SOLUTIONS FROM THE LAND

Voices of Farmers Around the World:

Circular Approaches for Scaling Bioeconomies

2026

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Circularity practices hold high potential for the renewal, recycle, reuse, regeneration, and recovery of material and natural resources

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INTRODUCTION

There is considerable agreement that local and global agricultural systems must produce an abundance of food and more nutritious diets, improve rural incomes, safeguard the environment, and reduce the release of pollutants into ecosystems. With populations expanding, agrifood systems are faced with a dilemma: how to meet urgent food insecurity and malnutrition needs, protect the environment, not add to the earth's pollution, not compromise future capacities, and manage food production while concurrently delivering ecosystems services and providing opportunities to farmers[1].

Modern agriculture has been extraordinarily successful in increasing productivity and improving efficiency in delivering agricultural outputs. However, the current system is highly dependent on external inputs for plant nutrients, pesticides and energy. Linear production and consumption paths of 'take resources-make use-discard waste' often lead to lost resources and environmental pollution. The discard of waste byproducts is costly and does not promote healthy ecosystems, which are the basis of sustainable production. Circular approaches prioritize designing systems to account for resource uses. This involves recycling and renewing resources to better manage carbon; retaining, recycling and protecting water resources; reducing nutrient loss; and eliminating production and processing residues that might harm the environment and deplete resources. Recovering and retaining the value of material and biobased resources that otherwise might be wasted and left behind to do environmental harm is a model with potential to transform agriculture and food systems. Solutions for transforming agriculture and food systems that are realistic, practical and networked within and across local and regional bioeconomies are central to sustainability.

Farmers and agrifood systems value chain partners are key players in accelerating progress towards ending hunger and improving nutrition, enhancing biodiversity and delivering ecosystem services. **Circularity practices hold high potential for the renewal, recycle, reuse, regeneration, and recovery of material and natural resources** that in linear systems would be discarded as low value and waste that can harm the environment (Morton and Shea, 2022; 2025). Sustainable and circular agricultural systems harmonize economic, social, and ecological sustainability across production, utilization, conservation, and regeneration of material and biological resources (FAO, 2024a; Morton and Shea, 2025).

A better environment promotes the efficient use of renewable resources to replace and recycle fossil-based

[1]The term "farmers" encompasses farmers, ranchers, pastoralists, orchardists, fisherfolk, aquaculturists and all those who are stewards of working agricultural landscapes. Working landscapes are agricultural croplands, grasslands, orchards and forests, vineyards, fisheries, and other lands and waters that are managed for livelihoods and the production of food, fiber, energy, and ecosystem services.

Photo Courtesy of Girgis

resources with a strong focus on circularity and cascading uses of biological resources to regenerate ecosystems, ensure biodiversity, and adapt to and mitigate changes in short and long term weather. Circularity can reduce input costs, retain and add value in the production of agricultural co-products, and increase farmer profitability to achieve production and economic goals that stimulate local and regional economies and lead to better production and better life. Circular system approaches enable farmers to retain value and increase production to ensure household and community food security and better nutrition.

This report features farmers, the people who are safeguarding local and global food security and nutrition, and describes how they are managing their small, mid-size and large-scale farm enterprises to ensure productive systems and livelihoods. In interviews, farmers talked about drought and flooding, the management of soil and water resources, the technologies they were using, the protection of their environment, market conditions, policy barriers, and infrastructure needs. **They shared their adaptations, experiments, and the changes they had made in their operations to better manage challenges and uncertainties.** Each story describes their unique pathway that reflects specific geographical conditions and climates, crop-livestock systems, personal goals and cultural values, and farm and community resources. Some farmers have just begun their circular bioeconomy journey; others have more mature complex, multi-dimensional circularities.

Despite the variations in their production systems and scales of operation, they share a belief that circularity works for farmers. They reuse and recycle farm waste and byproducts and find ways to turn them into new, profitable products and/or to reduce input costs and decrease the side effects of potential environmental pollutants. Circular agriculture approaches enable farmers to improve and regenerate soil, water, and air; maintain pollination and biodiversity services; and to add value to their farmland, the wider watershed, and regional natural systems. Circular systems change the dynamics of local, regional and national economies, transforming entire agriculture and food systems and value chains into sustainable bioeconomies.

