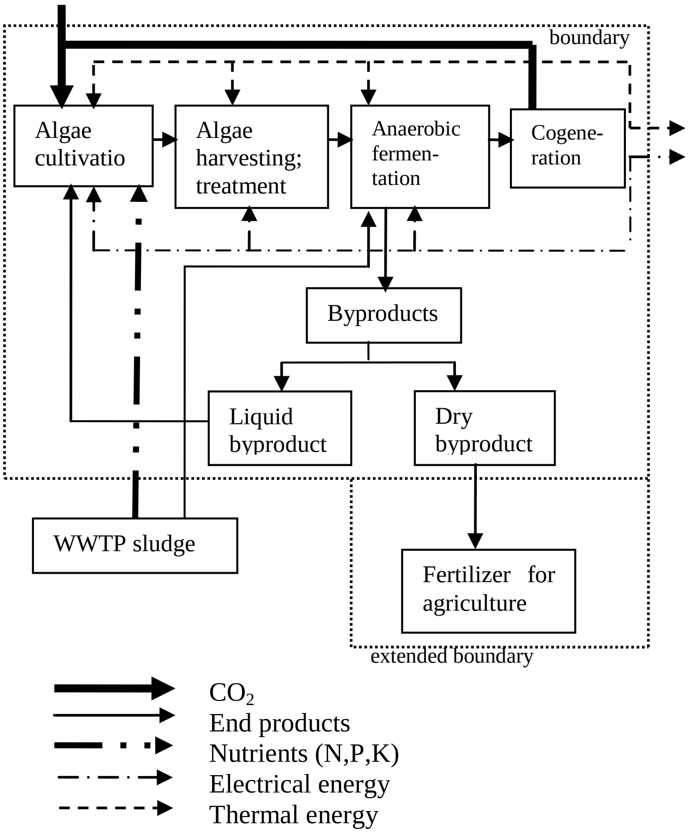

Fig. 2. Overview of the analyzed system.

D. Life cycle inventory

In the stage of Life cycle inventory, the data required to list all the main and relevant inflows and outflows within the process in reference to the functional unit has to be collected and compiled.

In this study, primary data were collected to quantify the operational inputs and outputs associated with each biogas production chain, while secondary data from published literature and reports were used to characterise various background processes. Where no other data were available, the Ecoinvent database [21], included in Simapro,was used.

Operational data for biogas production and a two-stage biogas production plant were obtained from the project partners. Calculations, on the basis of the project partners' information [17], were carried out in relation to the yearly production of algae biomass. Moreover, useful expert opinion was used in relation to the characterization of the WWTP sludge.

Key data for the Biogas pathways are shown in Tables I, II and III. In order to minimise uncertainties about the data quality as much as possible, all primary data were checked and compared with the recent and represented current technologies, in order to understand whether they were outside the normal range for similar products or processes. At this stage, the data could be considered as being of sufficient quality.

TABLE I

GENERAL INVENTORY DATA OF PLANT PROJECT

Parameter	**Data for LC inventory**	**Source**
Geographic setting	Europe	Assumed
Theoretical amount of biogas produced at the plant regime level	$40 m^3/h$	[11]
Total volume of the ponds	$3000\ m^3$	[11]
CO_2 from cogeneration unit	311,040 kg/year	Calculations based on [11]
Average monthly temperature of water	See Figure 3	[23]
CH_4 content in biogas	68%	[22]

TABLE II

SPECIFIC INVENTORY DATA OF SLUDGE

Parameter	**Data for LC inventory**	**Source**
Type of sludge	"Daugavgrīva"	[22]
Dray mass of total solids	23%	[22]
Volatile solids (of total dray mass)	68%	[22]
Chemical composition of sludge	NO_3 - 20 mg/g TS*; NH_4 - 46 mg/g TS; PO_4 - 26 mg/g TS	[22]
Theoretical biogas yield	0.412 m3/kg VS**	[22]

The main resources of the gathered data, in summary, were from:

- Scientific literature,
- "Biowalk4biofuels" project information,
- calculations,
- expert opinion – data has been acquired from the Biowalk4biofuels concerning dynamics of algae growing (NERI Institute, [17]) and biogas plant specifications (EcOIL, [18]);
- assumptions,
- Ecoinvent data base.

Tables I, II and III indicate the main data to be considered in the overall impact assessment. Table IV contains the assumptions for the transportation of material.

