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Direct Use of Geothermal Resources for Sustainable Circular Food Production – Results from Geofood Project

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ABSTRACT

The Geofood project showcases the opportunities of direct use of geothermal energy to increase sustainable food production. The overall purposes of Geofood are 1) to develop a geothermal well optimization model that considers greenhouses and fish farms for heat extraction 2) to design and build a research system to validate such model and 3) to design and optimize a demonstration plant with direct use of geothermal energy for circular food production techniques. The Geofood project also plans to disseminate the results to other geothermal areas in Europe and beyond.

Geothermal energy is already used several places in Europe as a sustainable energy source for food production, including horticulture, aquaculture and food processing. However, there are still substantial opportunities to increase the direct use of geothermal resources for food production and also to pave the way for circular food production techniques. In this study recent developments in aquaponics (the combination of aquaculture and hydroponics) are used as an example on how effluents from one production can be used as a resource for another, thus mimicking nature and minimizing environmental impact.

1. INTRODUCTION

The Geofood project is part of GEOTHERMICA (www.geothermica.eu) and addresses the thematic area: Supply and smart integration into the energy system. Geofood works toward innovative concepts illustrating how to increase the economic viability of geothermal heat infrastructure using circular food production systems optimizing the use of energy, water, nutrients, man power and other resources. Thus, the focus is on circular agricultural production processes, water treatment and waste recovery processes. Specifically, the circular production units are comprised by sequence of horticultural greenhouses, fish farming systems, wastewater treatment and nutrient recovery systems which have a variety of heating requirements through the year and that are able to use the waste heat from each previous step in the treatment train. This will lead to increased utilization of existing geothermal well capacity with a concomitant decrease in its operating costs. The thermal treatment trains' main outputs generating revenue streams are vegetables, fish, fertilizers and potentially algae and biogas.

A research plant has been built at Wageningen University & Research (WUR) in Bleiswijk in the Netherlands. The recirculation aquaculture system (RAS) is in total 55 m^3, based on three large and five smaller fish tanks on approximately 150 m^2, including a mechanical filter system, biofilter and both aerobic and anaerobic digestion. The RAS is connected to greenhouse production areas at WUR making this the largest and most modern aquaponics research system in Europe. The system has been under tests during recent months and monitoring is starting up.

Based on the design in Bleiswijk and earlier aquaponics research (Thorarinsdottir et al., 2015; Goddek et al., 2015; Thorarinsdottir et al, 2017; Kledal and Thorarinsdottir, 2017) a demonstration plant will be constructed in Iceland. The demonstration will be connected also to the emerging urban farming through the COST Action network CA17133 Circular City (www.circular-city.eu) and the development of educational and experience tourism (Milicic et al., 2017; Turnsek et al., 2020).

Both plants will be used to validate mathematical models which will predict the best combinations of steps in a thermal treatment train depending on climatic conditions. The model can be used to design systems using geothermal heat under different conditions. In close collaboration between the multidisciplinary consortium members, knowledge sharing and B2B activities is carried out to foster the inclusion of the Geofood technology to existing and upcoming geothermal heat installations. The Geofood consortium put emphasis on dissemination of the results focusing on geothermal areas in Europe and worldwide. The dissemination and communication cover technological, economic and social aspects of the sustainable models developed in Geofood.

2. DIRECT USE OF GEOTHERMAL ENERGY FOR FOOD PRODUCTION

Reliable sources of renewable energy are becoming increasingly important for sustainable future food production following growing concerns about greenhouse gas emissions and climate changes. Geothermal energy has been used with success for electricity production, house heating and cooling, snow melting, swimming, bathing, cooking, domestic hot water, aquaculture, horticulture, food processing and other industrial processes. The use of geothermal energy in the agrifood domain has been promoted by several reports, e.g. as an opportunity for promoting food security and economic development in the developing world (Van Nguyen et al., 2015), however, its global potential remains underutilized.

