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Project proposal

EU PROJECT OF LIFE PROGRAMME 'ALGAE SERVICE FOR LIFE' DEVELOPS ECOLOGICALLY SUSTAINABLE BIOPRODUCTS FROM FRESHWATER CYANOBACTERIA AND MACROALGAE BIOMASS

Judita Koreivienė[1], Jūratė Karosienė[1]*, Jūratė Kasperovičienė[1], Ričardas Paškauskas[1], Bogusława Łęska[2], Radosław Pankiewicz[2], Loreta Juškaitė[3,4], Alvydas Zagorskis[3,4], Elźbieta Wilk-Woźniak[5], Vaidotas Valskys[6,7], Zenonas Gulbinas[7], Edward Walusiak[5], Wojciech Krzton[5], Dmitrij Morudov[1], Kostas Radzevičius[8], Ewa Treska[9], Łukasz Tabisz[2], Monika Papsdorf[2], Zuzanna Piotrowicz[2], Beata Messyasz[9]*

[1]Nature Research Centre, Akademijos Str. 2, Vilnius LT-08412, Lithuania
[2]Adam Mickiewicz University in Poznan, Faculty of Chemistry, Uniwersytetu Poznańskiego Str. 8, Poznań PL-61-614, Poland
[3]Vilnius Gediminas Technical University, Faculty of Environmental Engineering, Department of Environmental Protection and Water Management Engineering, Saulėtekio Av. 11, Vilnius LT-10221, Lithuania
[4]Baltic Environment, LTD, A. Juozapaviciaus Str. 9, Vilnius LT-09311, Lithuania
[5]Polish Academy of Sciences, Institute of Nature Conservation, Adama Mickiewicza Al. 33, Kraków PL-31-120, Poland
[6]Vilnius University, Life Sciences Centre, Institute of Biosciences, Saulėtekio Av. 7, Vilnius LT-10222, Lithuania
[7]Nature Heritage Fund, A. Vivulskio Str. 41–113, Vilnius LT-03114, Lithuania
[8]Kaunas University of Technology, Faculty of Chemical Technology, Radvilėnų Rd. 19, Kaunas LT-50254, Lithuania
[9]Adam Mickiewicz University in Poznan, Faculty of Biology, Department of Hydrobiology, Uniwersytetu Poznańskiego Str. 6, Poznań PL-61-614, Poland
*Corresponding authors. E-mail: jurate.karosiene@gamtc.lt; beata.messyasz@amu.edu.pl

Abstract

Koreivienė J., Karosienė J., Kasperovičienė J., Paškauskas R., Łęska B., Pankiewicz R., Juškaitė L., Zagorskis A., Wilk-Woźniak E., Valskys V., Gulbinas Z., Walusiak E., Krzton W., Morudov D., Radzevičius K., Treska E., Tabisz Ł., Papsdorf M., Piotrowicz Z., Messyasz B., 2019: EU project of LIFE programme 'Algae Service for LIFE' develops ecologically sustainable bioproducts from freshwater cyanobacteria and macroalgae biomass. – Botanica, 25(2): 176–185.

'Algae Service for LIFE', the project supported by the European Union, seeks to promote best practices in ecological service and the circular economy by implementing innovative complex system of three interlinked elements: i) prototypes for harvesting of cyanobacteria and macroalgae biomass; ii) distant methods for surveying of the blooms and defining hot-spots of algal agglomerations; and iii) restitution of harvesting costs by redesigning of waste algal biomass into valuable products. The current paper describes application of algal biomass part of the project by providing actions in redesigning of harvested waste biomass of cyanobacteria and macroalgae into potential valuable products for sustainable management and recycling of environmental resources. It also highlights the socio-economic aspects of the project and added value of the project for the European Union.

Keywords: algal biomass, biofertilisers, biogas, bioproducts, circular economy, cyanobacteria, macroalgae.

