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Accelerating geothermal heat adoption in the agri-food sector

Key lessons and recommendations

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ABOUT IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future, and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity.

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Predominantly known for power generation and district heating, geothermal energy can also be used in its primary form (*i.e.* heat) in the agri-food sector – for instance in greenhouses or for food drying and processing. Using it for such purposes can help increase food availability, reduce dependency on fossil fuels, protect against price volatility and diminish harmful emissions from the sector. Furthermore, it can significantly reduce food waste.

Several geothermal applications in food processing and agriculture require low temperatures and can therefore be deployed in areas where the geothermal resources would not be suitable for power generation. These applications could increase the number of countries and regions that could benefit from such indigenous and renewable energy source. Despite its promising potential and increasing interest from policy makers and key stakeholders, direct use of geothermal heat in food-related applications across the world is still rather limited.

Against this background, this publication aims to increase awareness, share experiences and lessons, and provide recommendations for expanding geothermal heat use in the agri-food sector. The analysis in this document suggests the following six broad critical factors.

- The existence of legislation awarding rights to develop geothermal resources beyond power generation with clear and transparent licensing procedures and, where possible, streamlined for smaller-scale projects.
- The establishment of tailored policy instruments for geothermal heat, notably to share/mitigate the risks associated with the initial and more capital intensive phases of a project.
- The integration of geothermal plans into industrial and rural development strategies and the involvement of local communities and entrepreneurs. These strategies may include measures aiming to attract new productive activities around geothermal areas.
- In new and emerging markets, support provided to feasibility studies and pilot projects to improve the understanding of the geology and assess the heat demand profile of productive activities located near the geothermal resources.
- Capacity building and training of the local workforce in food production and processing (*e.g.* in dryer use) to ensure efficient operations and catalyse the wider deployment of geothermal in agri-food projects.
- Wise management of geothermal resources to ensure compatibility with the environment and long-term economic sustainability.

Countries aiming to develop geothermal energy applications for food and agriculture may benefit from international platforms such as the Global Geothermal Alliance to share experiences and insights on technical, policy, regulatory and financial solutions and to explore opportunities for co-operation.

This publication has been developed within the framework of the Knowledge Sharing Platform of the Global Geothermal Alliance.

INTRODUCTION

Renewable energy has experienced a remarkable growth over the last decade driven by innovation, increased competition and policy support in a growing number of countries. While there has been major progress in the power sector, enormous opportunities exist to deploy renewable energy in end-use sectors. The heating sector is particularly relevant as it accounted for more than half of total final energy consumption in 2015, of which over 70% originates from burning fossil fuels (IRENA, IEA and REN21, 2018).

Geothermal energy is not dependent on weather conditions and has very high capacity factors; hence it can play a crucial role in the global energy transformation, including in the heating sector. Across the world, 25 countries had geothermal power plants in operation in 2017 representing a total installed capacity of 13 gigawatts electric (GWe) (IRENA, 2018). Meanwhile, 82 countries were reported to have geothermal heat (or direct use) projects representing a total installed capacity of around 70 GW thermal at the end of 2014 (Lund and Boyd, 2015).

The estimated thermal energy used from geothermal sources amounts to 587,786 terajoules (TJ) per year, of which more than half is for heating and cooling from ground source heat pumps[1], 20% for bathing and swimming, 15% for space heating without heat pumps, 5% for greenhouses and open ground heating, 2% for aquaculture ponds, 1.8% for industrial process heating, 0.4% for snow melting and cooling, 0.3% for agricultural drying, and 0.2% for other uses (Lund and Boyd, 2015). The potential of geothermal energy stored in aquifers[2] (the focus of this report) remains largely untapped. Estimates suggest that less than one thousandth of the technical potential worldwide is currently exploited (Limberger et al., 2018).

The wider adoption of all geothermal energy applications is restricted by a variety of barriers. The most common obstacles in many countries with promising potential include, for instance, high upfront investment, risk related to the appraisal of geothermal resources, inadequate policy and regulatory frameworks, and a shortage of qualified workforce. In addition, transporting geothermal heat long distances from geothermal wells may not be economically viable. Hence the bankability of geothermal direct use projects may be undermined by the need to find either a single large or several smaller customers located nearby and presenting heat demand profiles matching the temperatures of the geothermal resource.

Given this background, international co-operation can help increase awareness, strengthen enabling frameworks, and address technology, policy, financial and capacity building challenges. The Florence Declaration, adopted at the first High-Level Conference of the Global Geothermal Alliance held in Italy in September 2017 (see Box 1), encouraged the expansion of information and facilitation of knowledge-sharing on all geothermal energy applications, including the agri-food sector.

To this end, IRENA, the Ministry for Foreign Affairs of Iceland, and the Iceland Geothermal Cluster convened experts and policy makers at a workshop in Iceland in April 2018 entitled "Geothermal Direct Utilisation and Food Security". Discussions and case studies from the workshop form the basis of this publication, which aims to share experiences and provide direction to scale up the deployment of geothermal heat for agri-food industries. This report is concerned with areas in which geothermal can replace fossil fuels, as well as areas lacking access to modern energy services. It complements "Uses of Geothermal Energy in Food and Agriculture – opportunities for Developing Countries", a report produced in 2015 by the Food and Agricultural Organization of the United Nations (FAO) (Van Nguyen et al., 2015).

This document is structured as follows: Section 1 briefly introduces the energy-food nexus and the role of geothermal energy; Section 2 presents an overview of the geothermal applications in the agri-food value chain; and Section 3 looks at the experience and lessons from selected countries worldwide. Finally, Section 4 puts forward broad recommendations to governments, development partners and key stakeholders committed to supporting geothermal development in the agri-food sector.

1 Ground source heat pumps, also known as geothermal heat pumps, exploit normal earth conditions, even only 3-15 °C, at depths ranging from one metre (m) to 400 m. This is used throughout the year for space heating and cooling and hot sanitary water in buildings or other applications (DiPippo, 2016; heatunderyourfeet.eu, n.d.).

2 Heat pumps are increasingly employed to boost the temperature of low temperature geothermal fluids. The hybrid district heating and cooling system in Paris Saclay is one example, containing seven semi-centralised heat pump stations and two geothermal wells reaching a depth of 700 m and temperatures of 30°C (see Galindo Fernández et. al., 2016).

BOX 1. GLOBAL GEOTHERMAL ALLIANCE AND OUTCOMES OF THE FLORENCE HIGH-LEVEL CONFERENCE

Launched in December 2015 at COP21, the Global Geothermal Alliance provides an inclusive and neutral multi-stakeholder platform for enhanced dialogue, co-operation and co-ordinated action among public, private, intergovernmental and non-governmental actors that share a common vision for accelerating the deployment of geothermal energy for power generation and direct use.

Co-ordinated by IRENA, the Global Geothermal Alliance aims to:

- Foster an enabling environment to attract investments in geothermal energy.
- Provide customised support to regions and countries with geothermal market potential.
- Facilitate the exchange of insights and experience among key stakeholders along the geothermal value chain.
- Identify and promote models for sharing and mitigating risks to attract private investment and integrate geothermal facilities into energy markets.
- Promote the visibility of geothermal energy in the global energy and climate debates.

As of December 2018, the Alliance has 80 member countries and partner institutions from geothermal industry, development partners, international finance institutions and academia.

To facilitate knowledge-sharing and define the way forward to accelerate the deployment of geothermal energy worldwide, the Government of Italy and IRENA organised the Alliance's first High-Level Conference in September 2017 in Florence, Italy. The event represented the largest ministerial gathering dedicated to geothermal energy development to date and was attended by 230 high-level public, intergovernmental, non-governmental and private sector representatives. Through the Florence Declaration – an outcome of the meeting – Global Geothermal Alliance members reaffirmed their commitment to work together to identify and implement measures that will significantly increase the speed of geothermal energy development around the world[3].

3 Further information available at www.globalgeothermalalliance.org.

The key messages from the 2017 High-Level Conference are set out below.