Geothermal areas are per definition divided into high temperature fields (>200°C at 1 km depth) and low temperature fields (<150°C at 1 km depth). Whereas high temperature areas are found in active volcanic zones, low temperature fields can be quite widely found in continental areas (Gupta and Roy, 2007). High temperatures fields are explored and used for production of electricity and combined heat and power production, while low temperature geothermal fields fit well for direct use for e.g. fish farming, horticulture and food processing (Malloy, 2010). At least 24 countries use geothermal power to generate electricity, the top ten based on generation in the period 1990-2010 are El Salvador, Iceland, Indonesia, Italy, Japan, Kenya, Mexico, New Zealand, Philippines and United States (Van Nguyen et al., 2015). Even more interesting in the context of this paper is the direct use of geothermal energy, mostly from moderate temperature fields (20-150°C). The top ten countries for direct use of geothermal energy in 2011 were China, United States, Sweden, Turkey, Norway, Iceland, Japan, France, Germany and the Netherlands (Lund, et al., 2011). The fields are reached via 1,000-3,000 deep wells. The number of countries using geothermal resources for direct use is at least 75 around the world and is increasing steadily (Mburu, 2012; Rajver et al., 2016). Many of them work within agricultural and agro-industrial processes and more than 30 countries worldwide use geothermal energy to heat greenhouses for the production of food and flowers, e.g. the European countries Iceland, Turkey, Greece, Romania, Russia, Hungary, Netherlands and Slovenia. In some of the countries the development of geothermal energy use is supported by the government and the European Union has also put direct use of geothermal energy on the agenda. This is not surprising as direct use of geothermal energy for aquaculture, agriculture and the food industry in general offers large unrevealed opportunities in Europe and globally.

The three collaborating countries in the Geofood project, Iceland, the Netherlands and Slovenia have all developed the direct use of geothermal resources. However, the potential is in all countries underutilized. In Iceland the industrial use and the use for agriculture (horticulture and fish farming) can be increased substantially. Today these uses account for less than 10% of the total use of geothermal sources in Iceland (Fig. 1). All commercial greenhouses in Iceland are heated with geothermal energy, but all horticulture companies in Iceland are relatively small, in average 2,000 m^2 production area (Fig. 2), compared with competitive companies in Europe with several hectares each. The largest greenhouse company in Iceland has 12,000 m^2 production area after two big expansions during the last 6-7 years. For comparison the average greenhouse size in the Netherlands has increased from 12,000 m^2 in the year 2000 to 37,000 m^2 in 2016 and is still expanding.

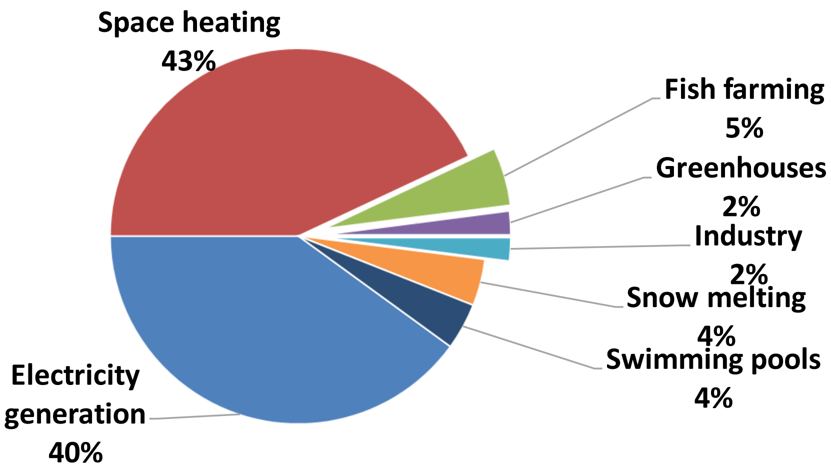

Figure 1: The use of geothermal energy in Iceland (Orkustofnun 2017).

