Proceedings World Geothermal Congress 2026
Calgary, Canada, June 8 – 11, 2026

Geothermal Energy for Sustainable Food Production and Preservation: Tackling the Global Crisis of Food Insecurity and Hunger

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Keywords: Geothermal, Sustainable Energy, Food Security, Sustainable Development Goals, Greenhouse, Economic Development, Heating and Cooling, Agri-food Systems, Carbon Reduction, SDG 2

ABSTRACT

Progress towards achieving the United Nations Sustainable Development Goal (SDG) 2: Zero Hunger, remains insufficient as approximately 733 million people still suffer from undernourishment following a sharp rise during the pandemic. Global food insecurity requires transformative solutions within agri-food systems to sustainably increase food productivity and preservation. This paper investigates the direct utilization of geothermal energy for food production and preservation as a strategic solution to combat hunger, reduce waste, and cut emissions. Whether through tapping into low-medium enthalpy systems, or cascade utilization of geothermal resources, there are diverse agricultural uses without adding additional pressure to land and water resources, amongst other sustainable development goals.

By leveraging geothermal energy, integrated agri-food systems, such as greenhouses, aquaculture, food drying, dehydration, and processing facilities, can maintain optimal operational temperatures independent of climatic variability, while reducing the carbon footprint of food production. Drawing on examples from across the globe, this report highlights how geothermal energy enables low emission agri-food operations, backed by carbon reduction calculations. These systems maximize energy efficiency, reduce cost volatility, decrease operational costs, and enhance year-round output.

Geothermal energy's versatility in heating and cooling, drying, and processing not only acts as a substitute for fossil energy use, but aligns directly with SDG 2 by offering a sustainable pathway to affordable and nutritious food. Through supportive policies, stakeholder collaboration and knowledge sharing, geothermal energy can become widely adopted for building climate-smart, resilient agri-food systems that are essential for advancing global food security.

1 INTRODUCTION

Global hunger has reached alarming levels, with approximately 733 million people, about one in eleven globally, suffering from undernourishment in 2023 and one out of every five in Africa (FAO et al., 2024). This marks an increase of 152 million individuals since 2019, underscoring the escalating crisis of food insecurity worldwide (FAO et al., 2024). Rural and marginalized populations are facing the highest risk. These figures highlight the urgent need for transformative solutions in agri-food systems to sustainably increase food productivity and preservation through low emission resources.

The food crisis is a global phenomenon, but affects low-income countries (LICs) the most. The Sahel region and other parts of Sub-Saharan Africa are most affected: together, these regions account for a large share of the 20–30 countries with the most elevated vulnerability to the food crisis and include many countries that are fragile and conflict-affected (Rother et al., 2022). The exposure to the food shock is combined with other challenges, such as weak macroeconomic conditions, poor institutional governance and capacity, and socio-political instability (Rother et al., 2022).

Energy, in particular, underpins every stage of the food value chain, from production and processing to storage and distribution. Yet, the agri-food sector remains heavily reliant on fossil fuels, contributing significantly to greenhouse gas emissions while facing rising energy costs and supply instability (IRENA, 2022). Geothermal energy, as a renewable resource, offers a strategic and underutilized opportunity for sustainable agri-food development. Geothermal energy is always on, making it available year-round independent of climatic variability. As such, it is particularly well suited for agricultural applications such as greenhouse heating,

aquaculture, food drying and dehydration, and processing. These direct-use applications of low-medium enthalpy geothermal systems have been successfully demonstrated in diverse geographies across the globe. Cascade systems are also of importance, which sequentially use residual geothermal energy across multiple temperature thresholds to optimize energy use.

This paper explores the benefits of geothermal energy as a solution for transforming agri-food systems and addressing the United Nations Sustainable Development Goal 2 of zero hunger, drawing on international examples. By highlighting the role of policy, supportive governance, stakeholder collaboration, local capacity building, and knowledge sharing, this report aims to contribute to the broader discourse on climate-smart and resilient food systems.