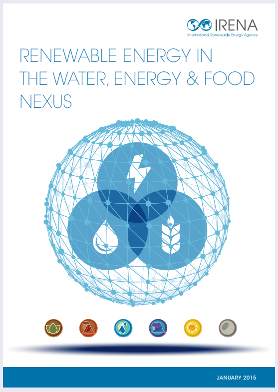
- Due to technology advances, geothermal energy is becoming technically feasible and economically viable beyond traditional geothermal areas. However, to fully appreciate the contribution of geothermal energy to local development, there is a need to look beyond electrical use only and support all its applications. This includes end-use sectors such as heating in industry, agriculture, buildings etc.
- As with other renewable energy technologies, there is no one-size-fits-all approach that guarantees the successful deployment of geothermal energy. Experience demonstrates that a combination of different policy and financial instruments may be required at different stages of market and technology development that should be tailored to local conditions, market maturity and type of applications.
- Sound resource assessment and innovative risk mitigation mechanisms can play a key role in reducing real or perceived uncertainty during the early and riskiest phases of geothermal projects. In addition, transparent licensing procedures must be put in place.
- Constructive exchange and strong co-operation between industry and governments as well as between contiguous industrial sectors can enable cross-sectorial synergies and contribute to cost reduction, especially for drilling.
- Together with the adoption of best industry practice, regulation can improve sustainability related to the use of geothermal resources. The early involvement of local communities can support and increase the social acceptance of geothermal projects.
- There is huge untapped geothermal potential in many small islands in the Caribbean and South Pacific as well as Comoros in the Indian Ocean. However, more research is needed to devise appropriate solutions that overcome unique barriers arising from isolation, poor interconnection and a small economy.
- Training and capacity building programmes are key to developing a critical mass of skilled professionals and institutional capacity. The expansion of a specialised workforce will contribute to satisfying expected growing demand from the geothermal industry.
- The Alliance can play a crucial role as a platform for sharing experiences, allowing expertise to flow and mobilising international capital. It should encourage the creation of geothermal practitioner groups to facilitate peer-to-peer co-operation and be an open source model to disseminate information, specific lessons on policy and regulation, and technology developments.

1. THE ENERGY-FOOD NEXUS

The interlinkage between energy and food is key when discussing major global trends such as growing population, poverty and climate change. The energy-food nexus mostly concerns the use of energy in the food supply chain, including food production, harvesting, processing, storage, transportation, retail, preparation and cooking. Indeed, the FAO estimates that the food sector accounts for some 30% of global primary energy consumption. It thereby contributes to significant fossil fuel consumption and to approximately 20% of total annual greenhouse gas (GHG) emissions, excluding land use change (FAO, 2011a). The extensive use of fossil fuels along the agri-food value chain has a negative environmental footprint and increases the cost of food production and preservation in areas experiencing high energy costs, thereby undermining quality and availability of food (IRENA, 2015).

In developing countries, one-third of annual food production is wasted, costing 310 billion US dollars per year (FAO, 2011b). This is a striking figure considering that the population suffering undernourishment worldwide (nearly 821 million in 2017) is increasing after a prolonged decline, especially in some areas of Africa and Latin America (FAO et al., 2018).

Lack of access to modern energy and technology contributes to food waste at every segment of the food chain. Inadequate harvesting techniques and processing technology, poor storage facilities and insufficient supply of energy obstruct food security and can trap rural economies into persistent poverty. Losses during processing are much higher in developing (14%-21%) than in developed countries (less than 2%) (INC, 2017).



The IRENA report "Renewable Energy in the Water, Energy & Food Nexus" looks at how adopting renewables can ease trade-offs between water, energy and food, bringing substantial benefits to all three key sectors and providing less resource-intensive energy services compared to conventional energy technologies. Renewable energy technologies can boost water security by improving accessibility, affordability and safety. Integrating renewable energy into the agri-food supply chain helps to rein in cost volatility, bolster energy security, reduce GHG and contribute to long-term food sustainability.

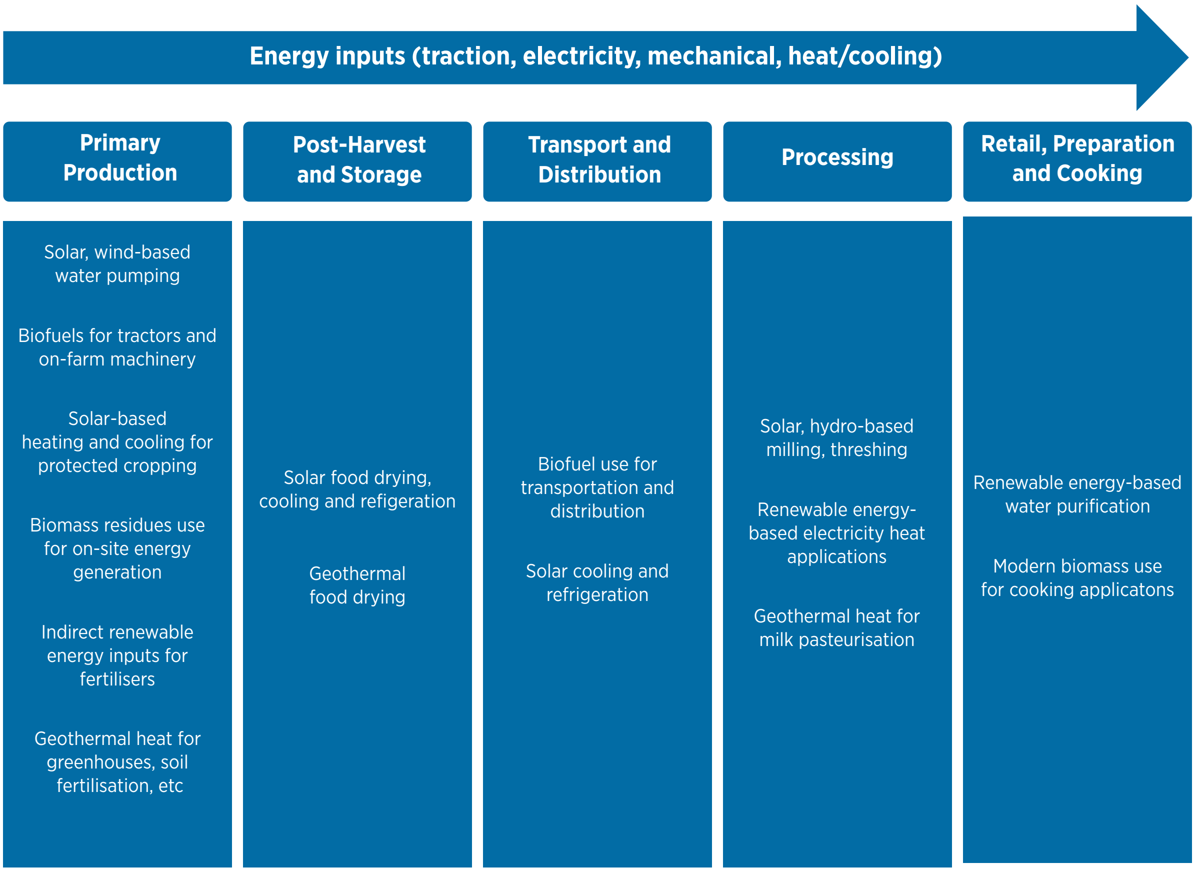
The IRENA brief entitled "Renewable Energy Benefits: Decentralised Solutions in the Agri-food Chain" analyses the socioeconomic impacts of deploying off-grid technologies in the agri-food chain. Launched at the Third International Off-grid Renewable Energy Conference (IOREC 2016), the report finds that using off grid renewables along different segments of the agri-food chain can generate considerable time and economic savings as well as improve output. However, maximising the benefits of decentralised renewables depends on effective policies and regulations, appropriate business models and integrated resource management.

The importance of the nexus between energy and food is addressed in the 2030 Agenda for Sustainable Development[4]. This sets the objective by 2030 to end hunger, achieve food security and promote sustainable agriculture as well as to ensure access to affordable, reliable, sustainable and modern energy for all. This is aligned with the need to gradually decouple food production from dependency on the availability of fossil fuels.

In this context, renewable energy can improve the sustainability of the food value chain as well as enhance food security and nutrition towards more sustainable development. Renewable energy applications are possible at different stages of the food supply chain (see Figure 1 below). Deploying them provides a range of benefits, such as alleviating energy security concerns, boosting local productive activities, reducing GHG emissions, and supporting the achievement of Sustainable Development Goals (IRENA, 2015; FAO, 2011b).

The next section will analyse the role of geothermal heat in direct applications in food and agriculture, including practical experiences from countries and regions across the globe.

Figure 1 Entry points for renewable energy into conventional energy supply systems



Source: Based on IRENA, 2015.

4 General Assembly Resolution A/RES/70/1 adopted on 25 September 2015, "Transforming our World: The 2030 Agenda for Sustainable Development".

2. GEOTHERMAL ENERGY APPLICATIONS IN THE AGRI-FOOD SECTOR: AN OVERVIEW

Low and medium temperature geothermal resources suitable for direct use applications are more widely available globally than geothermal resources required to generate electricity[5]. Estimates suggest that between $4{\cdot}10^5$ and $5{\cdot}10^6$ exajoules (EJ) stored in suitable aquifers can theoretically be used for direct heat applications. With a recovery factor of 1% and an assumed lifetime of 30 years, the annual recoverable geothermal energy could match world final energy consumption of 363.5 EJ per year (Limberger et al., 2018). Nevertheless, actual exploitation is estimated at 587,786 TJ per year (Lund and Boyd, 2015) – less than one-thousandth of the technical potential (Limberger et al., 2018).