INTRODUCTION

Global warming and eutrophication are the main drivers responsible for excessive growth of algae. Ongoing climate change causes alterations in the hydrological regime and precipitation. As a consequence, the cumulative effect with nutrient over enrichment in modulating blooms will be increased (Moss et al., 2011). Algal blooms determine different types of problems; therefore, various ways of addressing this problem are proposed and applied. The current LIFE project focuses on the blooms and mitigation of the negative results; however, it goes even further than any other projects and proposals by seeking to involve a circular economy approach.

In general, the European Union supported international project 'Algae Service for LIFE' of the LIFE Environment and Resource Efficiency sub-programme seeks to promote best practices in ecological service and the circular economy by implementing innovative complex system. Three interlinked elements of the system are: i) construction of prototypes for harvesting of cyanobacteria and macroalgae biomass as a tool to improve water quality and provide ecosystem services; ii) apply distant methods for surveying of the blooms and defining hot-spots of algal agglomerations; and iii) restitution of harvesting costs by redesigning of waste algal biomass into valuable products.

In the previous paper (Koreivienė et al., 2019), 'Ecological Service' part of the project has been presented. It describes the causes and mechanisms of eutrophication in inland freshwaters, the consequences of algal blooms as well as highlights ecological measures to control blooms. The proposed measures for ecological service are briefly discussed in the light of the European Union directives. The raise of awareness of the national and local authorities, business community and society on the environmental, water quality and health hazard issues are highlighted as well.

The aim of the current paper is to describe 'Algal biomass application' part of the project and provide planned activities for redesigning of waste biomass of cyanobacteria and macroalgae into potentially valuable products for sustainable management and recycling of environmental resources. It also highlights the socio-economic aspects of the project and added value of the project to the European Union.

ALGAL BIOMASS APPLICATION FOR PRODUCTION OF VARIOUS BIOPRODUCTS

Algal biomass is a valuable raw material for agriculture and industry in the broader sense, e.g. chemical, cosmetic, pharmaceutical, feedstock and food sectors. Therefore, algae have received substantially increasing interest from research, industry and policy makers as the potential renewable resource for low value products (biofuel, bioplastics, fertilisers, etc.) and highly valuable compounds (vitamins, ferments, antioxidants, pigments, etc.) suitable for industrial use (Spolaore et al., 2006; Brennan et al., 2012; Markou & Nerantzis, 2013). In most cases, the particular species are cultivated in open outdoor systems or closed photobioreactors that determine relatively high biomass price and some problems of their maintenance. High cost of biomass production is the biggest barrier to enter into the market. Primarily, significant reduction of costs may be achieved if CO_2, nutrients and water can be obtained at low cost (Slade & Bauen, 2013).

Harvested excess algal biomass from aquatic ecosystems is cheaper, but has some limitations for its application due to a mixture of species in the agglomerations; non-algal contaminates harvested together and volatile chemical structure of the biomass. Consequently, it is difficult to predict in advance what valuable bioproducts could be obtained from a particular biomass. Therefore, the project is focused on two approaches of utilisation of harvested biomass, depending on obtained biomass quality: 1) transfer of entire biomass into *low value bioproducts* (biogas, fertilisers); 2) extraction of the *high-value components* from the biomass (phycocyanin, other high-value compounds). This action will demonstrate biomass applicability and economic feasibility, which is very important for developing a successful strategy for the production of bioproducts obtained from algal biomass.

1) Suitability of algal biomass for low value bioproducts

Biogas production. Cyanobacteria and algae convert through the photosynthesis carbon dioxide, nutrients and solar energy into chemical compounds that can be useful alternative to conventional energy sources. The carbon contributes around 50% of algal biomass; on the other hand, they contain little cellulose and no lignin. As algae undergo a more complete hydrolysis compared to other degradable substrates, algae have become a topic of interest in the production of biogas through anaerobic fermentation. Thus, cyanobacteria and macroalgae biomass is the source of organic matter that can generate energy through anaerobic digestion, and the amount of methane exceeds 60% in the biogas obtained (Baltrėnas & Misevičius, 2015). Depending on algae type, the biogas yield can be estimated up to 400 L/kg of total volatile solids. Co-digestion of algal biomass with other organic substrates results in doubling of specific methane yield, increase of loading rate and volumetric reactor productivity (Park & Li, 2012). During the project implementation, up to 34 t of harvested macroalgae biomass will be tested for biogas production in semi-pilot biogas digester (up to 10 m^3). The amount, quality of biogas in algal purely biomass and in combination with other degradable substrates will be tested.