2 METHODS

This study evaluates the role of geothermal energy in sustainable agri-food systems through a synthesis of global datasets and literature. Key sources include reports and databases from the International Geothermal Association (IGA), International Renewable Energy Agency (IRENA), and the Food and Agriculture Organization (FAO). Global geothermal utilization data were compiled from the IGA direct-use databases (2024) to identify agricultural applications such as greenhouse heating, aquaculture, and food drying. These datasets informed the development of regional maps highlighting geothermal agri-food systems.

3 LOW-MEDIUM ENTHALPY GEOTHERMAL RESOURCES

Low-medium enthalpy geothermal resources, typically ranging from 30°C to 150°C, are well suited for a variety of agricultural applications offering stable, renewable heat for processes that support food security and rural development. These temperature ranges are particularly effective for greenhouse heating, soil warming, aquaculture, and food processing operations, such as drying and dehydration (Lund & Boyd, 2015). Geothermal heated greenhouses enable year-round crop production independent of external climate conditions, which are especially valuable in colder regions or high altitude areas (Ghosal & Tiwari, 2006). Similarly, geothermal aquaculture supports controlled fish and shrimp farming environments, enhancing yield and reducing vulnerability to disease (FAO, 2015). By tapping into local geothermal resources, communities can reduce reliance on fossil fuels, lower operational costs, and create resilient agricultural systems that contribute to both economic and environmental sustainability (IRENA, 2022). These systems not only improve local food availability, but also open new value added opportunities for rural development. There are currently eighty-eight countries that use geothermal for heating and cooling through direct utilization (Figure 1; IGA, 2024).



Figure 1: 88 Countries using geothermal for direct utilization across the globe (IGA, 2024).

Across the globe, 173.3 gigawatts thermal (GWt) of geothermal energy is generated for heating and cooling with 2.4%, representing 4.31 GWt, used in the agriculture sector (Figure 2; Lund and Toth, 2021; IGA, 2024). Based on the calculations by Lund and Toth, the energy savings from the generation of the 173.3 GWt amounts to 822 million barrels (112.0 million tonnes) of equivalent oil annually, preventing 107.65 million tonnes of carbon and 348.2 million tonnes of CO2 from being released to the atmosphere (2021).

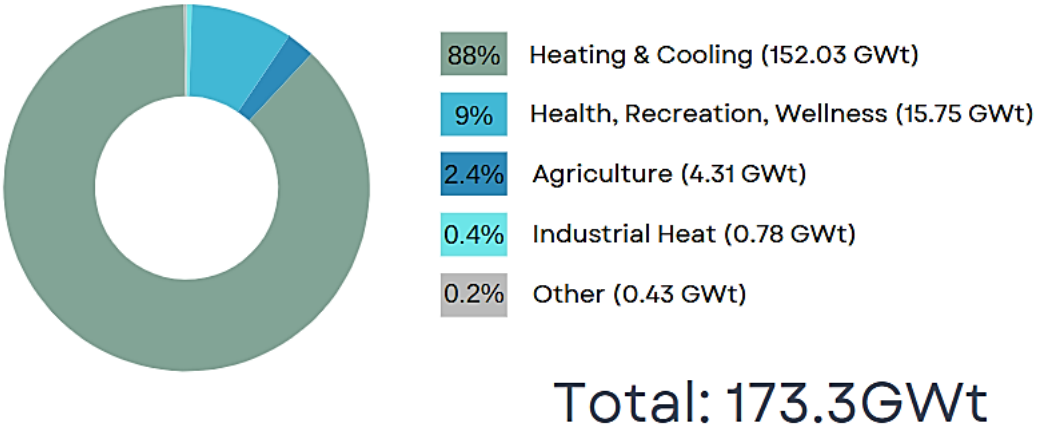


Figure 2: Categories for geothermal direct utilization, modified from IGA, 2024; Lund and Toth, 2021.

Geothermal energy is increasingly being harnessed for agricultural applications worldwide, particularly in countries with accessible low-medium temperature geothermal resources. There are 46 countries that are currently using geothermal within the agriculture sector shown in Figure 3.



Figure 3: Geothermal Map of 46 countries with direct utilization in the agricultural sector (IGA, 2024).