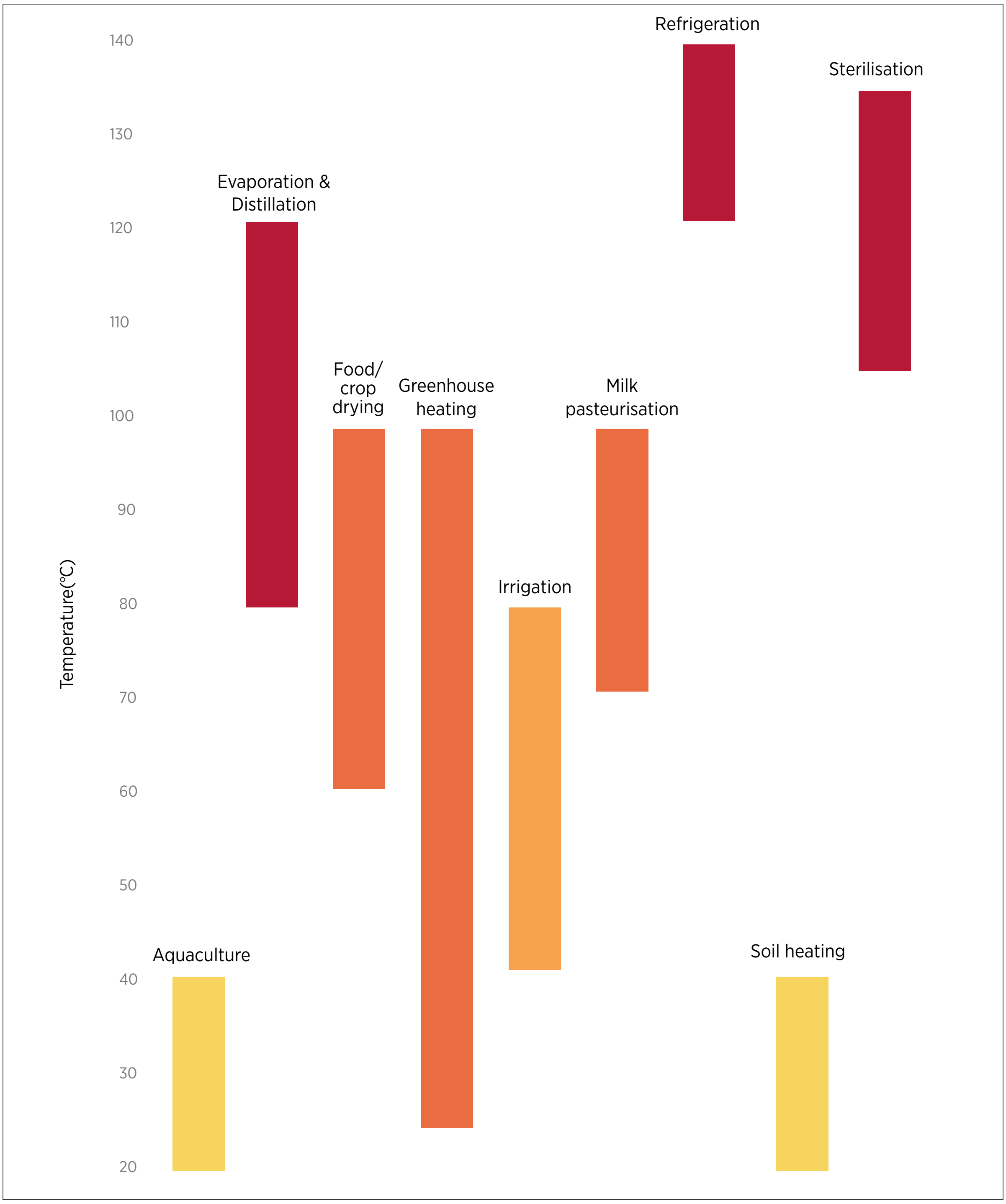
Increasing the use of geothermal heat offers significant benefits. Geothermal direct utilisation boosts the development of economic activities in the areas near the resource location, thereby providing employment for local communities. Additionally, geothermal is a renewable and indigenous energy source. Increasing its use can reduce dependency on fossil fuels, therefore improving the trade balance and protect businesses and consumers from the risk of volatile prices and energy shortage. Geothermal energy in the agri-food sector can be used to heat greenhouses and sterilise the soil, creating growing environments suitable for food production in locations where natural conditions would not normally allow. Additionally, protection from diseases and extreme weather conditions increases productivity and off-season availability of products. Geothermal heat can also serve for drying purposes, which helps preserve a wide range of foods. It contributes to mitigating food waste and results in a substantial reduction in drying space and time requirements. Furthermore, food drying can maintain a high protein content of some products.

The wide range of geothermal applications in the agriculture and agro-industry sector depends on varied fluid temperatures. This is illustrated in the Figure 2 known as the Lindal diagram and briefly summarised in Box 2. These applications are described in detail in Van Nguyen et al. (2015) and Lund (2017).

Source: Shutterstock

5 Geothermal resources higher than 150°C are usually required for electricity generation, although advanced technologies such as binary cycle power plants can make use of lower-temperature resources.

Figure 2 Utilisation of geothermal water and steam in the agri-food sector



Based on Lindal, 1973; Van Nguyen et al., 2015; Lund, 2017.

"Low and medium temperature geothermal resources suitable for direct use applications are more widely available globally than geothermal resources required to generate electricity"

BOX 2. SELECTED GEOTHERMAL HEAT APPLICATIONS IN THE AGRI-FOOD SECTOR

Aquaculture (20°C-40°C) Geothermal waters can be used to heat freshwater in heat exchangers or mixed with freshwater to obtain suitable temperatures for fish farming. This application has been reported in 21 countries worldwide and it is mainly used for aquaculture pond and raceway heating. Cultivation of algae – mainly spirulina – is another growing use, which requires temperatures of 35°C-37°C.

Soil heating (20°C-40°C) The constant soil temperature increases the yields and makes it possible to extend the growing season. Soil heating is used, for example, to grow carrots and cabbages.

Greenhouse heating (25°C-100°C) This is one of the most common direct applications of geothermal energy reported in 31 countries worldwide. Greenhouse heating is employed to grow crops such as vegetables and fruit in addition to flowers, houseplants and tree seedlings.

Irrigation (40°C-75°C) Geothermal energy at this temperature range can be employed to heat winter crops in open field agriculture and in greenhouses.

Food/crop drying (around 60°C up to 100°C) Low to medium temperature geothermal resources can reduce energy consumption in the drying process, which consists of removing water contained in the product, thus reducing moisture quantity to below 20%. Drying vegetables, fruit and fish typically requires temperatures of 70°C-95°C.

Milk pasteurisation (around 70°C up to 100°C) Geothermal hot water can be used for milk pasteurisation, while geothermal steam can be used for milk drying and ultra-heat treatment (UHT) processes.

Evaporation and distillation (around 80°C up to 120°C) This is commonly employed to separate mixtures and/or to increase the concentration of some components of the product. Examples include milk evaporation, sugar and liquor processing.