Fertiliser and plant biostimulant production. Freshwater algal biomass can be applied as slow-release fertiliser as the main nutrients and microelements are well balanced and are gradually released threw biodegradation process (Mulbry et al., 2005, 2008; Coppens et al., 2015; Messyasz et al., 2015). Algae also contain trace elements, growth-promoting and antifungal substances, and increase the water binding capacity of the soil (Pulz & Gross, 2004; Spolaore et al., 2006). Algal compounds have been confirmed to provide plants with nutrients, support the increase of biomass production, and activate anti-stress abilities of the plants (Dmytryk & Chojnacka, 2018). The market of biofertilisers amounts to approximately 5×10^9 USD per year (Mulbry et al., 2008). Currently, the European Parliament has laid down the rules and harmonised conditions for making fertilisers from recycled or organic materials for their further use in the market of the union (Amendments of Regulations (EC) No 1069/2009 and (EC) No 1107/2009 (COM(2016)0157–C8-0123/2016–2016/0084(COD)). Therefore, the characterisation of new products, elaboration of the EU standards and regulations for the products from secondary feedstock is of great importance.

During the project implementation, up to 27 t of wet harvested macroalgae and non-toxic cyanobacterial biomass will be tested for suitability as slow-release fertilisers and growth activity promoters for wild plant seedlings (spruce, pine) and prevailed culturing plants in the countries (potatoes, carrots, cucumbers, tomatoes). Wet and dried-pulverised biomass will be tested on a lab and field scale. The analysis of the constituents (main nutrients and microelements) will be done to ground the real-testing results and for preparation of market-friendly bioproduct declaration.

2) Suitability of algal biomass for high value bioproducts

Extracts of valuable components. The raising awareness of the society on harmful effects of the synthetic compounds promotes consumer interest towards natural bioproducts that could be obtained also from harvested biomass of cyanobacteria and algae. Marine algae species are already recognised for their properties and components suitable for cosmetics, drugs, dietary supplements and food products. The current interdisciplinary research shows that freshwater macroscopic green algae species may also be a rich source of bioactive substances showing their potential to be used in the production of cosmetics (Łęska et al., 2018).

High value components such as pigments, polyphenols, fatty acids, polysacharides will be analysed in harvested high quality freshwater macroalgal biomass. Analysis undertaken in the course of the present project concerns chiefly the methods of isolation and analysis of biologically active compounds from freshwater green macroalgae commonly encountered in Poland (*Cladophora glomerata*, *C. rivularis*, *Chara fragilis*, *Ulva flexuosa* and *Oedogonium* sp.) (Messyasz et al., 2018). Results concerning their composition of biologically active compounds, obtained up to this point, are very encouraging, and the biomass of said species could be a potential raw material for the production of animal feed, food and cosmetic industry. It is possible that freshwater algae will become an alternative for their marine counterparts.

Utilisation of a range of "classical" and advanced methods such as a Soxhlet apparatus, ultrawave-assisted extraction, microwave-assisted extraction, extraction with supercritical carbon dioxide allows isolating specific bioactive compounds for their later selection towards a specific goal. The testing focuses on quantitative and qualitative analyses of fatty acids, chlorophylls, carotenoids, sulphated polysaccharides and phenolic compounds. Some of these substances have been identified for the first time in freshwater species during previous research undertaken, e.g. palmitooleic acid, sulphated polysaccharides in *Cladophora glomerata* and *Ulva flexuosa*, and carotenoid fucoxanthin in *C. glomerata* and mactraxanthin in *Chara fragilis* (Łęska et al., 2018). Analysis of the bioactive compounds in prepared algal extracts encompasses different instrumental methods such as elemental analysis, UV-Vis spectrophotometry, gas, high-performance liquid and size-exclusion chromatography, mass spectrometry or infrared spectroscopy.