4 CASCADE UTILIZATION OF GEOTHERMAL RESOURCES

Cascade geothermal systems offer a highly efficient approach to utilizing geothermal energy by sequentially applying the residual heat from one process to subsequent lower temperature applications. This tiered use of thermal energy maximizes resource efficiency, minimizes waste, and supports a range of economic activities (Lund & Boyd, 2015; Gudmundsson et al., 2020). For example, high temperature geothermal fluids can first be used for electricity generation, followed by medium to low temperature applications such as district heating, greenhouse cultivation, aquaculture, and food processing. An alternative example involves harnessing low to medium enthalpy geothermal resources for heating, while cascading the residual heat from each process to support subsequent lower temperature applications (Figure 4). For communities, especially remote or resource-constrained regions, cascade systems present a viable opportunity to enhance energy self-sufficiency, reduce carbon emissions, create local jobs, and support year round agricultural productivity. Additionally, integrating multiple uses within a single geothermal system fosters resilience and circularity in local economies, while lowering overall operational costs (IRENA, 2019). The Lindal diagram showcases the geothermal temperatures required for various agri-food systems (Figure 5, FAO 2015; IRENA 2022).

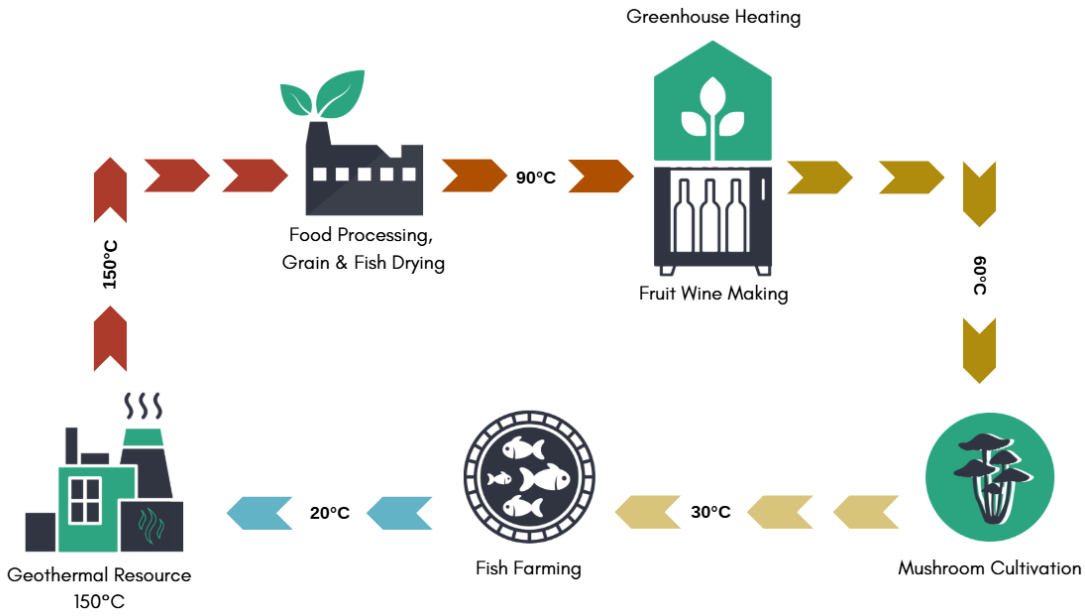


Figure 4: Cascade system where geothermal resource is utilized and residual heat is applied to lower temperature applications prior to re-injection.