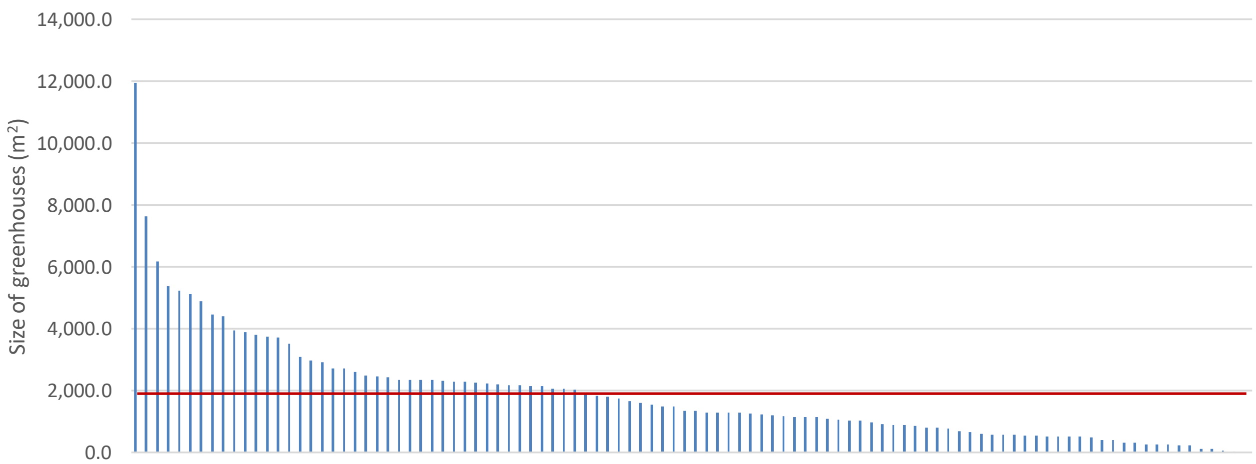

Figure 2: The size of greenhouses (number of farms is 101) in Iceland in m^2 (average size is 2,000 m^2) (Orkustofnun 2017).

In the Netherlands, the first greenhouse company started to drill for geothermal heat in 2006. Soon after this first project, Ammerlaan TGI developed its own geothermal well. As the energy from the well is far more than Ammerlaan could use for its own greenhouse operation, the company supplies geothermal heat to greenhouse companies in the neighborhood, as well as to a school and a gym. Ammerlaan and other geothermal well operators have faced several severe problems, among other with oil and gas in the geothermal fluid. Dutch geothermal operators started the Dutch Association of Geothermal Operators (DAGO) and together with the Dutch energy transition programme for greenhouse horticulture "Kas als Energiebron", they formulated an R&D agenda. A lot of technical issues like drilling techniques are on this agenda, but also options for the use of excess heat (www.kasalenergiebron.nl).

Slovenia is a country with a very high geothermal energy pool which is unfortunately not yet used enough for innovative food production. In Slovenia the direct use of geothermal energy is mainly attributed to space heating, bathing and swimming pools (Rajver et al., 2015; Rajver and Lapanie, 2005). The use has increased slowly with new boreholes. The direct use for greenhouses, soil heating as well as the use of heat pumps (GHP) has been developing during recent years and it is expected that the use of GHP units will continue.

There are currently only two large greenhouse producers in Slovenia that are using geothermal energy: Ocean Orchids, a grower of orchids and Paradajz, a hydroponic tomato grower both of which are located in the Eastern region of Prekmurje. There was a third producer in the municipality of Brežice owned by Terme Čatež with an annual tomato production of 115 tonnes but this production was recently closed down. The position of the Municipality of Brežice in energy structure of Slovenia is extremely high due to both geothermal energy and the newly established hydropower plant on the Sava river (2017). There is a need to investigate further the options of extending the use of geothermal energy for innovative food production, and inclusion of the latest state of the art knowledge and results.

Geofood will support direct use of geothermal energy for eco-friendly food production by offering new solutions to the emerging environmental challenges and innovative ideas to create new business opportunities based on circular integrated food production with nutrient recovery, closing water cycles and making use of the underutilized renewable geothermal energy source, as well as support further research and innovation, training and education. Geofood develops and tests a modelled approach to integrate energy requirements at hour-level (of aquaculture and horticulture) for optimal use of a geothermic well. The model is developed primarily for the chosen crops and fish species in this project, but can be adapted to different climate regions, choice of species and crops and geothermic well temperatures.

3. DEVELOPMENT OF AQUAPONICS

Circular production systems are receiving increased interest to obtain better use of resources and minimize waste piling up in the environment. Combining direct use of geothermal heat to circular food production systems provide a unique platform for increased use of geothermal energy worldwide.

Aquaponics is the combination of hydroponics and Recirculating Aquaculture Systems (RAS). The nutrients from the fish farming are used as fertilizer for the plants. Many small scale research and hobby systems exist globally, and the interest for implementing large scale production units is increasing (Thorarinsdottir et al., 2015).

A simple aquaponic system (Figure 3) consists of the RAS unit for the fish and the hydroponic unit for the plants. The RAS includes the fish tanks, the solids removal, the biofilter, and optionally a sump (Thorarinsdottir et al., 2015). In RAS, it is important to maintain good water quality for the fish by removing waste solids and dissolved nutrients that would become toxic to the fish when in high concentrations. The release of large amounts of nutrients into the environment can cause eutrophication, leading to imbalances in the ecosystem such as algal bloom and changes in the local fauna. Conversely, in hydroponics, it is beneficial to keep high nutrient concentrations for good growth and health of the plants. Combining these two production systems thus reduces nutrient waste through reuse, making the food production system sustainable.

The effluent from the fish tanks is mechanically filtered removing suspended solids. This is a very important step as accumulated organic particles will lower the dissolved oxygen concentration in the water and can lead to reduced effectiveness of the biofilter. After removal, the solids can be mineralized to release nutrients through aerobic or anaerobic digestion and then introduced into the hydroponic system, where the released nutrients can be of further use for the plant growth.

