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Direct Use of Geothermal Resources for Circular Food Production †

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Abstract: The objectives of the work are to increase the direct use of geothermal resources for circular food production systems. The focus is on circular agricultural production processes: combining recirculating aquaculture systems and hydroponics into one system, including water treatment and waste recovery processes. The main outputs are vegetables, fish, fertilizers and potentially, algae and biogas. These outputs can generate revenue streams that can cover the costs of heat extraction while supporting viable businesses. The results and conclusions from a pilot case that was conducted in Iceland in recent years are presented, and the next steps are discussed. The pilot setup is now in the process of expansion to a semi-commercial production unit. However, there are still scientific, technical and commercial challenges to be solved. The scientific challenges are interdisciplinary and relate mainly to the optimization of the overall production system. Optimization involves creating good environmental conditions for each production unit while maintaining optimal oxygen, carbon dioxide, relevant pH and temperature levels and supplying all necessary nutrients. Additionally, accumulation of salts or other unwanted substances must be prevented. The primary technical challenges are to develop the circular food production system for optimized production while controlling the expenditure of energy, water, nutrients and manpower resources. Optimization also involves careful choices of species and the integration of new ideas into the value chain, both of which increase the synergy between the different components of the system. Furthermore, energy efficiency needs to be improved through using excess heat for other parts of the system and developing enhanced heating and cooling cycles. The aim is to transform the semi-commercial unit into a showcase model for solving commercial challenges while presenting a feasible business model for installing and operating a geothermal well for circular food production, making the most use of all available resources, securing optimum production conditions and minimizing waste.

Keywords: direct use; geothermal; aquaculture; hydroponics; aquaponics; feasibility

1. Introduction

Direct use of geothermal energy for aquaculture, agriculture and the food industry offers new and considerable opportunities, both globally and within Europe. Currently, geothermal energy is mainly used for residential heating and electricity generation. However, combining the use of geothermal resources and the development of productive, eco-innovative and resource-efficient food production and food processing methods creates a viable business opportunity. The main goal of the work is to provide valuable showcases on how low-temperature geothermal energy (temperatures below 150 °C at 1 km depth) may be used for food production and how establishing eco-innovative food production and processing with a low carbon footprint and minimal environmental impact is possible.

Low-temperature geothermal energy is an underutilized natural resource found in several places in Europe. There is an increased interest in using this resource for sustainable food production, which is supported by the growing worldwide geothermal networks (International Geothermal Association, www.geothermal-energy.org; Geothermal Energy Association, www.geo-energy.org; European Geothermal Energy Council, www.egec.org) and the increased focus on geothermal resources from policy makers. Iceland provides a unique opportunity for creating showcases and learning programmes due to the experience and knowledge in the field based on the abundant geothermal resources in the country. A zero-waste food production unit using 100% renewable energy and creating innovative by-products will address EU-wide challenges and strengthen Europe's competitiveness on the world's stage. It is certain that aquaculture, horticulture and other food production and processing will have to develop towards a closed nutrient loop, improved energy efficiency and reduced water use.

Interest in circular food production is increasing because of the environmental impact of food production and the rapidly increasing world population [1]. Rising energy costs and dwindling natural resources, such as phosphorus and water [2], are forcing the world to act and change present-day food production systems from linear production lines to circular structures. In Europe, a few small and medium-sized enterprises (SMEs) have started integrated production of fish and vegetables, known as aquaponics, on commercial and semi-commercial scales. The nutrient-rich waste water from the aquaculture is used as fertilizer for the plants [3,4].

The main outputs of the aquaponics production are vegetables, fish and fertilizers. Most aquaponics systems operate with Nile tilapia (*Oreochromis niloticus*) and leafy greens such as lettuces, basil and mint, although a wide range of plants and fish species have been tested in such systems with good results [5].

2. Pilot Case

A few aquaponics companies that focus on implementing circular food production have been emerging in Europe. However, large commercial-scale units have yet to be developed. The main aim of this work is to provide showcases for the direct use of geothermal energy in increasing food production in highly productive circular systems.