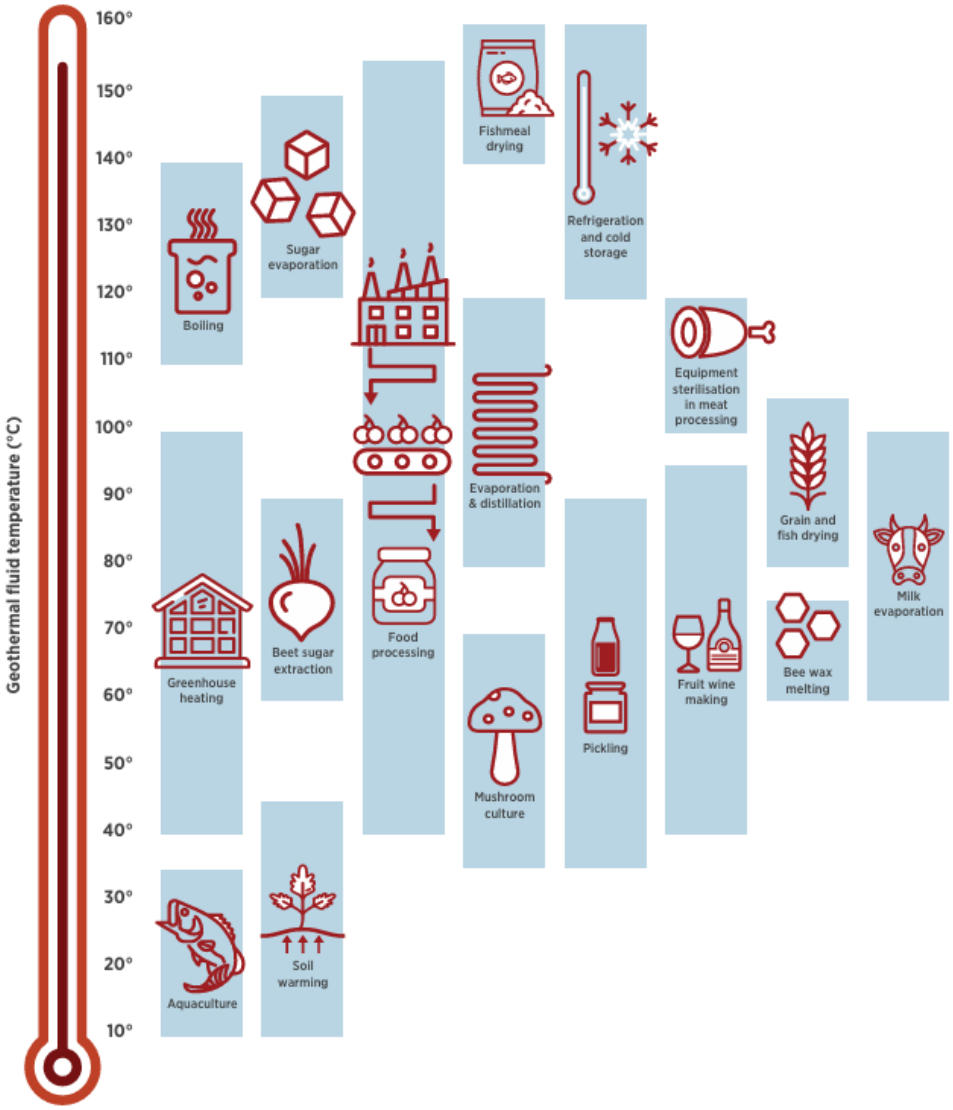


Figure 5: Lindal diagram of geothermal agri-food utilization by temperature (FAO, 2015; IRENA, 2022)

5 UNITED NATIONS SUSTAINABLE DEVELOPMENT GOALS (SDG'S)

Expanding geothermal access in agriculture can boost productivity, support inclusive growth, and generate long-term local employment opportunities, benefiting multiple United Nations SDG's (Figure 6, IRENA 2022). The growing adoption of geothermal heating is driven by concerns over climate change, energy security, fuel price volatility, and sustainable economic growth. As global populations rise, increasing food production without intensifying pressure on land and water resources is critical. Within this context, the water–energy–food nexus provides a pathway for sustainable development, where geothermal is well suited for agri-food systems. (IRENA, 2022). Rising temperatures and shifting rainfall patterns are already affecting agricultural productivity and food preservation, especially in regions lacking cold storage, where geothermal solutions can help adapt to these climate impacts (FAO, 2015). In many developing countries, agriculture remains a key source of employment and empowerment, particularly for women and youth, who produce most of the food supply (IRENA, 2016).