TABLE III

SPECIFIC INVENTORY DATA OF ALGAE

Parameter	**Data for LC inventory**	**Source**
Type of algae used	*Ulva prolifera*	Assumption
Theoretical period of algae growth in Latvia	See Figure 3	[19]
Minimum algal daily production	440 kg (fresh weight)	Calculations
Algae cultivation duration	10 days	Expert opinion [17]
Algae daily growth rate (DGR), natural condition	Depending on temperature (see Figure 3)	Calculations
Increase of the DGR due to additional CO_2	21%	[24, 25]
Dissolved Organic Compounds (DOP) and Particulated Organic Compounds (POC)	%C = 5% of the dry weight	[15]
Amount of CO_2 in solution sea water	Assumed to be equal to the 0.09 g/l	[26]
Amount of CO_2 absorbed in the process of algal biomass growing	300 kg/year (with starting assumption: percentage of the carbon contained in the algal biomass equal to 30%)	Calculation
CO_2 per unit of bubble air rate flow	$1500\ \mu l/l_{air}$	[15]
Dry mass of total mass	20%	[17, 24]
Volatile solids (of dry mass)	78%	[17, 24]
Theoretical biogas yield	$0.275\ l/g_{VS}$ **	[17, 24]
Absorbed nutrients per day by algae	NO_3= 20 mg/g $_{TS}$ * NH_4 = 100mg/g $_{TS}$ * PO_4 = 25 mg/g $_{TS}$ *	[17, 24]

* g $_{VS}$ - g of volatile solids
** g $_{TS}$ – g of total solids

TABLE IV

ASSUMPTION FOR TRANSPORTATION

Parameter	**Data for LC inventory**	**Source**
Alga cultivation tank	From Germany – 1290 tkm	Assumption
Stell	From Germany – 36.6 tkm	Assumption
Anaerobic digestion plant	from the Czech Republic – 685 tkm	Assumption
Cogeneration unit	From Germany – 62.3 tkm	Assumption
Ulva prolifera protoplast	From Denmark – 72.3 tkm	Assumption
Dry digestate transportation	To local area – 640 tkm	Assumption

IV. RESULTS

The following section explains the results of each stage of the system and its specific characteristics in more detail.

A. General results of algae growth

This study has been focusing on the biogas generated from the macroalgae. The yearly amount of biogas required by the CHP unit is on average equal to 40 m^3/h. This amount is supplied by the digestion of the algae biomass and from the digestion of the WWTP sludge, the proportion of which are defined in Table V.

One of the parameters that affects the production yield of biogas is the total production of algal biomass that the cultivation can provide. In this respect, it is crucial to know the daily growth rate of the algal species. The daily growth rate (DGR) represents the growing rate as a percentage. This can be calculated from the resulting increase in the algal biomass in fresh weight and is expressed as percentage of growth per day. The formula is expressed as follows [19].

$$\mathrm{DGR} = [(\mathrm{Wt}/\mathrm{Wo})^{1/t} - 1] \times 100 \qquad (1)$$

where:

- DGR (daily growth rate) is the daily growth rate in fresh weight per day, %;
- Wo is initial weight, kg;
- Wt is weight after t days, kg.

The algae growing phase is dependent on the temperature of water of the growing medium [15, 19, 27] and consequently, the seasonal variation of temperature can affect the global biomass production yield.

The algae growth phase is influenced by the temperature of the growing medium which meant that the seasonal variation of temperature can affect the global biomass production yield. Data for the water medium temperature has been taken from the Latvian National Metrology Centre [23].

In order to calculate DGR (depended on the water temperature), the following formula for *Ulva prolifera* [19] is used:

$$\mathrm{DGR} = -0.234T^2 + 10.134T - 64.647 \qquad (2)$$

where:

T = temperature of the water medium, °C

In Fig. 3 the mean water temperature in Latvian conditions is reported which varies from a zero value, during winter time, till a value of approximately 23°C during summer time; in fact a suitable temperature for natural growth of algae. By using this formula, it is possible to understand that the cultivation period – and, consequently, the harvesting period - for algae in natural Latvian conditions is from May until October. This means that the production of biogas will be coupled with the algae biomass digestion only within period from May until October.

Algae growth depends on several parameters, such as: water temperature, water aeration, water salinity, density of the biomass in the pond, added nutrients and CO_2 [25, 28, 29].