Phycocyanin is a unique blue colour protein, which is characteristic particularly of cyanobacteria contributing up to 20% of their dry biomass (Eriksen, 2008). This pigment has a massive commercial value as natural colorant in nutraceutical, cosmetics and pharmaceutical industries, besides their health benefits (Kuddus et al., 2013). In 2016, the evaluation of global phycocyanin market was defined as 87 million USD. It is estimated to further grow by 4.7% to reach 114.8 million USD in 2022. The one of the major drivers for the global phycocyanin market is the growing demand for the natural colorants, especially in the Western Europe region, as chemical colorants or dyes are totally banned in Europe (Market.Biz, 2019). During the project, pigment phycocyanin will be extracted from freeze biomass of cyanobacteria scum (~0.5 t of harvested cyanobacteria wet biomass) and its chromatographic purification will be performed following conditions described in Cuellar-Bermudez et al. (2014) and Yu et al. (2016). We will seek to reach the purity of the phycocyanin pigment of food grade (620/280 greater than 0.7). We expect that reaching sufficient quality and acquiring necessary certifications, those bioproducts could be tested under real conditions as the dietary supplements for domestic animals after the implementation of the LIFE project.

At least 1–2 market-friendly products are expected to be obtained for the declaration. Therefore, the testing of biomass component extracts (chemical composition, toxicity, phycocyanin yield and quality) that are necessary for product declaration will be carried out. Further possibilities of market-friendly product application, launching for the real-life tests and transferability will be outlined in the After-LIFE plan.

Life Cycle Assessment (LCA): *calculation of ecological and economic benefits of algae biomass harvesting and its suitability for human needs.* Cost analysis of the harvesters operation, increase of water quality and incomes from obtained algal bioproducts will be included into LCA. The project seeks to demonstrate harvested biomass applicability to bioproducts and as an economically feasible alternative to compensate ecological service costs giving the best pay-back (Fig. 1). The data obtained during the project will allow commercialisation of bioproducts from algae as the next step and the 'Business opportunities plan' will be prepared after the implementation of the project. Finally, this will support replicability of the project results. The goal plan is to also offer full scale services combining technological approach.

SOCIO-ECONOMIC EFFECTS OF THE PROJECT

Every project has the potential to provide socio-economic benefits for the community in which it is implemented. The project 'Algae Service for LIFE' is primarily relevant for the Baltic Sea region, because the testing of innovative complex system and demonstration of activities will be implemented in Lithuanian and Polish freshwater bodies, which constitutes the Baltic Sea catchment area. Due to high replicability of the proposed measures, it is also important for all citizens of Europe. Four trends of feasible impact of the project actions on the local economy and several social groups can be defined:

1) Effect of increased water quality on recreation

All inland waters and the Baltic Sea shore are a source of bathing, recreation, leisure, camping, fishing, etc. for most population of Lithuania and Poland. This represents a huge impact on human life and recreation. Recreational activities bring visitors into contact with the quality of aquatic ecosystems. Agglomerations of macroalgae aggravate the quality of bathing, tourism, recreation, canoeing in the rivers and they lose attractiveness directly influencing incomes of tourism operators, accommodation, canoeing centres. Collection of cyanobacteria scums and macroalgae mats primarily will improve the water quality and also can provide an added value to develop active eco-tourism in both countries implementing the project.