Between 2018 and 2021, a research plant for circular food production in the Netherlands and a demonstration plant in Iceland will be designed, built and operated. This plan is based on results from earlier research, development and innovation (RDI) projects. The low-temperature geothermal resources in Iceland are <150 °C at a depth of 1 km and <80 °C at a depth of about 2 km in the Netherlands. The plants will be used to validate mathematical models for predicting the best combinations of steps in a thermal treatment train, depending on climatic conditions. The models will also be used to design systems using geothermal heat in Slovenia. Knowledge-sharing and B2B activities will be done to foster inclusion of the proposed technology in existing and upcoming geothermal heat installations in other geothermal areas in Europe and worldwide. These activities also include economic and social aspects of the sustainable models developed.

Food production in Europe requires further steps in reducing the carbon footprint. Currently, the sectors of greenhouse horticulture and aquaculture are major users of heat. Integrating these two sectors in a circular, zero-waste production system with direct use of geothermal energy can lead to better and more efficient use of heat, water and nutrients. The pilot units showcase the opportunities available when applying sustainable geothermal energy to increase food production in highly productive systems and improving energy-efficiency through optimal configuration via species choice, cultivation strategies and targeted technologies.

The results achieved from the operation of the pilot units [3] and other EU-funded projects [6,7] show that the circular models offer resource efficient food production by closing the water cycle for re-use of nutrients—producing fish and plants in an integrated system. However, due to the differences in optimum environmental parameters for the fish and plants, there is a need to decouple the two production systems in competitive commercial-scale systems (Figure 1). The decoupling means that two loops are made, one for the fish and another for the plant system and the water is not necessarily returned from the plants to the fish. By doing this, the pH of the waste water from the fish system can be lowered to optimal levels for the plants, and other environmental parameters can be adjusted, thus ensuring good product quality and making the commercial production competitive regarding best practices.