In this paper, the authors have focused only on the proper addition of nutrients (also CO_2), water medium temperature and water salinity [29].

It is also important to mention that this paper has only considered natural conditions of sun light (which influences the water temperature), in order to avoid additional energy consumption.

TABLE V

INFLOWS AND OUTFLOW OF ALGAE GROWTH PROCESS

Harvested algal biomass [t/year]	Used sludge for algae growth [t/year]	Absorbed CO_2 [t/year]
802.91	769.78	295.21

As mentioned before, nutrients for algae growth are supplied by sludge. In order to guarantee algae growth for the whole year, approximately 770 t of sludge are needed (see Table V). The needed amount of sludge has been calculated based on the sludge chemical composition and algae fixation capacity (see Table III).

In order to get the highest possible growth rate, additional CO_2 is added. The theoretical maximum amount of CO_2 that can be fixed has been calculated by the methodology proposed by Romagnoli et al. [25]. The obtained results are presented in the following table.

As it can be seen, in the whole period, when algae can be cultivated, the total amount of carbon dioxide used for their cultivation is 295 t. At the same time, the cogeneration plant produces 129.6 t of CO_2 from combustion processes (see Table I), therefore, the avoided environmental impact is 165 t of CO_2 per year. However, in the months when algae cannot be harvested, there is no fixation of CO_2 and, consequently, no benefits from the absorption of CO_2.

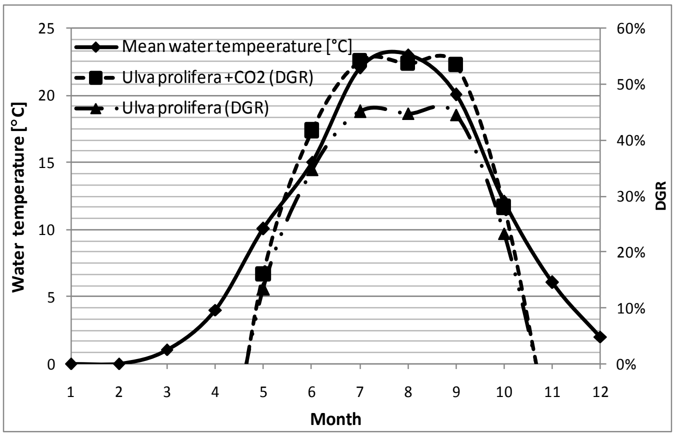

Fig. 3. *Ulva prolifera* daily growth rate and average water temperature in Latvian conditions.

TABLE VI

BIOGAS GENERATED FROM ALGAE AND SLUDGE THROUGHOUT ONE YEAR

	Sludge [t/month]	Algal biomass [t/month]	CH_4 from algae [m^3/month]	CH_4 from sludge [m^3/month]	CH_4 in total [m^3/month]	Biogas in total, [m^3/month]
January	231.1	0	0	10118.4	10118.4	14880.0
February	208.7	0	0	9139.2	9139.2	13440.0
March	231.1	0	0	10118.4	10118.4	14880.0
April	223.6	0	0	9792.0	9792.0	14880.0
May	210.9	13.18	555.1	9236.9	9792.0	14880.0
June	125.4	94.35	3974	5491.6	9465.6	14880.0
July	6.4	225.87	9513.5	278.5	9792.0	14880.0
August	13	218.99	9224.1	567.9	9792.0	14880.0
September	16.5	215.33	9069.6	722.4	9792.0	14880.0
October	189.7	35.19	1482.3	8309.7	9792.0	14880.0
November	223.6	0	0	9792.0	9792.0	14880.0
December	231.1	0	0	10118.4	10118.4	14880.0
Total	1910.98	802.91	33818.4	83685.5	117504	172800

Figure 3 presents the mean water temperature, whereby the triangle curve presents DGR of *Ulva prolifera* in natural conditions and squared curve – the DGR of macroalge when additional CO_2 is added. In this study, only the case with additional CO_2 is examined. As it can be seen in Figure 3, a maximum of 54% can be reached during July and September (when the optimum mean water temperatures are from 22 to 23 °C). Under natural conditions, the salinity of the Baltic Sea water is around 6 ‰. However, for the *Ulva prolifera* growth, salinity level needs to be 36 ‰, and theoretical increase of NaCl per year has been supposed to reach the same level.