Ecology of living environment is highly interlinked with socio-economic components. Harvesting

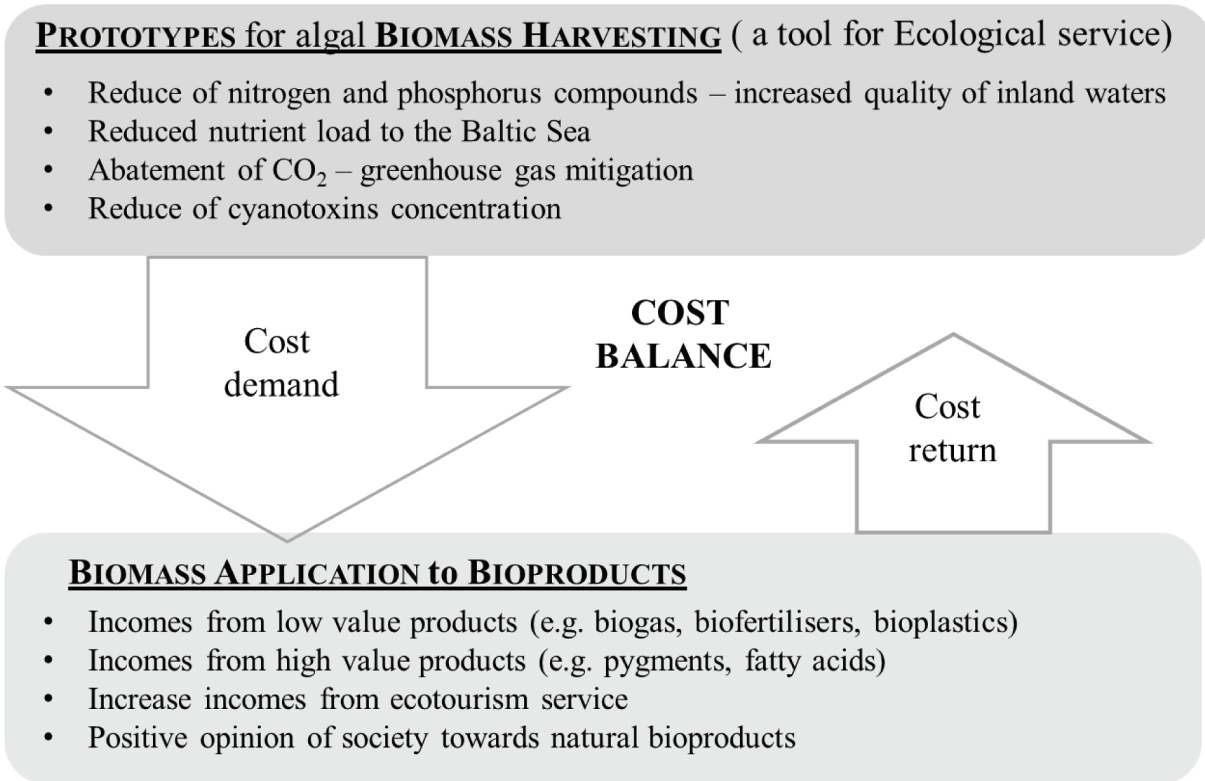

Fig. 1. Circular economy approach of the project: expenditure on eco-services is intended to be partially compensated by valuable products produced from waste biomass

of excess algal biomass will provide long-term environmental benefits for the community of the region through the increase of water quality, attractiveness of recreational activities and welfare of local community. Attractive recreational environment may accelerate increase of local inhabitants and local tourists that will accelerate regional development and well-developed rural tourism network.

2) Reduce of unemployment and increase of incomes to business

Tourism contributes to the GDP of Lithuania and Poland by about 3% and 6%, accordingly. Socio-economic benefits that arise from improved water quality include the creation of business opportunities, for instance, for fishing industries and angling tourism that require clean water. Achieved increase of good water quality stimulates beach visitors that generate employment of service staff. Municipal and private beaches can be developed for active water sport services (car parking fee, rent of boats and other water vehicles), cafes and restaurants can increase beach services by employing local people as well as canoeing centres will gain additional incomes also. Therefore, increased recreation activities and tourism will lead to the rise of tourism sector incomes, promote rural tourism and reduce regional unemployment. Moreover, with the increase of the quality of water bodies the cost of land and homesteads nearby can give additional profit for local people.