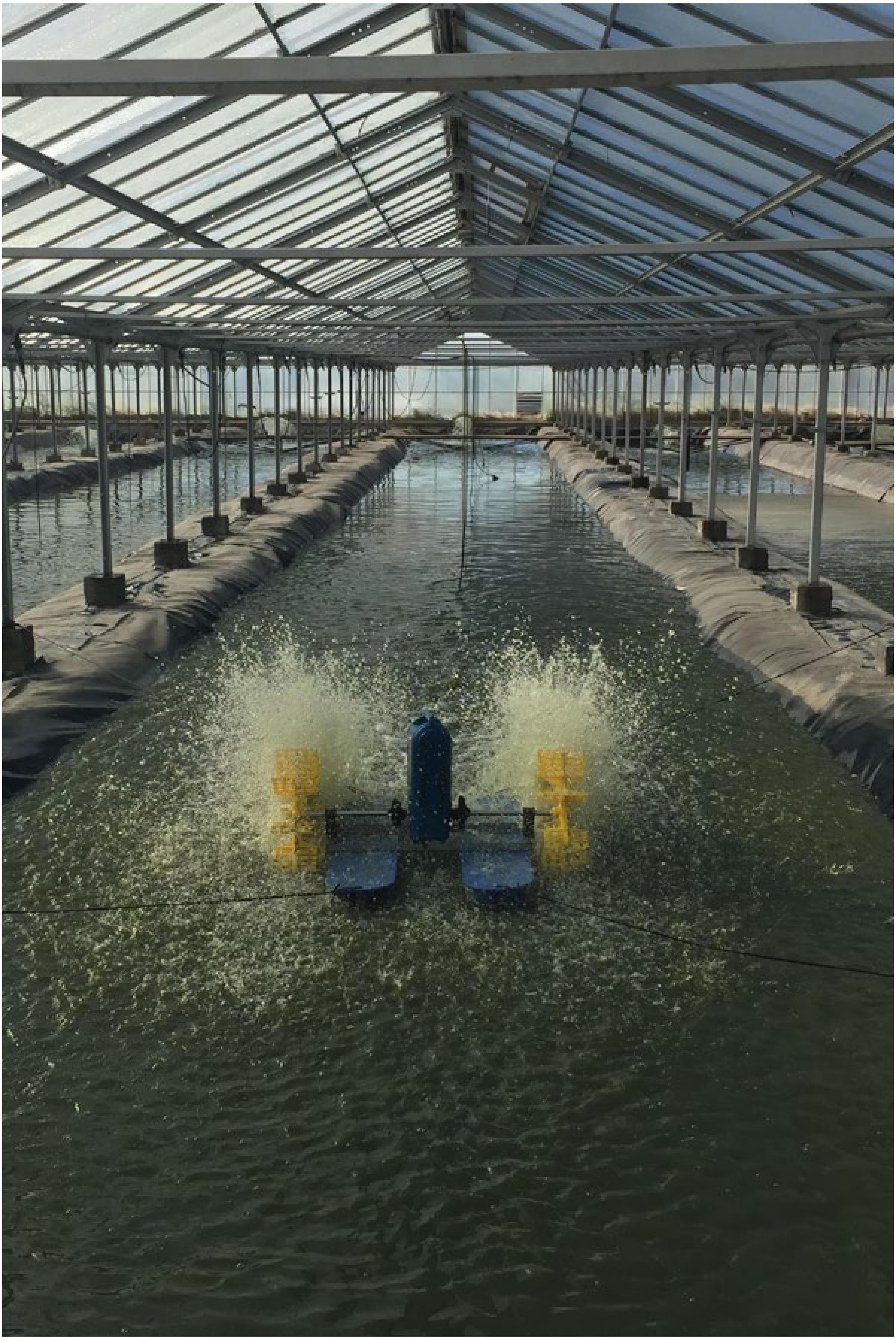
Sterilisation (>105°C) Geothermal heat is used to achieve a temperature of 121°C for food sterilisation in the meat and fish industry, which is a standard temperature for food sterilisation. Besides, geothermal water can also be used at 105°C-120°C to sterilise food processing equipment.

Refrigeration (>120°C) Geothermal energy can be used for refrigeration by absorption technology, using an ammonia/water cycle for applications below 0°C. So far, there has been very limited use of this geothermal application.

Source: Van Nguyen et al. (2015); Lund (2017)

An important aspect to consider is that, once the first process for which it was intended is complete, the geothermal fluid still has potential for further uses requiring lower temperatures (Rubio-Maya et al., 2015). This use of the same fluid at different thermal levels for various processes, known as cascaded use, can improve the economics of small and large projects, including power projects. In addition, it increases resource efficiency and reduces primary energy consumption.

Another approach is to use steam from the same field in parallel for both power and direct use. An example of this can be found in **New Zealand**. The Mokai geothermal field supplies steam from two of its wells to a dairy factory to process more than 250 million litres of milk every year. The milk supply comes from around 70,000 cows at 100 local farms located within 85 kilometres from the factory (Blair, 2018). Currently, dairy products from the plant are exported to 23 countries in Africa, East Asia and the Pacific, Latin America and the Middle East (GNS Science, 2017).



Geothermal energy for fish farming in Kazakhstan. Source: Þorleikur Jóhannesson

3. EXPERIENCE FROM SELECTED COUNTRIES

Geothermal energy development is often accompanied not only by environmental benefits but also by the creation of new and stable jobs, security of energy supply, and the possibility to develop industrial and touristic activities. This section highlights examples of the uptake of geothermal direct use applications in the agri-food sector in developed as well as in emerging markets.

3.1 Developed markets

Iceland is a well-known example from the 82 countries reporting direct use projects in operation (Lund and Boyd, 2015). In the second half of the 20th century, the country has experienced extraordinary economic growth partly enabled by deploying cost-efficient geothermal energy. Facilitated by the country's exceptional geological conditions, geothermal projects have contributed to a major energy transformation. Having been 80% dependent on imported oil and coal in the 1940s, Iceland now sources nearly 100% of its domestic power and heating requirements from renewables. In 2017, geothermal energy met 27% and 90% of power and heating demand respectively (Orkustofnun 2018a and 2018b). In addition, the use of geothermal heat in horticulture and fishing is very common, has dramatically enhanced food security and nutrition and has boosted the local industry by enabling large-scale export of stock fish (Box 3).

BOX 3. FOOD SECURITY AND COMPETITIVENESS WITH GEOTHERMAL ENERGY IN ICELAND

For centuries. Iceland's main economic activities consisted of agriculture and fishing, while the basic diet consisted chiefly of fish and livestock. Food imports therefore became necessary to enhance the diet. Towards the end of the 19th century, farmers discovered that warmer soils were more productive, leading to the establishment of the first greenhouse using geothermal energy in 1924.

Over the last century, geothermal energy has been utilised to increase the availability of vegetables such as tomatoes, cucumbers, peppers, carrots, salad crops, strawberries and mushrooms. Greenhouse horticulture in Iceland has become increasingly high-tech in terms of heat, humidity, carbon dioxide and lighting control.

Locally produced food in Iceland is now abundant, and some geothermal sites have also become tourist attractions.

In the seafood industry, geothermal is used especially for fish farming and drying. Indoor fish drying in Iceland requires large amounts of energy, which was very costly when using oil or electricity; Indoor fish drying was therefore tested in areas with geothermal resources because hot water or geothermal steam was less expensive. The cost reductions in the drying process allowed Iceland to become one of the main producers of dried fish worldwide along with Norway. In 2016, dried fish exports in Iceland amounted to more than 52, 000 tonnes, worth more than 200 million US dollars.

Iceland's successful experience demonstrates the possibility of addressing various challenges, including food security, through domestic geothermal resources. This may represent in several countries potential drivers for economic development.

Source: Flóvenz and Jónsdóttir, 2017; Statistics Iceland, 2017

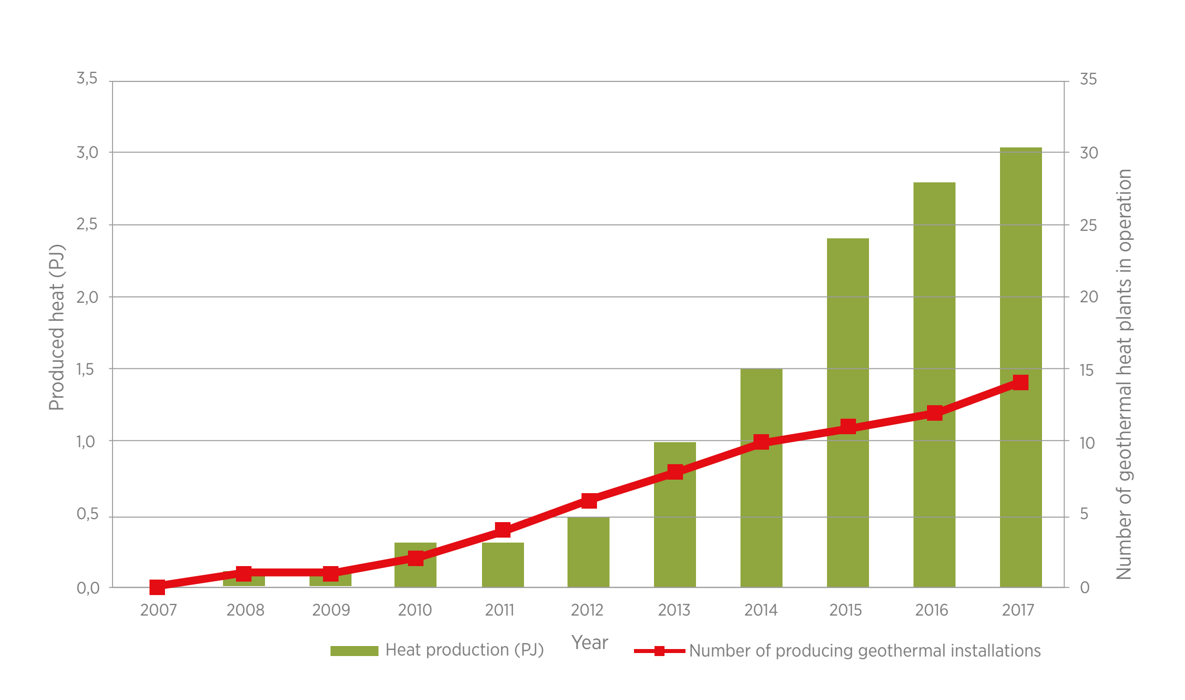
The direct use of geothermal heat in the agri-food industry, especially in greenhouse applications, is also well known in **China, Hungary, Russia, and Turkey** (Lund and Boyd, 2015). A more recent successful example is represented by the Netherlands. The Dutch horticulture sector is one of the pillars supporting the economy, and **the Netherlands** has prioritised geothermal energy to minimise dependency on natural gas. As illustrated in Box 4, the deployment of geothermal heat has been increasing for more than a decade also due to a number of dedicated policies. These combine targets and plans, a private-public insurance scheme addressing the resource risk through well productivity insurance, and a market-based support scheme open to renewable electricity as well as renewable heat sources.