B. General results of biogas generation

As said before, biogas is generated from a mixture of macroalgae biomass and sludge. During the period from May until October, the bigger amount of biogas produced depends on algal biomass, and during the period from November until April, only sludge biomass is used for biogas production, since it is not possible to cultivate algae during this period (see Table VI). The results in Table VI take into account the biogas production yield described in Table I.

In the referenced Figure 4, the dark columns represent the biomethane generated from algal biomass, the light ones – CH_4 from sludge biomass. As it can be seen, each month almost 10 000 m3 of biomethane is needed to supply the cogeneration unit, the share of biomethane in the biogas mix use is equal to 68%. This means that, in respect to the total amount of biogas produced, a share of 30% is from the digestion of the algal biomass.

C. Impact assessment through the whole life cycle of the base scenario

In order to evaluate the environmental "hot spots" of the model, the evaluation of the impact assessment has been focused on the following steps of the process:

- algae cultivation, all inputs and outputs related to the production of the algae biomass – including environmental benefits;
- cogeneration unit, represented by the emission from combustion in the CHP unit;
- energy inflows, all the energy inflows required related to all the unit processes on the production chain are taken into account;
- co-product management, that takes into account the environmental benefit from the use of the co-products in the extended boundary (e.g. reuse of the liquid digestate in the ponds and use of the solid fraction as fertilizers);
- materials, all the components required to build the plant;
- transportation, all the assumptions in relation to the transportation of the inflow materials (see Table IV).

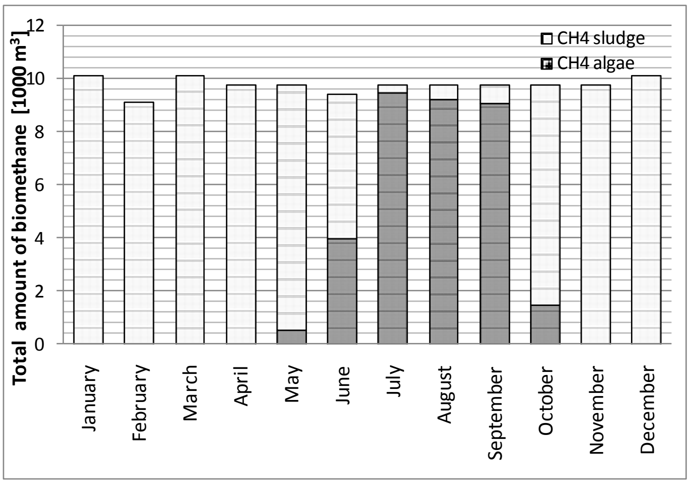

Fig. 4. Biomethane generated from *Ulva prolifera* and sludge throughout the year [1000 m^3].

For the scenario which has been described in this article (base scenario), the outcomes and endpoints category are presented the Figure 5 in reference to Pt/functional unit (f.u.).

As it can be seen in the Figure below, the most potentially negative effects are related to the climate change category, mainly due to CO_2 emissions from the cogeneration unit. This means that the cogeneration process is the most undesirable one from the environmental point of view. At the same time, the climate change category has a gain of environmental benefits due to CO_2 fixation in the algae biomass. The result of this category in the net impact (environmental load less benefits) is a value -2.37 Pt, which means a total environmental beneficial load. Thus, due to the photosynthesis process of the algae, the damage driven by the cogeneration processes can be fully recovered.

The biggest net impact is related to the human health category, which is mainly due to emissions from the cogeneration unit.

The total impact (summing up of all impact categories) of the algal biogas system throughout the life cycle is equal to 1.02 Pt. This means that the whole process does not show a total environmental beneficial effect but the result itself has to be compared with the scenario that takes into account the use of natural gas in the CHP unit. In fact, this is the real goal of the study, in order to understand the real environmental feasibility of the technology analyzed.