UN Sustainable Development Goal	Description
	SDG 1: End poverty • Due to increased food production, food producers can sell the excess food to boost income. • Value addition of agricultural produce means more income for farmers and employment opportunities. • Agri-food products labelled as "green" due to the use of clean energy and sustainable practices in their production fetch premium prices in the market.
	SDG 2: End hunger • Increased yield from the use of geothermal energy promotes food security. • Food can be grown in environments/conditions when it would naturally not be possible (*e.g.* fruits and vegetables during winter months). • Less food is wasted due to timely processing and cold storage/refrigeration.
	SDG 4: Quality education • Opportunities for higher education are created in relevant fields such as food, agriculture, engineering and finance to support geothermal and agri-food industries.
	SDG 5: Gender equality • Women play a key role in the agri-food sector, particularly in developing countries. Enhancement of agri-food systems through geothermal contributes to improved fortunes for women.
	SDG 7: Affordable and clean energy • Geothermal energy is a clean and affordable solution that provides energy for electricity production or for direct use.
	SDG 8: Decent work and economic growth • Geothermal applications in the agri-food sector offer a wide range of opportunities for productive and sustained employment and economic growth. • Geothermal creates high-quality, long-term jobs with career development pathways.
	SDG 9: Industry, innovation and infrastructure • Geothermal energy applications support the development of resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation in the agri-food sector.
	SDG 10: Reduced inequalities • Decentralisation of agri-food industries to rural areas where most geothermal resources are found provides opportunities for infrastructure development and access to social amenities in those areas. • Employment opportunities for local communities in the development and operation of direct-use projects serve to increase income and reduce income inequality. • Stimulation of the local economy from direct employment and sales to agro-industrial markets results in improved standards of living.
	SDG 12: Responsible consumption and production • Geothermal energy resources are used more efficiently, including through cascading systems. • Co-location of industries that can exchange energy and materials promotes a circular economy.
	SDG 13: Climate action • Geothermal technologies operate with little or no emissions. • Geothermal energy development can reduce CO_2 emissions when substituting the technology for fossil fuels and can help countries achieve their climate objectives and NDCs.

Figure 6: Geothermal agriculture utilization linkages to the United Nations SDG's (IRENA, 2022).

6 APPLICATIONS OF GEOTHERMAL ENERGY FOR FOOD PRODUCTION BY COUNTRY

Geothermal energy supports a wide range of applications within agri-food systems, offering sustainable solutions across multiple stages of the food value chain, from production and processing to storage and distribution. To illustrate the global diversity of these applications, a series of maps using data from the IGA district heating database (2024) have been developed to highlight geothermal agri-food systems for the top 5

producing geothermal energy countries across Latin America (Figure 7), North America (Figure 8), Europe (Figure 9), Asia Pacific (Figure10), and Africa (Figure 11). These regional examples demonstrate how geothermal resources can be harnessed to strengthen food security, enhance productivity, and build climate-resilient agricultural systems.