The biological conversion of ammonia in the fish waste water to nitrate takes place in the biofilter via a two-step bacterial nitrification. In the first step, ammonia is converted to nitrite, and in the second step nitrite is converted to nitrate. Ammonia and nitrite are toxic for the fish even in low concentrations. The nitrate is used for plant growth in the hydroponic unit. The main types of hydroponic setups are deep water culture (DWC), nutrient film technique (NFT) and flood-and-drain (F&D) systems, and these differ mostly in the method of irrigation.

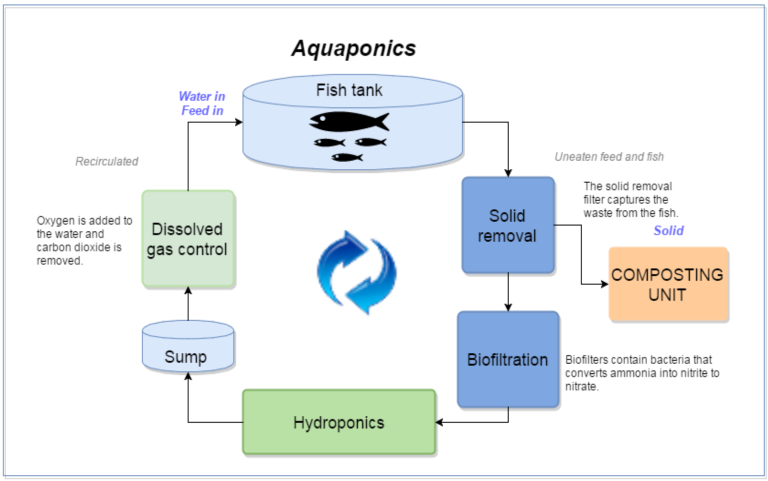

Figure 3: Schematic diagram of a simple aquaponic system (Thorarinsdottir et al., 2015).

A few innovative companies, focusing on a circular food production system, have been emerging in Europe, however, many of those have proven to be unsuccessful and several new companies have given up and closed their operations in the early days never becoming profitable (Milicic et al., 2016). However, the Geofood team believes that large commercial scale units are still to be developed. There is a need to improve the technology used, the energy efficiency and also close the circle with better use of waste water and sludge producing valuable by-products.

The consortium partners from Iceland ran together with companies in Denmark and Spain the EcoPonics project in the period 2013-2016 supported by H2020 EASME (Executive Agency for SMEs) (former EcoInnovation). The aim was to develop aquaponics pilot units for commercial aquaponics. The project resulted in the largest commercial aquaponics system in Europe (6,000 m^2) run by the company NERBREEN in Spain (Thorarinsdottir et al., 2015). One of the main results from the EcoPonics project as well as from the EU-funded Inapro project (2014-2017) was to move towards "decoupled systems" (Thorarinsdottir et al., 2015; Kloas et al., 2015; Goddek et al., 2016) where the water flow is divided into two circulation systems for the fish and for the plant, respectively (Fig. 4). This is to ensure optimal environmental conditions for both the fish and the plant units as well as closing water and nutrient cycles.