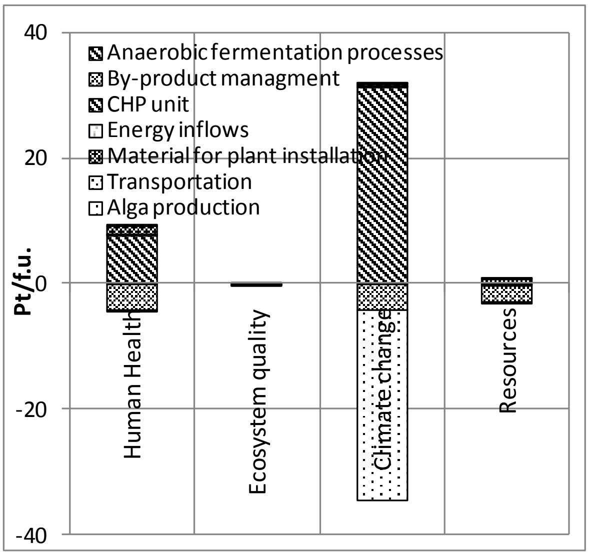

Fig. 5. Base scenario impact assessment at endpoint categories [Pt/f.u.].

D. Impact assessment of scenario considering no algae growth

In order to highlight the effect of using algae in the biogas production process even more, two scenarios have been compared – the base scenario and the one where biogas is produced only by sludge without algae (see Fig. 6). Results in Fig. 6 are presented in Pt/functional unit (f.u.). In the Figure, it can be seen that the environmental benefit of the base scenario overcomes the benefit of the scenario when algae is not used. When algae is not used for biogas production, the system`s net environmental impact is approximately 30 times worse.

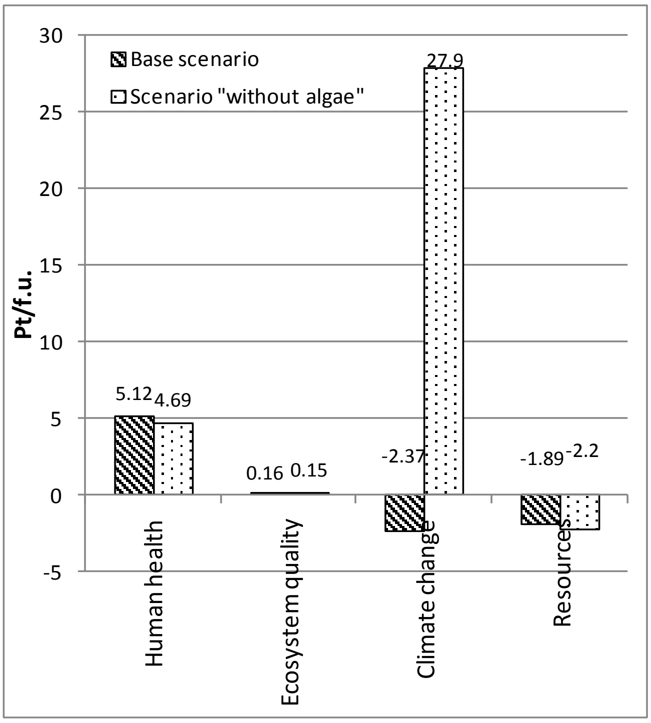

Fig. 6. Comparison of the base scenario and the scenario “Without algae” [Pt/f.u.].

E. Impact assessment of scenario which consider no cogeneration process

As mentioned before, the cogeneration processes cause the biggest environmental loads. In order to avoid that, a new scenario without a cogeneration process has been developed. As it can be seen in Figure 7, the most positive effects have influenced the climate change category, due to the algal capability to fix CO_2. In this case, the inflow energy for the system is supplied by external energy generated in the cogeneration process (average European electrical mix, and thermal energy from natural gas combustion). Due to this, environmental load is caused on the human health, climate change and resources categories. The net impact of the system is –7.8 Pt, which is environmentally beneficial.

Although, the “without cogeneration process” scenario and the base scenario cannot be compared on the basis of the same functional unit, the final load of the scenario without the cogeneration unit, in comparison with the base scenario, is more environmentally sound.

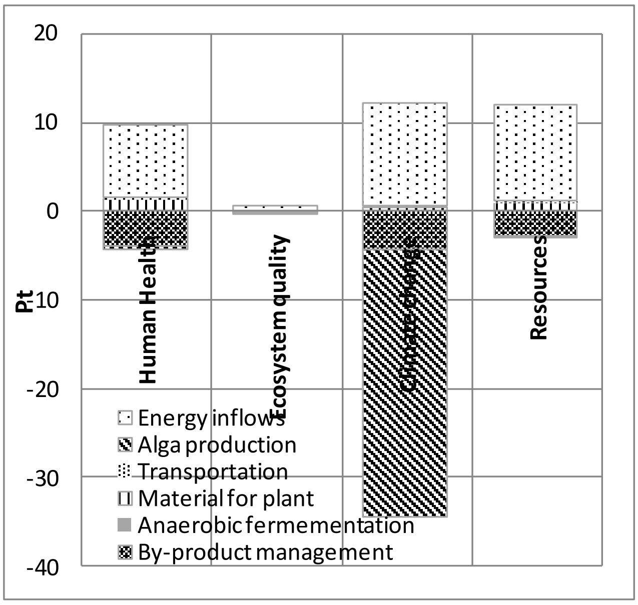

Fig. 7. Scenario "without cogeneration processes" impact assessment.