The raising of awareness among population and demonstration of the benefits achieved by applying suggested algal biomass harvesting measures will increase willingness of local municipalities and business people to pay for the social benefits and better welfare. Tourism as recreation-related business has a growing economic importance especially in the coastal areas. Project actions will take place in the largest brackish lagoon of the Baltic Sea – the Curonian Lagoon. Water quality is a long-lasting problem in the lagoon that has influence not only on local visitors, but also it determines the attractiveness of the UNESCO World Heritage sites nearby for the foreign tourists. If the quality of water in the Curonian Lagoon will increase, tourism acceleration can give considerable raise to the service sector in the coastal municipalities.

In 2016, twenty two companies had fishing quotas for their business in the Curonian Lagoon. Neurotoxic cyanobacteria blooms determine mass fish mortalities, which reduce fish resources and influence commercial, recreational fishing and angling. Removal of cyanobacteria biomass and their toxins via harvesting will increase safety of the society, improve quality of fish-stock and fishing activities. Particularly, this will make it possible: i) to avoid fish contamination with toxic substances and to maintain clean, healthy and productive aquaculture resources that are important for the industrial fishing and angling; ii) to restore and maintain good conditions in water bodies for sustainable environment driving economic growth especially in tourism and recreation along with the quality of life; iii) to raise the value of waterfront property through removal of toxic compounds, while values can decline because of the unpleasant sight and odour of algal blooms.

Operation of manufactured prototypes applied in the freshwater fish farms experiencing toxic cyanobacteria blooms will reduce fish mortality and their contamination with the cyanotoxins that can accumulate in their muscles. This directly relates with the companies' profit.

3) The added value from natural safe bioproducts obtained from algal biomass

In 2012, bioeconomy was recognised and promoted by the European Commission in the publication 'Innovating for Sustainable Growth: A Bioeconomy for Europe'. The bioeconomy undoubtedly has social, economic and environmental impacts on society, but algal biomass production may affect people, regions and countries in different ways. During the project implementation, the potential of various applications of harvested algal biomass will be tested and target bioproducts will be defined for the further development of the market strategy. Therefore, the realistic socio-economic effect of bioproducts from algae on regional development will be possible to forecast only after the implementation of LIFE project.

Promoting a bio-based economy is a crucial involvement of different stakeholder groups, thus, the results obtained during the project will be presented at the workshop. Representatives from the business will be invited to attend the meeting and raise their interest on algal bioproducts. Production of biofertilisers will influence agricultural sector, whereas innovations of biogas production from algal biomass can find the interest among biogas producers. Valuable products from algal biomass are targeting the industries of cosmetics, food and additives of nutrition.

4) Indirect socio-economic impact

The implementation of the raise of public awareness activity has an important indirect socio-economic impact on different target groups and stakeholders. The importance of all the project actions and their effect on aquatic ecosystems and people will be communicated in various ways (leaflets, presentations at schools and other institutions, interviews, mass media, etc.). We hope for remarkable response from different groups, their expressing support to watching of harmful algae blooms in aquatic ecosystems.

THE ADDED VALUE OF THE PROJECT FOR THE EUROPEAN UNION

The European Court of Auditors defined that the implementation of the Nitrates Directive, Water Framework Directive (WFD), Marine Strategy Framework Directive and Baltic Sea Action Plan is not fully effective (European court of auditors, 2016). The implemented actions in the EU by the Member States have led to limited progress towards reducing nutrient inputs into the Baltic Sea. Only a slight reduction of the nitrate concentration in surface waters and the nutrients load from agricultural land was observed. Therefore, significant abatement of the nutrient loads thought the rivers flowing into the Baltic Sea is required. Substantial input is expected from Lithuania, Poland and Russia for contributing to the achievement of the HELCOM nutrient reduction targets. The economic costs for implementation of nutrient reductions are estimated to be high yet (Elofsson, 2010). Therefore, the proposed supplementary measures such as harvesting of algae biomass are suggested to be applied in the water bodies of two neighbouring EU countries – Lithuania and Poland.