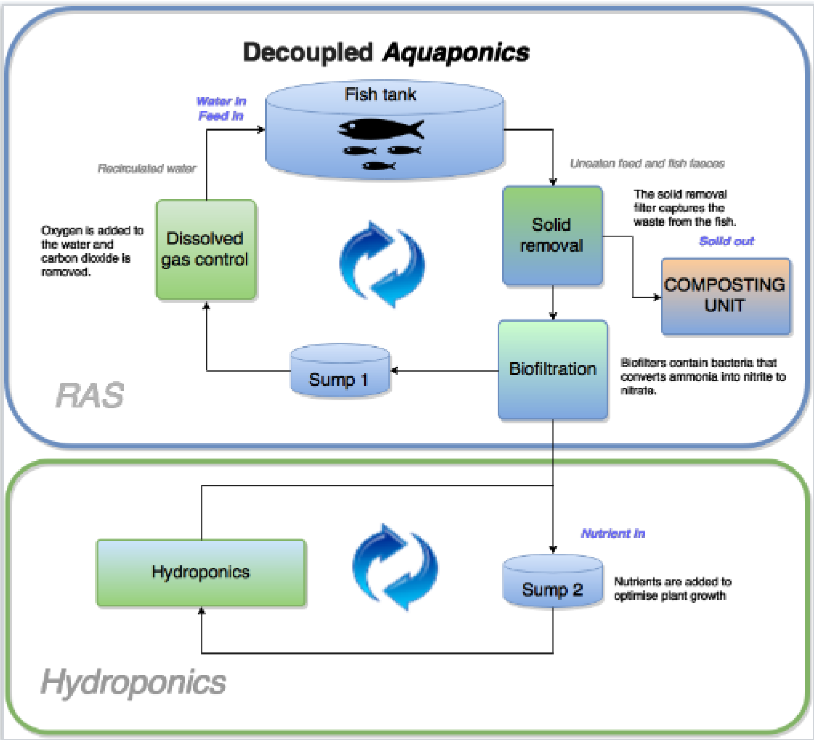

Figure 4: Schematic diagram of a decoupled aquaponic system (Thorarinsdottir et al., 2015).

4. GEOFOOD SHOWCASES

The Geofood showcase implemented at the WUR greenhouse facilities in the Netherlands provides exceptional infrastructure to carry out the necessary tests and R&D work for further development. The RAS is based on the state-of-art technology for landbased fish farms and includes all necessary monitoring and alarm systems. Moreover, the system includes both anaerobic and aerobic digestion tanks. Connecting the RAS to the modern greenhouses at WUR creates a unique research and development environment for testing and implementing future innovative ideas.

The showcase to be implemented in Iceland will include education about the geothermal resources available worldwide and how they have been used in Iceland with focus on food production, horticulture, aquaculture and processing. Also, the emerging interest in local food production even within cities will be followed and investigated. A few startup companies are operating in Reykjavik in this field producing lettuces and microgreens in indoor systems.

Geofood has developed a model for optimizing the energy use and the results will be compared with real values from monitoring in the first Geofood setup during the next months. The monitoring will include the main nutrient values and the productiveness in the aquaculture and horticulture units, respectively. In addition, comparisons will be done in the aerobic and anaerobic digestion tanks on effectiveness and energy use.

5. ADDITIONAL VALUE

The general trend in Iceland and the Netherlands is toward larger greenhouse companies. In Iceland, especially, there is clearly a room for new innovative horticulture companies. Vegetables and fruits are mainly imported, even tomatoes and lettuces that can easily be produced in the country. A few attempts have been carried out for building large greenhouse companies with export opportunities. The business plans so far have mainly focused on export of fresh tomatoes and they have not been realized. Additional value by adding drying and/or canning to the process, making increased use of the geothermal resources available and increasing the value and shelf life of the products should be considered. Other higher value products both for the domestic market as well as for export are also discussed and tests have been carried out in Iceland on using fish waste water for algae production (Lugo et al., 2019).

Expanding the greenhouse business from a production company to include also tourism has shown to be successful. People like to learn about the production and taste the products while they relax in a tropical environment inside the greenhouses. The University of Maribor has made a comparison on four tomato greenhouse companies in Iceland, the Netherlands and Slovenia, respectively. All companies welcome visitors, however one of them only visitors from the industry and student groups. All the companies are successful with both their production and the visiting parts, educating on the use of geothermal resources and about their products and providing a good experience for visitors. The results show that there is even room for more innovation adding escapism and entertainment dimensions that could contribute to an overall improved method of sharing knowledge about geothermal resources (Turnsek et al., 2020).

6. CONCLUSION

As shown in this article the unused potential for direct use of geothermal energy for food production is substantial, not only in Europe but globally. Moreover, it is argued that circular food production methodologies have been developing in recent years with promising results. Although many startup companies have failed, it has often been due to small scale, lack of best practice knowledge and technology and/or lack of financial capacity. By combining increased use of sustainable geothermal resources with the implementation of circular technologies a new platform is emerging providing novel solutions to future food production. Geofood presents the results by real showcases and has now the largest and most modern research unit in Europe within the aquaponics technology. This provides valuable potential for future improvements and has already led to the development of an energy efficiency model combining aquaculture into greenhouse farming. This can be expanded also to include food processing. The Geofood team has also integrated additional values through education and experience tourism. A few farms in Europe can proudly show the successful addition of educational tourism providing powerful education and well-being to their guests. However, this can be expanded further by emphasizing escapism and entertainment dimensions in a bolder way adding fun and lively self-expressing to the experience design (Turnsek et al., 2020).

Geofood joins people from various industries, with multidisciplinary skills and different backgrounds leading to novel solutions combining technical, social and economic advantages. The team is certain that novel circular food production technologies in combination with increased use of geothermal resources in Europe and worldwide will provide one of the important pillars to a more sustainable modern industrial farming in the future taking different shapes and forms and including various aspects of innovative developments.

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