Drying fish factory in Iceland. Source: Haustak.

BOX 4. MIX OF POLICIES AND TOOLS TO SUPPORT GEOTHERMAL HEAT DEVELOPMENT IN THE NETHERLANDS

Renewable energy has become a priority in the Netherlands to minimise dependency on natural gas in different sectors such as district heating and agriculture. The figure below shows the exceptional growth of geothermal heat since 2007 in the Netherlands, where 18 out of 19 projects operating at the end of 2017 were dedicated to heating commercial greenhouses.

Figure 3 Annual production of geothermal heat in the Netherlands



Source: Ministry of Economic Affairs and Climate Policy of the Netherlands, 2018

In the early 2000s there was no dedicated policy framework for geothermal energy in the Netherlands. The Mining Act and a geological database developed within the framework of oil and gas were the only instruments available. However, the government developed a plan for geothermal heat in the years that followed and put in place a mix of complementary measures to facilitate its implementation. Combined with solid expertise and knowledge of its geological conditions originating from long experience of oil and gas, this has enormously facilitated the geothermal energy boom in the Netherlands in the recent years.

The enabling environment for geothermal energy in the Netherlands is currently composed of the following supporting instruments.

- **Public geological database** The Netherlands Oil and Gas (NLOG) portal is a public database that holds all subsurface data (*e.g.* well logs and geophysical surveys) gathered under a mining permit. This includes data from the oil and gas industry, mining and scientific research. The Dutch mining law requires all parties operating under a mining permit to deliver the data acquired through the process to the governmental organisation TNO. These data are made public five years after acquisition and have significantly reduced resource risk for geothermal project developers.
- **Geothermal Action Plan** Published in April 2011 by the Ministry of Economic Affairs, Agriculture and Innovation, this was the first white paper on geothermal energy in the country. Among other things, the document set the target of generating 11 petajoules (PJ) from geothermal heat plants by 2020.
- **Operating grant (Stimulation of Sustainable Energy Production -SDE+)** Under this scheme, geothermal heat plants operators have been eligible since 2012 to receive financial support for a fixed number of years for the renewable energy they generate. The programme pays the difference between the price of fossil fuels and the cost of the renewable fuel as a feed-in premium. The support scheme is open to renewable electricity, renewable heat and biogas.
- **Post-damage guarantee scheme** Established by the Ministry of Economic Affairs in 2009 and renewed in 2013, this risk mitigation fund pays out 85% of well costs if the thermal power output is lower than expected. In the Dutch scheme, participants pay an insurance fee of 7% of the maximum support. The maximum support/risk covered is 7.2 million euros. A similar risk insurance scheme linked to the performance of geothermal installations has been available in France since the 1980s and enabled the installation of 500 megawatts of thermal power.
- **Acceleration Plan Geothermal Energy in Horticulture** Launched in 2014, the plan sets a target for 5 PJ of deep geothermal heat per year and includes strategies to achieve its target. These are concerned with knowledge development and dissemination, addressing the financing constraints, and reducing risk exposure by improving and extending the budget of the guarantee scheme.
- **The "energy-producing greenhouse" programme** This is a collaborative venture in which government and industry work together to reduce carbon dioxide emissions from greenhouse horticulture, notably by providing businesses with information.

Source: Babóczky; 2017; Boissavy, 2017; EGEC, 2016; Government of the Netherlands, n.d.; Ministry of Economic Affairs and Climate Policy of the Netherlands, 2018; Netherlands Enterprise Agency, n.d.; NLOG, n.d.; Van Heekeren, et al., 2015

Aerial view of greenhouses in the Netherlands. Source: Shutterstock.

Governments at national or local levels can also put in place a variety of mechanisms complementing policy and financial instruments to ensure the greater involvement of local communities and fair distribution of the benefits arising from the geothermal exploitation. As an example, part of the revenues from the concessions for the exploitation of geothermal energy resources in the **Italian Region of Tuscany** is channelled through a consortium of local municipalities to promote initiatives involving all the local economic and social actors.

One of these initiatives is the Renewable Energy Food Community. This brings together food-related businesses using geothermal energy and other renewable energy sources, promotes its sustainability model through a common brand, and supports marketing and outreach to new markets (Box 5).

BOX 5. TUSCANY'S INNOVATIVE GEOTHERMAL GOVERNANCE MODEL AND THE RENEWABLE ENERGY FOOD COMMUNITY

The 14 municipalities within the geothermal areas in the Italian region of Tuscany developed an innovative model for expanding the use of geothermal energy in the agri-food sector. This area was home of the world's first ever commercial geothermal power plant, which was built in 1913 over a complex of hot water springs used since Roman times. In this region, however, the further deployment of geothermal energy is limited by a number of social and environmental concerns.

A new governance model was therefore put in place through a General Agreement on Geothermal Energy which envisages revenue redistributed from geothermal energy projects to benefit local populations, make geothermal territories more attractive to investors and/or tourism, and improve the environmental impact of industrial activities. In this context, the Consortium for Development of Geothermal Areas (CoSviG) seeks to promote the creation of development paths involving all economic and social actors in the Tuscan territories. Moreover, a roadmap for sustainability has been designed relating to the diversification in production and use of energy from renewable sources, in line with the social, cultural and environmental features of the area.

As part of this strategy, CoSviG founded the Renewable Energy Food Community in 2009 together with the Tuscany Slow Food and Slow Food Foundation for Biodiversity. This is reported to be the world's first community of local food businesses using clean and renewable energy in their manufacturing cycles. The Renewable Energy Food Community contributes to reductions in GHG emissions by using renewable energy. It allows its members to display a collective label on their products as a guarantee of clean energy use and respect for the principles of slow food as "good, clean and fair". Currently the Renewable Energy Food Community contains various projects using geothermal energy in their manufacturing cycles. Examples include geothermal greenhouses for growing basil and other aromatic plants to produce pesto; geothermal heat in the production of fresh sheep cheese; and geothermal steam as primary energy source in a craft brewery.

Source: Renewable Energy Food Community, 2017; Torsello, 2018

3.2 Emerging markets

While countries like Iceland or the Netherlands are well known for their commercial direct heat applications, including in the agri-food sector, other countries have limited the use of their geothermal energy for power generation and/or recreational purposes only. However, more and more governments are showing interest in deploying geothermal heat as a solution to improve food security and nutrition and to stimulate economic development. Many of these are currently working on gaining experience and putting in place the necessary enabling frameworks.

In **Kenya**, for example, the nexus between food and geothermal energy appears to be very strong. While the country has a long tradition of geothermal power and more than 650 megawatts of installed capacity, the first geothermal heat projects were deployed in Olkaria (greenhouse heating) and Eburru (pyrethrum drying).

More recently, Kenya's Geothermal Development Company (GDC), which supports geothermal development in the country, has implemented four pilot projects at Menengai for greenhouse heating, milk pasteurisation, aquaculture pond heating and a laundry (Nyambura, 2016). Meanwhile, a fifth project featuring a grain dryer is under development.

Moreover, further potential has been identified for meat, milk, and honey processing as well as for postharvest crop preservation and storage in Nakuru County – where the Menengai field is located – and in other prospects such as the counties of Narok, Baringo and Turkana (Ole Nchoe, 2018).

Hot spring in Kenya. Source: Shutterstock.

In Africa, geothermal direct use projects are also in operation in **Tunisia** for oasis irrigation and greenhouse heating purposes, and in **Algeria** for greenhouse heating and fish farming (Lund and Boyd, 2015). However, the potential for geothermal direct use remains largely untapped, notably along the East African Rift System. Suitable geothermal resources there could be harnessed by drilling shallow and therefore lower-cost wells with a depth of less than 1,000 m (Feliks et al., 2015).