Figure 7: Latin America geothermal energy uses in the agriculture sector

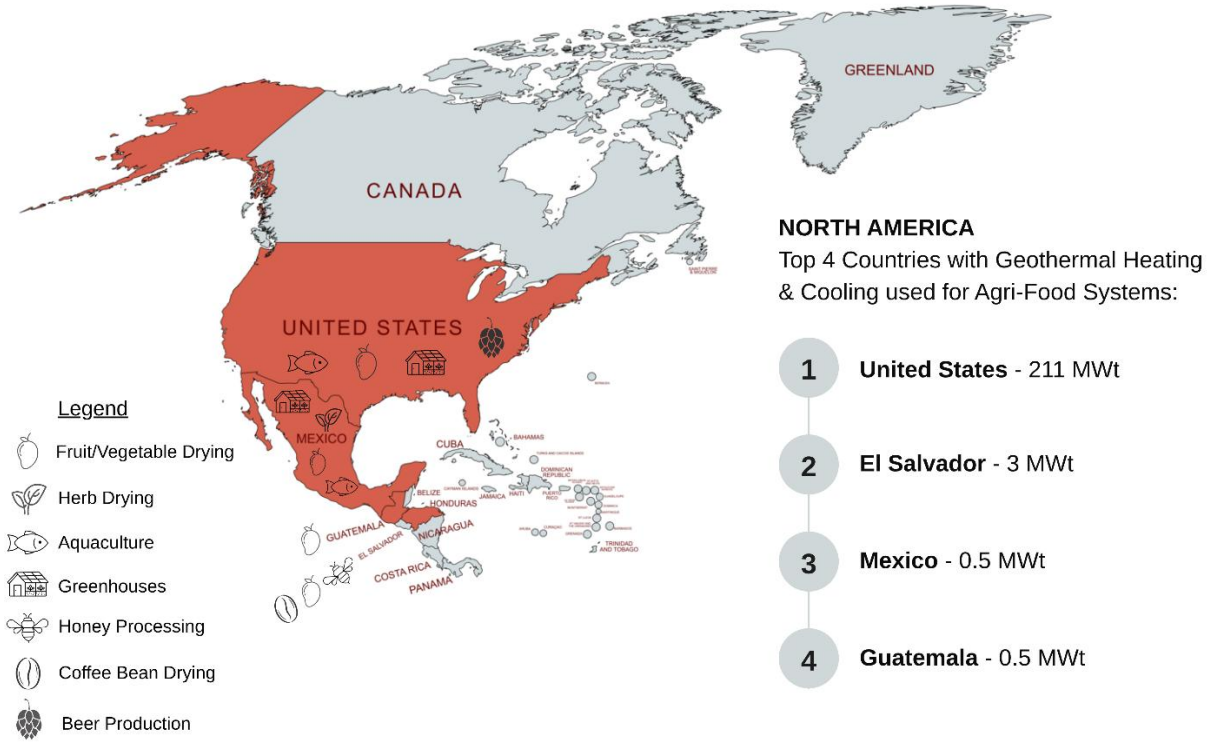


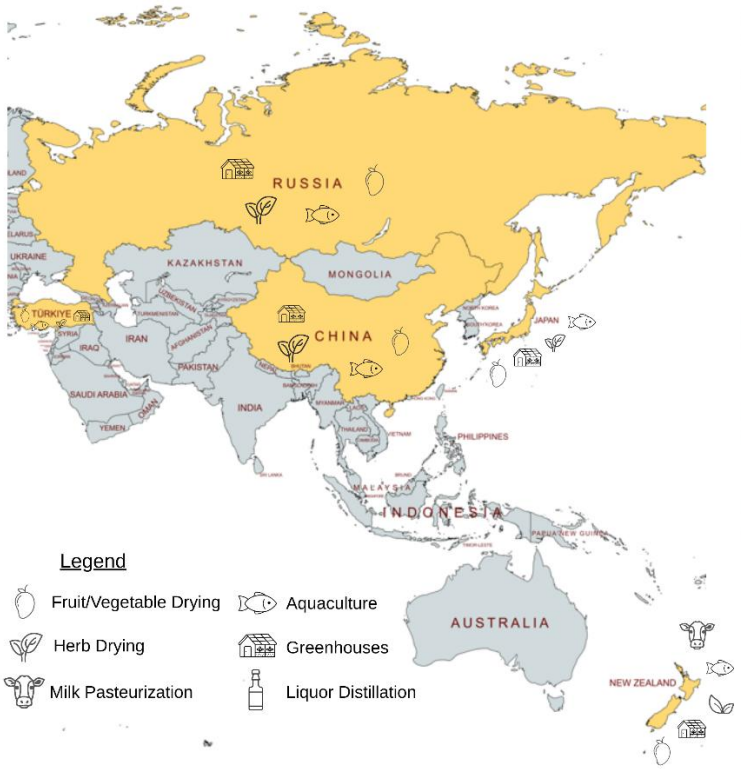
Figure 8: North America geothermal energy uses in the agriculture sector



EUROPE
Top 5 Countries with Geothermal Heating & Cooling used for Agri-Food Systems:

1. **Turkey** - 1,240 MWt
2. **Hungary** - 402 MWt
3. **Iceland** - 320 MWt
4. **Netherlands** - 230 MWt
5. **Italy** - 133 MWt

Figure 9: Europe geothermal energy uses in the agriculture sector



ASIA PACIFIC
Top 5 Countries with Geothermal Heating & Cooling used for Agri-Food Systems:

1. **Turkey** - 1,240 MWt
2. **China** - 1,108 MWt
3. **Russia** - 173 MWt
4. **New Zealand** - 41 MWt
5. **Japan** - 39 MWt