F. Base scenario compared with natural gas scenario

The base scenario can be compared with other scenarios which have equal functional units. When the base scenario is compared with a reference scenario where energy (in the same cogeneration unit) is generated from natural gas, the following results are obtained (see Fig. 8.).

The natural gas scenario has been taken from the Ecoinvent database. As it is clearly shown, the base scenario gives a much lower environmental load.

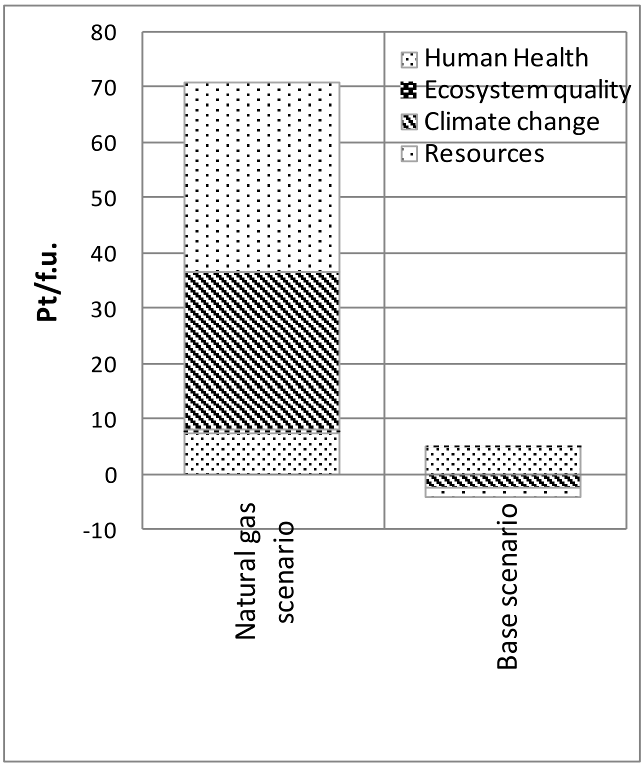

Fig. 8. Comparison of base and natural gas scenarios [Pt/f.u.].

G. Sensitivity analysis

Sensitivity analyses have been conducted to assess the effects of the variation of key input parameters and assumptions on the results of the impact categories of the study. The elasticity method (i.e., the ratio of the change in the results to the change in data input [30]) was used to perform the sensitivity analysis. At this stage, the sensitive analyses were performed for the CHP efficiency factor and the average water temperature. A sensitivity analysis for choice of the impact assessment method (comparison with CML method [31]) has also been evaluated not through the use of the elasticity mythology.

The elasticity method states that the model is sensitive to a certain parameter variation, if the ratio of the change in the results to the change in data is bigger than 1.

Efficiency of the CHP – initially equal to 90% - in sensitivity analysis it is decreased by a factor of 9% (according to [32]), the results of the analysis show an increase of the environmental load of 9 % in respect to the base scenario. According to the elastic factor, this means that the model is slightly sensitive to changes on the efficiency value.

The sensitivity analysis executed for the water mean temperature (relevant for algae cultivation) shows that a variation of 5% (around 1 °C less) during the biomass production months produces a negative environmental impact change equal to 6%. This means that the system is not sensitive to changes in temperature, even if the value is slightly lower than one rather close to change in sensitivity. More accurate investigation should be required for the evaluation of the average temperature for the water to be used in the model. Other sensitivity analyses should involve: the transportation assumption, the biogas yield, the co-product management, and the electricity grid-mix used. At this stage, these evaluations have not been considered.

The sensitivity analysis on the choice of another impact assessment method (CML compare to IMPACT 2002+) - carried at the mid-point stage - shows only evident changes in the respiratory inorganic impact category.