"The potential for geothermal direct use remains largely untapped along the East African Rift System. Suitable geothermal resources there could be harnessed by drilling shallow and therefore lower-cost wells."

Source: National Autonomous University of Mexico - UNAM

Latin America and the **Caribbean** is another region in which policies and incentives have mostly concentrated on power generation rather than direct use applications (Bergman et al., 2018). However, the direct use of geothermal energy can undoubtedly have a transformative impact in terms of food security and rural economic development. In **Mexico**, for instance, food loss and waste are estimated at around 20 million tonnes annually. The development of technologies using geothermal resources for food drying could contribute to solve this problem (Aviña, 2018). To accelerate the deployment of geothermal heat for productive uses as well as for space heating and cooling, Mexico is finalising dedicated licensing procedures and has produced a roadmap projecting significant growth in geothermal heat in the coming years (see Box 6).

BOX 6. PERSPECTIVES FOR GEOTHERMAL HEAT DEVELOPMENT IN MEXICO

Mexico has large geothermal potential traditionally used for power generation. As part of the Mexican energy reforms aiming to liberalise the energy sector, the Government of Mexico introduced the Geothermal Energy Law in 2014. This included the use of geothermal energy for power generation as well as heat for direct applications. This new law created an opportunity to develop projects intended to harness heat for all uses, including agriculture, which is considered particularly important due to Mexico's potential in the sector.

The National Energy Secretariat of Mexico (SENER) is currently making efforts to support the development of projects related to direct use of geothermal energy. It has drafted guidelines to streamline the process for the acquisition of permits and concessions for this type of project. At time of writing (December 2018), the draft guidelines were under review and are expected to be published in the first quarter of 2019. Simpler regulatory procedures for geothermal direct use applications are expected to facilitate the development of projects in Mexico, with a special focus on food and agriculture.

The main project related to food in Mexico is a mango dehydration plant in the newest geothermal field located in the state of Nayarit on the Pacific coast. Yet more projects are currently under development, financed by public and private funds.

Furthermore, in 2018 Mexico published a roadmap for geothermal direct use, which projects a rise in geothermal heat installed capacity from around 156 megawatts thermal (MWth) in 2013 to 1,950 MWth in 2024 while targeting 3,800 MWth by 2030. The roadmap compiles information about current direct use projects installed in the country and highlights potential application areas and technologies for direct use of geothermal heat, including cascaded use and ground source heat pumps. Furthermore, it identifies the main barriers to the accelerated implementation of direct use projects in Mexico and proposes strategies to overcome regulatory, economic, capacity building, technological and social barriers. It highlights commitments, responsibilities and timeframes in the short and medium term for each of the stakeholders involved. The targets and main outcomes of the roadmap are the result of consultation workshops that involved stakeholders from the national government, academy, research and industry.

Sources: Aviña, 2018; SENER, 2018

Central America is another region with good opportunities for direct applications of geothermal resources. Key factors are the significant geothermal potential and expertise in the region, together with the strong engagement of development partners to work on these types of geothermal applications. The industry and businesses in the region have recently shown interest in exploiting the geothermal potential and there are a few pilot projects driven by large, experienced government-owned energy companies. They include, for instance, pineapple, apple, banana, coconut and coffee drying at the Berlin field in **El Salvador**, milk pasteurising, hot water applications and fruit drying in **Costa Rica**. Private sector projects include dried pineapples and apples for export in **Guatemala**. However, the further development of these applications faces barriers such as lack of awareness of geothermal direct use and its benefits; lack of dedicated licensing procedures; and concerns about possible decrease of electricity production in high-enthalpy fields. At the same time, the major energy companies in the region have a mandate only to generate and sell electricity, and direct use sometimes remains a legal grey area. Different countries in the region (Guatemala, Nicaragua and Costa Rica) are working on pilot projects involving direct uses of geothermal energy in order to overcome the main barriers mentioned above and to take advantage of the region's favourable geological conditions (GIZ, 2018).

Source: shutterstock

4. RECOMMENDATIONS FOR ACCELERATING GEOTHERMAL HEAT DEVELOPMENT IN THE AGRI-FOOD SECTOR

Analysing the experience of countries that have successfully deployed geothermal energy in past decades, as well as countries at an early stage in the journey, allows specific barriers and success factors to be identified and demonstrates that public policy plays a crucial role in creating the conditions for private investment. However, there is no one-size-fits-all approach, and regulations and policies must be adapted to the local contexts and market maturity. Bearing these considerations in mind, this section puts forward recommendations that could help accelerate the deployment of geothermal direct use applications in the agri-food sector.

Establish adequate licensing procedures covering all geothermal applications

The implementation of a geothermal project requires multiple permits during the exploration, development, construction, and operation phases. The exact procedures vary based on the legal system (common or civil law), the definition, and the classification of geothermal resources. Legal provisions relevant to geothermal heat projects are sometimes found under the mining and/or water laws and in other cases in specific geothermal laws.

In some jurisdictions the whole permitting process may be lengthy and burdensome. thereby increasing the overall costs of a project, Therefore, one of the main prerequisites for successfully developing geothermal projects is the existence of a transparent licensing regime defining in advance the rights as well as the technical, economic, and other requirements for the licence holder. To enable geothermal direct use development, regulations should at the outset foresee the possibility for the use of geothermal energy beyond power generation. They may allow energy companies, including independent power producers, to sell heat as well as power. In addition, where possible, dedicated and streamlined authorisation procedures for small-scale direct use projects could be put in place while taking the specific legal contexts into consideration. As reported in the previous section, efforts in this direction have been taken in some countries such as Mexico (see Box 6).

Develop tailored policy instruments and address key financial barriers

From the economic point of view, geothermal energy is a competitive yet highly capital-intensive technology. As highlighted, the resource risk related to the initial phases of a geothermal project remains one of the most challenging barriers to scaling up geothermal energy investments for power generation as well as heating. To overcome the financial challenges, governments and development finance institutions have assisted geothermal development through national or regional support schemes. These instruments have often taken the form of non-recoverable grants, convertible grants or guarantee funds. They either cover part of the costs of exploration and drilling or provide well productivity insurance (IRENA, 2016). However, very often the availability of these support mechanisms has been limited to geothermal power projects alone.

The Netherlands (see Box 4), is an exception. The case study shows how risk mitigation mechanisms and other dedicated support schemes open to geothermal heat projects have played a critical role in attracting investors and leveraging private finance for geothermal direct use projects in food and agriculture.

Governments and development partners willing to support an increase in geothermal direct use may extend/adapt the eligibility of existing support mechanisms to include geothermal heat projects or establish dedicated instruments.

Integrate geothermal energy in development and industrial plans, involve local actors and promote partnerships to attract industry to settle near the geothermal area

Aligning geothermal plans with industrial, economic and rural development strategies is crucial to generating consistent frameworks to attract productive activities close to the geothermal resource. Partnerships between local authorities and industrial operators must therefore be nurtured in order to develop local direct-use projects. As illustrated by the example of the Renewable Energy Food Community in Tuscany, Italy, supporting local enterprises and promoting a local label for food produced or processed sustainably using geothermal energy and other renewable energy sources can incentivise businesses to switch fuels. At the same time, it can open up business opportunities for sustainable food. This necessitates consultations with a wide range of stakeholders, including public authorities and the private sector involved in agriculture and rural development, as occurred in Mexico (see Box 6 above). The involvement of local communities is of crucial importance and should be considered also when issuing or renewing licences for geothermal development.

Support pilot projects and feasibility studies to improve knowledge of the geology and assess compatibility with specific productive activities

Geological data is key to assessing resource availability as well as the conditions of the geothermal fluids, including temperature, pressure, chemical composition etc. to find the most suitable applications. High-quality geological data will contribute to accurate feasibility studies, which are of utmost importance for the project evaluation.

One of the purposes of feasibility studies should be to map and identify any overlap between the geothermal resource available and demand for low, medium or high-temperature heat from economic activities located, or to be located, nearby. In new and emerging markets, accurate feasibility studies could be supported through public funding or technical assistance programmes. The results of these assessments can also be key to attracting investors or raising debt finance, thereby facilitating the implementation of subsequent phases of a project.

Develop capacities for downstream direct use operations

Some technology applications, such as food drying, can be considered mature. However, the limited experience of public authorities and shortage of qualified workers can restrict the wider adoption of geothermal direct use. Local communities and experts even in particular regions with significant experience of geothermal power generation would benefit from further training on topics related to downstream operations, for instance food processing through geothermal heat. This would facilitate the development of more projects for the food and agricultural industries. To maximise the impact and outreach in different geothermal regions across the world, collaboration with and between geothermal training centres could be useful.