Figure 10: Asia Pacific geothermal energy uses in the agriculture sector

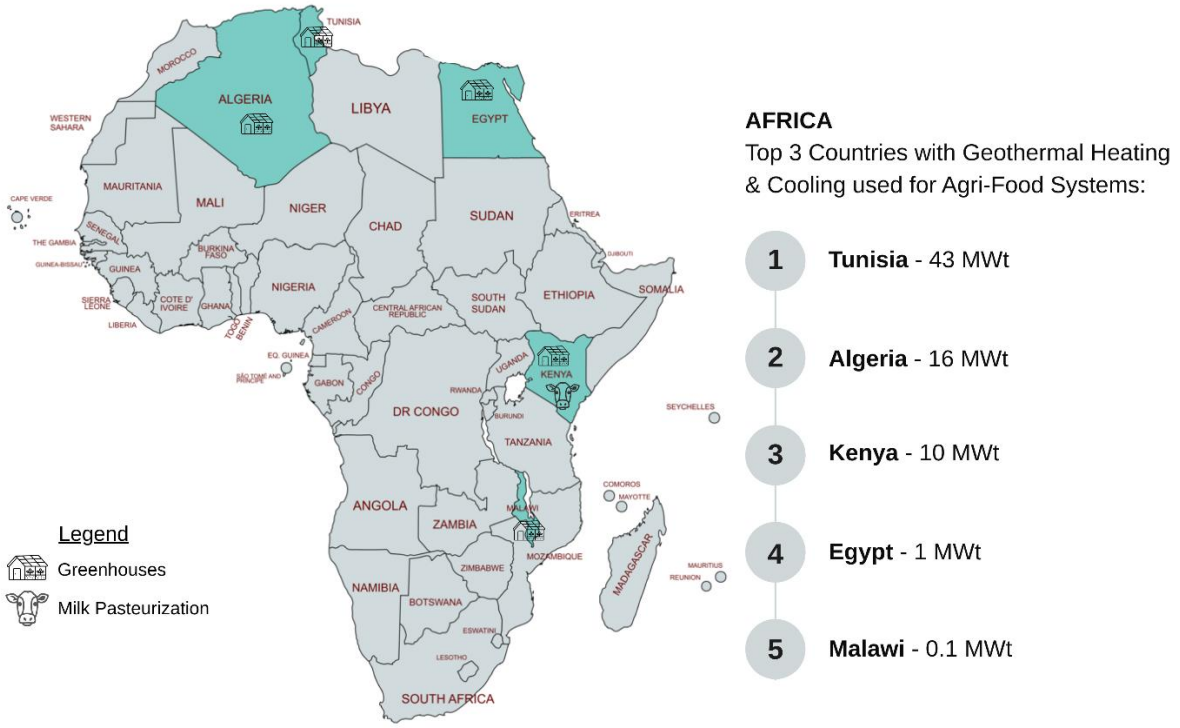


Figure 11: Africa geothermal energy uses in the agriculture sector

7 POLICY, STAKEHOLDER COLLABORATION & KNOWLEDGE SHARING

Achieving wide scale adoption of geothermal energy in agri-food systems requires not only technological feasibility, but also a strong enabling environment supported by coherent policy frameworks, multi-stakeholder collaboration, and systematic knowledge exchange. The interplay between these elements determines the pace at which geothermal solutions can be mobilized to enhance food security.

A roadmap to scale geothermal deployment in the agri-food sector with these elements is shown in Figure 12.



Figure 12: A roadmap to scale up geothermal deployment in the agri-food sector (modified from IRENA, 2022).

7.1 Policy and Institutional Frameworks

Policy alignment is central to integrating geothermal energy into national food security and energy strategies. In many countries, geothermal development remains confined to power generation rather than direct-use applications, despite the proven potential of low-medium enthalpy systems for agricultural productivity (IRENA, 2022). To unlock this potential, governments must adopt cross sectoral policies that bridge the energy, agriculture, and environmental sectors.