V. CONCLUSIONS

The principal aim of this study was to assess the environmental load of algal biogas system throughout the whole life cycle. The system is based both on the pilot project "Biowalk4biofuels" [11] and the specific Latvian conditions.

The main overall conclusions are:

- Due to the system performance (real impacts), the climate change category has been influenced the most. From the net impact perspective, the human health category has been the most negatively impacted.
- The cogeneration process is the most damaging one, but algae cultivation is the most environmentally beneficial element of the system.
- Use of algal biomass for biogas production gives 30 times better net environmental performance, in comparison with scenario when only sludge is used.

- In comparison with the scenario where natural gas is used for energy generation, algal biogas usage gives about 92% better real environmental load.
- Outcome results are slightly sensitive to change in the CHP unit efficiency.

VI. RECOMMENDATIONS

Further research is needed for deep investigation of all parameters that influence the growth rate of algae.

Improvement of the treatment of cogeneration unit emissions is needed.

An increase of the biomethane during the cold period (November until April) could be improved by implementing a greenhouse for algae growth, but in such case the environmental effect of implementing a new process in the analyzed system has to be evaluated. Practical experiments need to be done in order to investigate algal species in the Baltic Sea.

Sustainability criteria are needed to assess the performance of different systems.

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Iluta Piļicka, Dagnija Blumberga, Francesco Romagnoli. Dzīves cikla novērtējums biogāzes ražošanai no makroaļģēm: Latvijas scenārijs.

Saskaņā ar Eiropas Parlamenta un Padomes Direktīvu 2009/28/EK, par atjaunojamo energoresursu izmantošanas veicināšanu, arī Latvijā tiek veidoti alternatīvās enerģijas scenāriji, kas balstīti uz ilgtspējības kritērijiem. Kopumā saražotās biogāzes daudzums Latvijā ar katru gadu palielinās, tomēr izejmateriālu ziņā vēl joprojām ir nepieciešama izpēte, attīstība un optimizācija. Pateicoties aļģu spējai absorbēt CO_2, bioloģisko piesārņojumu (kas bagāti ar fosfora, kālija un slāpekļa savienojumiem) izmantošanai, kā arī pateicoties augsnes resursu saudzēšanai, to realizācija nodrošina augstu potenciālu vides aizsardzības jomā. Vēl jo vairāk aļģes netiek izmantotas pārtikas produktu ražošanā, tādējādi nerodas konflikti starp vides, sociālajiem un brīvās tirdzniecības pārstāvjiem.

Šī zinātniskā darba mērķis ir novērtēt biogāzes ražošanas un koģenerācijas procesa realizācijas sistēmas ietekmi uz vidi no dzīves cikla perspektīvas, kā arī salīdzināt ar līdzvērtīgiem scenārijiem, kuros izmantoti neatjaunojamie energoresursi (kā, piemēram, dabas gāze). Modelis ir veidots balstoties uz starptautisko standartu ISO 14044, kā arī imitācijas datorprogrammu „SimaPro". Šis zinātniskais raksts atspoguļo sākotnējo izpēti vēl nebijušas tehnoloģijas realizēšanai, iekļaujot arī biogāzes ražošanai piemērotāko makroaļģu sugu apskatu, Latvijas apstākļos. Šajā teorētiskajā anaerobās fermentācijas iekārtā par biogāzes iegūšanas substrātiem tiek pieņemts izmantot zaļo makroaļģu sugu *Ulva prolifera* un notekūdeņu attīrīšanas staciju nostrādātās dūņas. Izpētes rezultātā secināts, ka reāli visvairāk tiek degradēta klimata pārmaiņu kategorija (neņemot vērā vides ieguvumus), savukārt ietverot modeļa radītos vides ieguvumus, visnegatīvāk tiek ietekmēta cilvēku veselība. Sistēmas lielākā negatīvā ietekme tiek radīta galvenokārt koģenerācijas procesā radīto emisiju dēļ. Savukārt vidi saudzējošākais sistēmas posms ir aļģu augšanas process, kas klimata pārmaiņu kategoriju ietekmē pozitīvi, tādējādi kompensējot sistēmas negatīvo vides slodzi. Balstoties uz šī brīža un vēl vairāk nākotnes attīstības tendencēm klimata saudzēšanas un aļģu biogāzes ražošanas jomās, dzīves cikla novērtējuma analīze ieņems arvien būtiskāku lomu.