Training the local workforce in the use of dryers or in food engineering, for example, would support the efficient operation of pilot projects. It will prevent them from falling into disuse if not properly maintained. Furthermore, involving local communities in the development of these projects can contribute to creating awareness and sharing the benefits of geothermal energy development in those areas and allow for a better acceptance of geothermal plants.

Ensure wise management of the resource for long-term environmental and economic sustainability

The direct use of geothermal energy has many potential benefits. For example, as highlighted in the previous sections, it can increase the economic viability of power generation projects. Yet technical challenges sometimes affect the cascading use of geothermal resources. These can be addressed by strategies adapted to the characteristics of the resource and the reservoir.

In this context, it should be noted that thermal waters are rarely pure (Lund, 2017). In particular, geothermal fluids usually contain dissolved by-products of water-rock interactions and possible modification by magmatic gases. This causes chemical elements such as silicon, aluminium, sodium, potassium, calcium, magnesium, iron, manganese, chlorine, boron and bromine to dissolve (Gunnlaugsson, 2014). Heat exchangers are therefore needed to mitigate the presence of elements harmful to human health (Lund, 2017).

The stability and interaction between the elements dissolved in geothermal fluids is controlled mainly by temperature, pressure and pH but changes to these conditions can produce scaling and corrosion. The formation of scale on equipment surfaces exposed to geothermal fluids can cause energy losses, increase cost from equipment oversizing, pumping costs, and cleaning and maintenance costs, reduce production, or even lead to the abandonment of a production or reinjection well due to clogging (Andritsos et al., 2002).

The reduction in the temperature of the geothermal fluids due to cascading can increase the likelihood of scaling and at the same time constrains the use of fluid for reinjection. If the geothermal fluid is not reinjected, it may lead to negative environmental impacts e.g. subsidence and discharges into waterways, and reduce pressure in the reservoir, thereby reducing productivity. Numerous techniques control scale formation in geothermal systems. Some of the most common measures are pH adjustment, use of chemical additives and removal of deposits by chemical or mechanical means (Andritsos et al., 2002). A good understanding of the characteristics and behaviour of the geothermal reservoir including fluid chemistry is key to selecting the most appropriate power plant technology and subsequent cascading use applications.

Wise management of geothermal resources, including reinjection of the fluids into the reservoir to prevent depletion, as well as regulation to preserve the quality of air, water etc. will facilitate the maximum compatibility of a geothermal project with the environment. If these environmental considerations are not dealt with properly at the outset, they may have a negative impact on the long-term economic viability of the project. Furthermore, this may provoke social resistance and slow down geothermal deployment in certain areas. For these reasons, several governments have launched new strategies heavily geared towards reducing the potential environmental impact of geothermal plants. These strategies include, where technically possible, full reinjection of the geothermal fluids as well as greater public information and the involvement of the local communities.

Support international cooperation and facilitate insight sharing about technical, policy, regulatory and financial solutions

Enhanced dialogue and cooperation between governments, industry, development partners, and academia worldwide can spread knowledge and promote the adoption of the most suitable solutions, including for heating in the agri-food sector. This can be very beneficial especially for new and emerging markets that still face barriers hampering the uptake of geothermal applications in this field.

Sharing experience and lessons can help raise awareness and identify best practices. When tailored to local contexts, it can facilitate the creation of enabling frameworks and help address regulatory and financing gaps, including through innovative instruments. Moreover, international partnerships can be key to demonstrating the technical feasibility and economic viability of geothermal heating in the agri-food sector, which makes more likely to attract investors.

In this framework, policy-makers and key stakeholders may benefit from international platforms such as the Global Geothermal Alliance. All in all, international cooperation can promote the use of geothermal and its contribution towards sustainable development in a greater number of countries around the world.

REFERENCES

Andritsos, N., Karabelas, A.J. and Koutsoukos P.G. (2002), "Scale formation in geothermal plants", in *Proceedings of International Summer School on Direct Application of Geothermal Energy* under the auspice of Division of Earth Sciences, United Nations Educational, Scientific and Cultural Organization (UNESCO), International Geothermal Association (IGA), https://pangea.stanford.edu/ERE/pdf/IGAstandard/ISS/2002Greece/I/coutsoukos.pdf accessed December 2018.

Arason, S. (2003), "The drying of fish and utilization of geothermal energy – the Icelandic experience" *Proceedings: International Geothermal Conference*, Reykjavík, Sept. 2003.

Aviña, H. (2018), "IIDEA´s installation and geothermal food dehydration testing system in geothermal field at San Pedro Lagunillas (Nayarit Dome)", presentation, Global Geothermal Alliance event - *Geothermal Direct Utilisation and Food Security*, Reykjavik, Iceland, 24 April 2018, http://irena.org/-/media/Files/IRENA/Agency/Events/2018/Apr/IGC2018/GGA-food-2b-Avina.pdf?la=en&hash=22729D2B39E534F893DB1C9B256314DF0008FFB3 accessed December 2018.

Berman, L.W, Fridriksson, T., Herbas Ramirez, X. R., Jayawardena, M., Armstrong, J. S., Peabody, S. Turner, J. A., Rivera Zeballos, S. A. (2018), *Opportunities and Challenges for Scaling-up Geothermal Development in Latin America and Caribbean Region*, World Bank, Washington, DC. http://documents.worldbank.org/curated/en/173681539626591426/Opportunities-and-Challenges-for-Scaling-up-Geothermal-Development-in-Latin-America-and-Caribbean-Region accessed December 2018.

Blair, A. (2018), "Geothermal fuels prosperity: food for thought", presentation, Global Geothermal Alliance event - *Geothermal Direct Utilisation and Food Security*, Reykjavik, Iceland, 24 April 2018, http://irena.org/events/2018/Apr/GGA-Side-Events-Iceland-Geothermal-Conference accessed December 2018.

Babóczky, M. (2017), *Report on Financial Support Mechanisms*, DARLINGe project, December 2017, http://www.interreg-danube.eu/uploads/media/approved_project_output/0001/12/1e71140314efcf9c0a2cf26064af4c82d77f7ff1.pdf accessed December 2018.

Boissavy, C. (2017), "The successful geothermal risk mitigation system in France from 1980 to 2015", *European Geologist Journal*, issue 43, https://eurogeologists.eu/european-geologist-journal-43-boissavy-the-successful-geothermal-risk-mitigation-system-in-france-from-1980-to-2015, accessed December 2018.

DiPippo, R. (2016), *Geothermal Power Plants. Principles, Applications, Case Studies and Environmental Impacts*, North Dartmouth, MA, US.

EGEC (European Geothermal Energy Council (2016), *Geothermal Use in Agriculture*, https://www.egec.org/wp-content/uploads/2017/09/Brochure-Agriculture-2017-Web.pdf accessed December 2018.

FAO (Food and Agriculture Organization of the United Nations) (2011a), *"Energy-smart" food for people and climate*, FAO, Rome, www.fao.org/docrep/014/i2454e/i2454e00.pdf accessed December 2018.

FAO (2011b), *Global Food Losses and Food Waste – Extent, Causes and Prevention,* FAO, Rome, http://www.fao.org/docrep/014/mb060e/mb060e.pdf accessed November 2018.

FAO, IFAD (International Fund for Agricultural Development) and WFP (World Food Programme) (2015), *The State of Food Insecurity in the World 2015*, FAO, Rome, www.fao.org/3/a-i4646e.pdf accessed December 2018.

FAO, IFAD, UNICEF (United Nations International Children's Emergency Fund), WFP and WHO (World Health Organization) (2018), *The State of Food Security and Nutrition in the World 2018*. Building *Resilience for Peace and Food Security*, FAO, Rome, http://www.fao.org/3/I9553EN/i9553en.pdf accessed December 2018.

Feliks, M.E. J., Elliott T.P., Delacherois Day G., Percy G. D., Younger P., "Direct use of low enthalpy deep geothermal resources in the East African Rift Valley", *Proceedings World Geothermal Congress 2015,* Melbourne, Australia, 19-25 April 2015.

Flóvenz, J. and Jónsdóttir, B. (2017), "The Icelandic experience on integrated geothermal utilization", in: Bertani, R. (ed.) *Perspectives for Geothermal Energy in Europe*, pp. 77-126.

Galindo Fernández, M., Roger-Lacan, C., Gährs, U., Aumaitre, V. (2016), *Efficient District Heating and Cooling Systems in the EU - Case Studies Analysis, Replicable Key Success Factors and Potential Policy Implications*, http://publications.jrc.ec.europa.eu/repository/bitstream/JRC104437/study%20on%20efficient%20dhc%20systems%20in%20the%20eu%20-dec2016_final%20-%20public%20report6.pdf accessed December 2018.