Supportive measures include:

- Incentive structures such as feed-in tariffs, tax credits, or concessional financing for geothermal heat projects used in food processing or greenhouse operations.
- Integrated planning frameworks that incorporate geothermal resources into national agricultural and rural development plans.
- Regulatory streamlining, including simplified licensing and land use procedures for direct-use geothermal installations.
- Public investment in heat infrastructure, such as district heating networks or shared cascade utilization systems for agribusiness clusters (Gudmundsson et al., 2020)

Integrating geothermal energy into agri-food systems depends on well coordinated government policies and regulatory frameworks. Consistent and coherent policy alignment helps unify national objectives, attract both public and private investment, and ensures that the full benefits of geothermal applications are realized. Governments play a pivotal role in advancing geothermal adoption by establishing clear targets and standards, promoting awareness, strengthening institutional and technical capacity, investing in research and innovation, and developing infrastructure that enhances market accessibility (IRENA and FAO, 2021). In developing and emerging economies, these policy interventions can help overcome high upfront costs that currently limit private investment. Targeted policy coordination is also essential to mitigate the compounded food, energy, and macroeconomic shocks that heighten vulnerability in low income and fragile countries (Rother et al., 2022).

7.2 Stakeholder Collaboration and Partnerships

Transformative change in agri-food systems depends on the collaboration of diverse stakeholders, governments, research institutions, private developers, farmers, financial institutions, and international organizations. Effective partnerships can pool resources, share risk, and accelerate innovation uptake.

Examples from Iceland and Kenya demonstrate that public–private partnerships (PPPs) and community based geothermal projects can deliver shared benefits by integrating agricultural production with local heat utilization (FAO, 2015; IRENA, 2019). Such models foster inclusive development, enabling access affordable, clean thermal energy. Collaboration also extends to regional and international platforms to facilitate policy dialogues and technical cooperation. Multilateral financing institutions play an important role in de-risking investments through blended finance mechanisms and capacity-building programs.

7.3 Knowledge Sharing and Capacity Development

Knowledge exchange is pivotal for scaling geothermal adoption across the agri-food sector. Awareness gaps remain a major barrier to deployment. Building local technical capacity in geothermal resource assessment, system design, and operation enhances project sustainability. Universities, geothermal training centers, and international agencies can support this through joint research programs, regional workshops, and demonstration projects. For instance, the FAO's initiatives in East Africa have created replicable frameworks where geothermal demonstration farms act as hubs for training and technology transfer. Digital knowledge sharing platforms also facilitate the dissemination of operational data, best practices, and policy toolkits. Open access databases and collaborative networks enable practitioners and decision makers to learn from global experience, adapt technologies to local contexts, and track measurable progress toward SDG targets.

8 CONCLUSION

Progress towards achieving the United Nations Sustainable Development Goal (SDG) 2: Zero Hunger, remains insufficient with global food insecurity requiring transformative solutions in agri-food systems to sustainably increase food productivity and preservation through low emission resources.

The direct use of geothermal energy within agri-food systems offers a sustainable, resilient, and inclusive pathway toward achieving global food security and broader sustainable development goals. By providing stable, renewable heat for food production, processing, drying, and storage, geothermal applications enhance productivity, reduce food loss, and extend product availability beyond seasonal limits. These systems also create significant socio-economic benefits supporting job creation, empowering women and youth, and stimulating local enterprise development, particularly in rural and developing regions where agriculture remains the main livelihood source. Beyond socioeconomic gains, geothermal utilization contributes directly to climate

change mitigation and adaptation by lowering greenhouse gas emissions and helping food systems withstand temperature fluctuations and resource constraints.

The global examples of geothermal supporting agri-food systems demonstrate the diverse opportunities available. These regional examples highlight how geothermal resources can be adapted to different climatic, economic, and agricultural contexts to strengthen food security, enhance productivity, and build climate resilient agricultural systems. Cascade utilization models further exemplify how geothermal energy can be efficiently integrated into circular, low carbon economies that maximize resource value.

To realize this potential, coherent policy frameworks, cross-sectoral coordination, and sustained knowledge exchange are essential. Supportive government policies, coupled with public–private partnerships and strong research and training networks, can accelerate investment, technology transfer, and capacity building. Together, these efforts will enable geothermal to grow into a cornerstone of climate-smart agriculture.

Ultimately, embedding geothermal energy into agri-food planning demands a systems-thinking approach, recognizing that food security, clean energy, and climate resilience are deeply interconnected. Through effective governance, innovation, and collaboration, geothermal direct-use systems can drive the transition towards zero hunger.

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