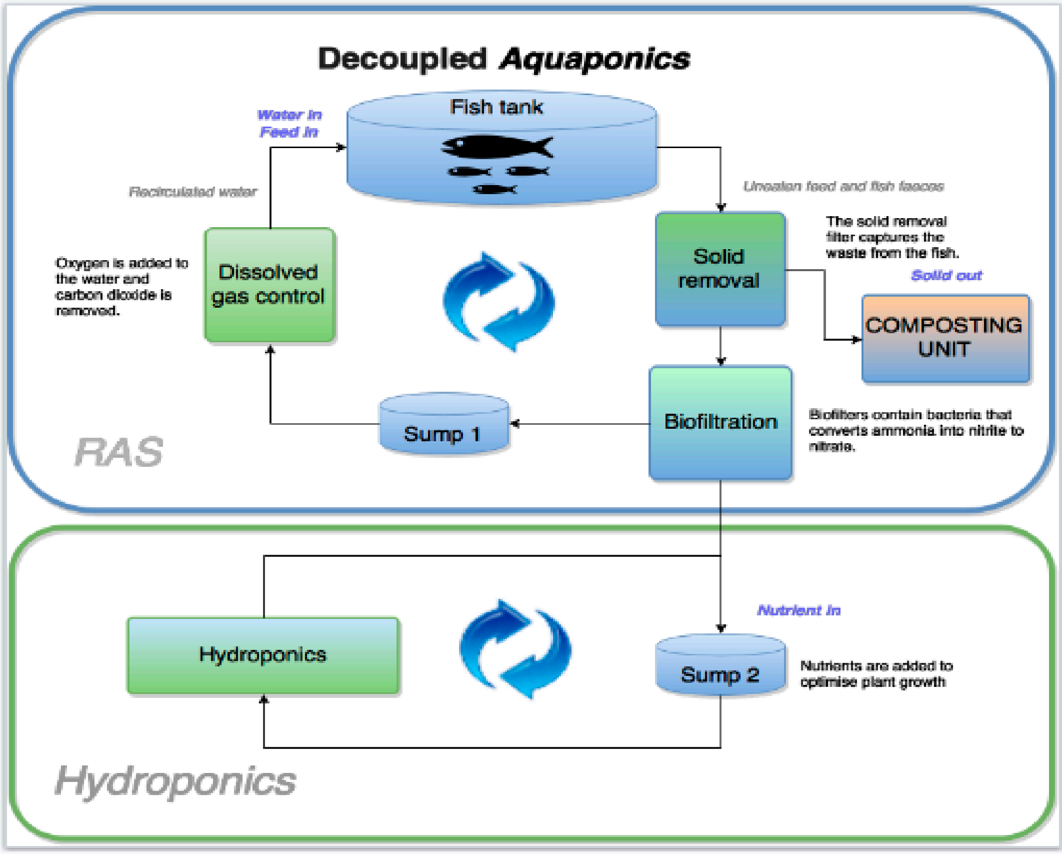

Figure 1. Schematic diagram of a decoupled aquaponic system [3].

The scientific challenges are interdisciplinary, and they include producing complex models with enough predictive power and encountering unforeseen interactions between the different components of the thermal treatment train. Other challenges include securing good environmental conditions with all the necessary macro- and micro-nutrients and appropriate pH, oxygen, carbon dioxide and temperature levels for each production unit, along with preventing the accumulation of salts or other unwanted substances.

Primarily, the technical challenges surround developing the circular food production system for the optimized production and consumption of resources such as energy, water, nutrients and manpower. These challenges also include the choice of species and increasing the synergies between the different components of the system through the integration of new ideas into the value chain. Also, energy efficiency needs to be improved by finding uses for waste heat and developing improved heating and cooling cycles. The food production cycle needs to include monitoring and control of all production units and efficient, good quality food production. In decoupled systems, the water flow is divided into two circulation systems to ensure optimal environmental conditions for both the fish and plant units while closing the water and nutrient cycles. There is also a need to close the circle through better use of the sludge-producing valuable by-products.

The commercial challenges are to build feasible business cases for the installation and operation of geothermal wells for horticulture and/or aquaculture. Some pathways to this include more-efficient use of thermal energy use through cascading, establishing more balanced base loads, integration with other sustainable energy sources, and designing and developing circular production processes that make the best use of all available resources while securing optimum production conditions and minimizing waste. This will support the integration of geothermal energy sources and the operation of circular production systems by boosting the use of available geothermal sources whilst providing attractive business models that can generate profitable investments.

Several ongoing studies are aiming to improve the economy of small-scale systems through including value-added products and services with the aquaponics. This includes education, training, experience-based tourism, restaurant services, product processing (drying, canning) and even designer products. Several tests have also been carried out using the sludge for fertilizer production or to feed crayfish, worms and insects.

The social awareness of aquaponics and consumer acceptance also has been investigated. The results show that people's feelings are generally positive toward sustainable and local food production that is free from antibiotics, pesticides and herbicides. Although aquaponics is not well-understood by consumers, 17 percent of the respondents were willing to pay more for aquaponic products when the concept had been explained [8].

3. Discussion

There is a need to showcase cost- and energy-efficient integrated systems that combine the direct use of sustainable geothermal energy in cost-effective integrated aquaculture and horticulture activities. This need also includes added processing along the value-chain and the use of the by-products generated in the production from waste.

The circular production units in Iceland and the Netherlands are meant to be valuable models that will provide innovative concepts that illustrate how to increase the economic viability of the geothermal heat infrastructure.

The focus is on circular agricultural production processes, water treatment and waste recovery processes operating synergistically as circular food production systems. These processes can be operated in series as a thermal treatment train that extracts as much heat as possible from geothermal well installations. Specifically, this thermal treatment train will be comprised sequentially of horticultural greenhouses, fish farming systems and wastewater treatment and nutrient recovery systems. All will have a variety of heating requirements throughout the year, but they will be able to use the waste heat from the previous steps in the treatment train. The main outcome of such a setup will be an increased utilization of existing geothermal well capacity, along with a concomitant decrease in operating costs. The main outputs of the thermal treatment trains will be vegetables, fish, fertilizers and potentially, algae and biogas.

The ultimate goal is to support increased use of geothermal energy worldwide, while focusing on food production and other bio-based businesses.

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