Responsibility for nutrient pollution is an international challenge and cooperation between countries on the whole-watershed scale should be applied. The project is focused on cross-border threats in order to reduce risks associated with nutrient pollution and mitigation of the consequences of undesirable algal blooms in inland water ecosystems. Although the project actions will be implemented on national scale by the partners from Lithuania and Poland, the demonstrated measures can be applied widely in the EU as well. The environmental and economic significance of harvesters operation on the European scale is related to the relatively easy replicability of proposed instruments to various types of aquatic ecosystems. The results will contribute to achieve the aims on water quality issues, which are expressed in the numerous EU Directives and explained in detail in Koreivienė et al. (2019). The guidelines based on testing and calculations of harvesters operation will provide strong evidence to commit decision-makers to implement technology and proposed measures on the regulation basis.

In order to reduce nutrient inputs, to achieve and maintain a good status of the Baltic Sea, several legislation documents have been adopted at the national level. Particularly, in 2017, the Government of the Republic of Lithuania approved the Water Sector Development Programme in 2017–2023 and its action plan, whereas in 2016, the Management Plan for the Vistula and Odra Rivers basin was adopted by the Polish Government. The following key factors that affect ecological status of the water bodies were pointed: i) diffuse pollution, the main driver is agricultural pollution loads; ii) point pollution, loads from dischargers of wastewater treatment plants (WWTPs), storm water (surface) runoff, and industrial wastewater in towns and settlements; iii) transboundary pollution coming from the neighbouring countries. The basic mitigation options and prevention measures that need to be implemented to reduce nitrogen losses from agricultural areas to surface and ground waters in order to comply with the requirements of 11 EU directives were highlighted. Unfortunately, information of improved reliability of the estimated effectiveness of mitigation measures is missing.

Four training seminars on the regional scale in LT and PL for the representatives of governmental institutions and municipalities' authorities, administrations of protected areas and other relevant stakeholders will be organized. These events in terms of such audience and expected outcomes will engage policy makers from other policy sectors to widen the impacts of the project on the regional scale.

Harvesting of algal biomass is also important on broader political context that goes beyond the laws of Lithuania, Poland and EU. For example, part of two river catchments (25% of the River Nemunas, 14% of the River Vistula) and the area of two largest transboundary lagoons of the Baltic Sea (74% of the Curonian Lagoon, 56% of the Vistula Lagoon) are located in the territories of the EU non-Member States that lead additional management issues. The special mutual cooperation agreements between the Ministry of Environment of Lithuania and the Ministry of Natural Resources and Environment Protection of the Republic of Belarus, and the Ministry of Natural Resources and Environment of the Russian Federation have been launched for the environment protection in the non-EU countries. Therefore, the suggested harvesting of algal blooms applied in transboundary water bodies will enable to reduce the load of pollutants from Belarus and the Russian Federation in the line with prepared project related with the use and protection of water bodies in the Nemunas River basin, which also support implementation of WFD.

Project idea suggests how to enlarge the sustainability of ecosystem services and is in agreement with the Resource Efficient Europe (COM (2011) 571) Strategy. Project covers many kinds of the resources as for instance energy, stocks of fish, water, biomass and biodiversity that are all under consumption pressure. The innovative solutions to increase the efficiency of resource use are highly necessary for the sustainable development of European economy. Possibilities to redesign waste biomass from cyanobacteria and macroalgae into valuable products that will support sustainable management of environmental resources, greater reuse, recycling and resource savings will be tested in the project. Developing new renewable resources coincide with the policy towards a low carbon economy and support minimising impacts on the water environment. The project 'Algae Service for LIFE' suggests solutions to reasonable use of finances and other resources and to provide people of the EU with improved services related to water quality. Project is essential on economy scale and seeks to promote best practice for sustainable use of the resources in circular economy to make a transition step towards a green economy. The suggested technology of combining ecological service and the reuse of the waste as a resource will proceed restoration of ecosystems and the waste close to zero.