GIZ (German Agency for International Cooperation) (2018), "Direct use for food production – learning lessons in Central America", presentation, Global Geothermal Alliance event - *Geothermal Direct Utilisation and Food Security*, Reykjavik, Iceland, 24 April 2018, http://irena.org/-/media/Files/IRENA/Agency/Events/2018/Apr/IGC2018/GGA-food-1b-GIZ-FallertanjaRejkjavik.pdf?la=en&hash=A5E7E77C9F32766BD40C69EBEFA1CFE4535F39FA accessed December 2018.

Gissurarson, M. (2018), "Geothermal direct use, with a focus on agriculture and agro-industry sectors", presentation, *Global Geothermal Alliance event - Geothermal Direct Utilisation and Food Security,* Reykjavik, Iceland, 24 April 2018, http://irena.org/-/media/Files/IRENA/Agency/Events/2018/Apr/IGC2018/GGA-food-1a-Matis.pdf?la=en&hash=86C01F86A8DD5910CFDD2352B686A11A13A37399 accessed December 2018.

GNS Science (2017), *Case Studies: Renewable Geothermal Energy Used in Milk Processing*, www.gns.cri.nz/Home/Learning/Science-Topics/Earth-Energy/Case-Studies accessed December 2018.

Government of the Netherlands (n.d.), *Government Stimulates Geothermal Heat*, www.government.nl/topics/renewable-energy/government-stimulates-geothermal-heat accessed December 2018.

Gunnlaugsson, E., Ármannsson, H., Thorhallsson, S. and Steingrímsson, B. (2014), "Problems in geothermal operation - scaling and corrosion", presentation, *Short Course VI on Utilization of Low- and Medium-Enthalpy Geothermal Resources and Financial Aspects of Utilization*, organised by United Nations University -Geothermal Training Programme, and LaGeo in Santa Tecla, El Salvador, 23-29 March, 2014 https://orkustofnun.is/gogn/unu-gtp-sc/UNU-GTP-SC-18-19.pdf accessed December 2018.

Heatunderyourfeet.eu (n.d.) *"The technology"*, http://www.heatunderyourfeet.eu/the-technology/ accessed December 2018.

INC (International Nut and Dried Fruit Council) (2017), "Food loss and waste in the food supply chain", *NUTFRUIT Magazine*, edition 71 N2, pp. 26-27, http://www.fao.org/3/a-bt300e.pdf accessed December 2018.

IRENA (International Renewable Energy Agency) (2018), "Featured dashboard – capacity generation", RESOURCEwebpage, http://resourceirena.irena.org/gateway/dashboard/?topic=4&subTopic=16 accessed December 2018.

IRENA (2016), *Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance*, IRENA, Abu Dhabi, https://www.irena.org/DocumentDownloads/Publications/IRENA_Risk_Mitigation_and_Structured_Finance_2016.pdf accessed December 2018.

IRENA (2015), *Renewable Energy in the Water, Energy & Food Nexus*, IRENA, Abu Dhabi. http://www.irena.org/publications/2015/Jan/Renewable-Energy-in-the-Water-Energy--Food-Nexus accessed December 2018.

IRENA, IEA (International Energy Agency) and REN21 (Renewable Energy Policy Network for the 21st Century) (2018), *Renewable Energy Policies in a Time of Transition*, IRENA, Organisation for Economic Co-operation and Development (OECD)/IEA and REN21, https://www.irena.org/publications/2018/Apr/Renewable-energy-policies-in-a-time-of-transition accessed December 2018.

Lindal, B., (1973), "Industrial and other application of geothermal energy", in: Armstead, H.C.H., *Geothermal Energy*, UNESCO, Paris, pp.135-148.

Limberger,J., Boxem,T., Pluymaekers, M., Bruhn, D., Manzella, A., Calcagno, P., Beekman, F., Sierd Cloetingh,S., and Jan-Diederik van Wees, J. (2018), "Geothermal energy in deep aquifers: a global assessment of the resource base for direct heat utilization", *Renewable and Sustainable Energy Reviews*, Vol. 2, Part 1, pp. 961-975, https://www.sciencedirect.com/science/article/pii/S1364032117313345 accessed December 2018.

Lund, J.W. (2017), *A Guide for the Development of Geothermal Direct-Use Projects*, East Africa Geothermal Energy Facility, https://static1.squarespace.com/static/5aa14718697a980f6067bb98/t/5b476fca562fa757bc1e097c/1531408358014/REG05+D3_Final.pdf accessed December 2018.

Lund, J.W. and Boyd, T.L. (2015), "Direct utilization of geothermal energy 2015 worldwide review", *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, 19-25 April 2015.

Ministry of Economic Affairs and Climate Policy of the Netherlands (2018), *Natural Resources and Geothermal Energy in the Netherlands, 2017 Annual Review*, https://www.nlog.nl/sites/default/files/yearbook%202017-%20englishversion.pdf accessed December 2018.

Netherlands Enterprise Agency (n.d.), "Stimulation of Sustainable Energy Production (SDE+)", *Netherlands Enterprise Agency* Website, https://english.rvo.nl/subsidies-programmes/sde accessed December 2018.

NLOG (n.d.), the Netherlands Oil and Gas Portal, https://www.nlog.nl/en accessed December 2018.

Nyambura, E. (2016), "Direct use of geothermal energy: Menengai direct use pilot projects in Kenya", *Proceedings, 6th African Rift Geothermal Conference*, Addis Ababa, Ethiopia, 2-4 November 2016 http://theargeo.org/fullpapers/DIRECT%20USE%20OF%20GEOTHERMAL%20ENERGY-%20AN%20UPDATE%20OF%20THE%20MENENGAI%20DIRECT%20USE%20PILOT%20PROJECT%20IN%20KENYA.pdf accessed December 2018.

Ole Nchoe, J. P. (2018), "Direct use of geothermal energy for food security: towards achieving Kenya's BIG4 agenda",presentation, Global Geothermal Alliance event - *Geothermal Direct Utilisation and Food Security,* Reykjavik, Iceland, 24 April 2018, http://irena.org/events/2018/Apr/GGA-Side-Events-Iceland-Geothermal-Conference accessed December 2018.

Orkustofnun - National Energy Authority of Iceland (2018a), *Installed Capacity and Electricity Production in Icelandic Power Stations in 2017*, OS-2018-T006-01.

Orkustofnun - National Energy Authority of Iceland (2018b), *Space Heating by Energy Source*, OS-2018-T010-01.

Renewable Energy Food Community (2017), *Guardian Farmers of Tuscany's Renewable Energy Food Community*, http://www.distrettoenergierinnovabili.it/der/s/ccer/2017-10-brochure-ccer-eng.pdf accessed December 2018.

Rubio-Maya, C., Ambríz Diaz, V.M., Pastor Martínez, E., and Belman-Flores, J. M. (2015), "Cascade utilization of low and medium enthalpy geothermal resources - a review", *Renewable and Sustainable Energy Reviews 52 (2015)*, pp. 689-716.

SENER (National Energy Secretariat of Mexico) (2018), *Mapa de Ruta Tecnologica – Usos Directos del Calor Geotérmico (Technological Roadmap, Direct Uses for Geothermal Heat),* https://www.gob.mx/cms/uploads/attachment/file/416191/MRT_UDCG_Final.pdf accessed December 2018.

Statistics Iceland (2017), *Iceland in Figures 2017,* Vol. 22., Reykjavík, Iceland. https://www.statice.is/media/50481/icelandinfigures2017.pdf accessed December 2018.

Torsello, L. (2018), "Accelerating geothermal energy deployment in the agricultural and food sectors. What challenges and success factors?", presentation, Global Geothermal Alliance event - *Geothermal Direct Utilisation and Food Security,* Reykjavik, Iceland, 24 April 2018, http://irena.org/events/2018/Apr/GGA-Side-Events-Iceland-Geothermal-Conference accessed December 2018.

Van Heekeren, V., Bakema, G. (2015), "The Netherlands country update on geothermal energy", *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, 19-25 April 2015, www.geothermal-energy.org/pdf/IGAstandard/WGC/2015/01016.pdf accessed December 2018.

Van Nguyen, M., Arason, S., Gissurarson M. and Pálsson, P.G. (2015), *Uses of Geothermal Energy in Food and Agriculture – Opportunities for Developing Countries*, FAO, Rome.

World Bank (2011), *Missing Food: The Case of Postharvest Grain Losses in Sub-Saharan Africa*, World Bank, Washington, DC.

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