Project results related to potential of converting algal biomass into bioproducts will be presented and discussed with stakeholders. It is expected to raise interest of business people to produce new ecological products that will have a socio-economic effect due to newly created job opportunities, provided natural health products for further use after project implementation. Executive summary with recommendations derived from the project activities will be prepared and used as a mean for communication towards national and the EU policy makers. Summary of the aim of the present project, results and outcomes will be distributed through direct communication and different social networks, conferences in the EU. Taking into account increasing awareness of harmful effects of synthetic compounds, we hope that project results related to the promotion of natural and safe bioproducts will contribute the tendency through direct communication the EU citizens' opinion, consumption patterns of private and public purchasers towards the usage of natural products. Project results will provide tested accurate information that will be included into the Life Cycle Assessment, and information on the costs of resource use will help guide business people decisions.

Networking with the other EU projects is an important part for disseminating results and exchange experience with nonparticipants of the project. The project idea relates to several EU projects that have recently been carried out or had previously been developed. We gain experience participating in the EU Cost CYANOCOST and EUALGAE projects and got to know the achievements of Life projects GISBLOOM, Life Stop CyanoBloom related to mitigation of harmful blooms. Currently, the Nature Research Centre has been cooperating with the researchers from Klaipėda University (LT) as the users of EOMORES Horizon 2020 project for the development of novel tool for survey of algal blooms using satellite images.

The consortium of project Partners. International team members, focusing on the current ecological issues of the environment and being skilled in different technical-applied solutions, jointly carry out the project. The project is implemented by the research institutes of the Nature Research Centre (LT) as a coordinating beneficiary, Adam Mickiewicz University in Poznan (PL) and the Institute of Nature Conservation, Polish Academy of Sciences (PL). Also, the business companies such as the Baltic Environment (LT) and Spila (LT), and the non-governmental organization the Nature Heritage Fund (LT) contribute significantly to the implementation of the project.

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ES LIFE PROGRAMOS „ALGAE SERVICE FOR LIFE“PROJEKTAS, SKIRTAS EKOLOGIŠKŲ BIOPRODUKTŲ IŠ MELSVABAKTERIŲ IR MAKRODUMBLIŲ BIOMASĖS PAIEŠKAI

Judita Koreivienė, Jūratė Karosienė, Jūratė Kasperovičienė, Ričardas Paškauskas, Bogusława Łęska, Radosław Pankiewicz, Loreta Juškaitė, Alvydas Zagorskis, Elźbieta Wilk-Woźniak, Vaidotas Valskys, Zenonas Gulbinas, Edward Walusiak, Wojciech Krzton, Dmitrij Morudov, Kostas Radzevičius, Ewa Treska, Łukasz Tabisz, Monika Papsdorf, Zuzanna Piotrowicz, Beata Messyasz

Santrauka

Europos Sąjungos finansuojamas LIFE programos „Algae Service for LIFE“ projektas siekia skatinti gerąją ekologinių paslaugų praktiką ir žiedinę ekonomiką, įgyvendinant inovatyvų kompleksą, susidedantį iš trijų susijusių elementų: i) specializuotų įrenginių perteklinei melsvabakterių ir makrodumblių biomasei surinkti sukūrimas ir gamyba; ii) metodikos, skirtos melsvabakterių ir makrodumblių santalkų vandens ekosistemose vertinimui nuotoliniais metodais, sukūrimas; iii) perteklinės dumblių biomasės panaudojimas ekologiškų bioproduktų gamybai, siekiant kompensuoti surinkimo kaštus. Straipsnyje aptariamos dumblių biomasės, surinktos vandens ekosistemose, panaudojimo galimybės perdirbant į bioproduktus. Projektu siekiama pademonstruoti tvarų aplinkos išteklių valdymą. Straipsnyje pabrėžiama projekto socio-ekonominė svarba ir pridėtinė vertė Europos Sąjungoje.