Circularity in bioeconomies on the farm and in the community

Farmers and those who work the land and waters to provide food resources are critical building blocks of food and nutrition security and local and global agrifood systems. The intent of establishing on-farm circularity is to diversify revenue streams, reduce costs, manage waste, supplement on-farm feed, take control of the farm supply chain, and work with others to create sustainable solutions that increase farm and community resilience (Basso et al., 2021; FAO, 2024b). A close look at

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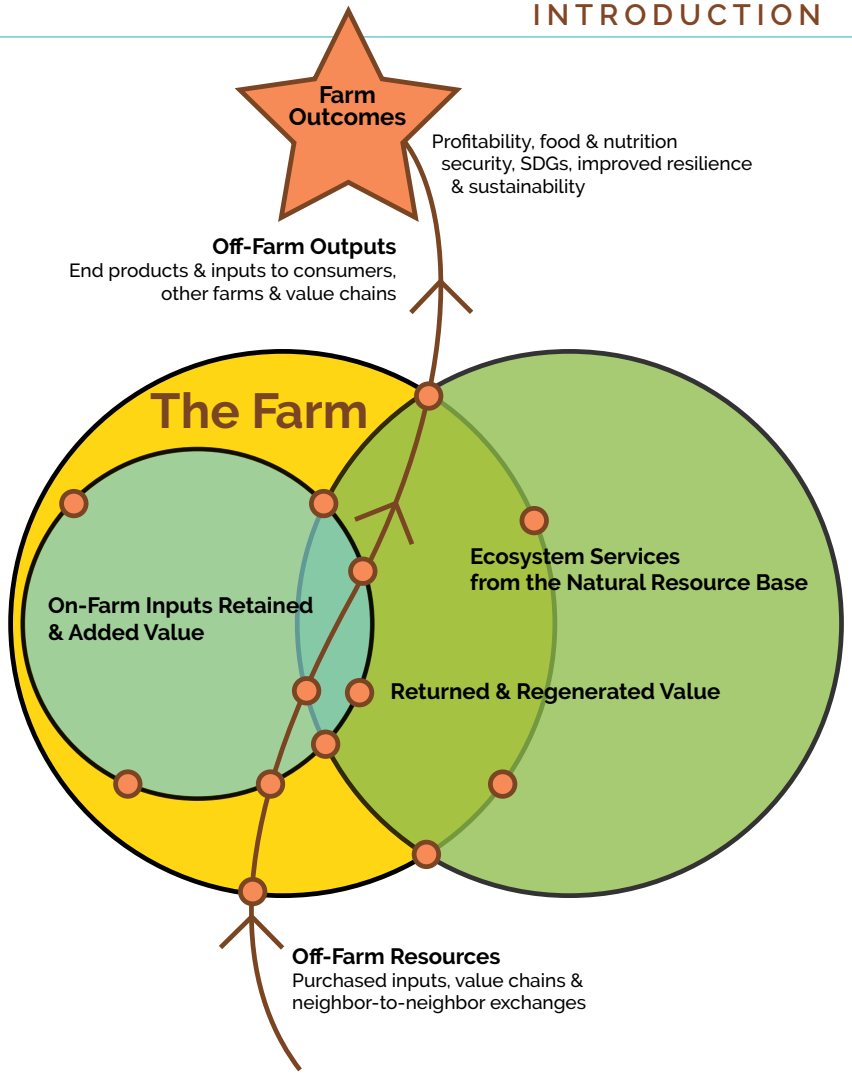

Figure 1. Farm-level circularity and the bioeconomy

Source: **Morton, L. W. & Shea, E. 2025.** Farm level circularities as solution pathways to sustainable development goals (SDGs). *Journal Natural Resources and Agricultural Ecosystems.* Volume 3(2), 81-87. https://doi.org/10.13031/jnrae.16192

where farm-level circularity might emerge reveals intersections and connections among farm resources (water, soil and other ecosystem services) and off-farm resources that can be adjusted and redesigned to accelerate the achievement of the goals of the agricultural enterprise. These intersections and connections are represented in **Figure 1.** Orange circles represent nodes where investments in circular practices at the interface of farm systems, ecosystem services, off-farm inputs, and off-farm outputs have the potential to retain and generate value; improve efficiency, profitability, resilience, and sustainability; and meet farm needs while achieving broader societal goals.

One of the first principles of successful circular approaches is to recover, recycle and reuse resources within the farm system before importing resources from outside the system (Barros et al., 2020). Each agricultural enterprise has nodes, places in their systems where increasing circularity at the intersections of resource inputs and/or outputs could reduce waste and pollution and improve efficiency. Figure 1 illustrates where circularity has potential to be implemented in agricultural production systems (Morton and Shea, 2025):

- within the farm system when farm-produced inputs are substituted for off-farm purchases and new products are generated;
- at the interface of the farm system and ecosystem services;
- at the interface of off-farm inputs and external resources; and
- at the interface of the farm system and off-farm outputs and products.

Activities at these nodes that promote and accelerate circularity include single and combinations of practices that improve soil-water dynamics and drought resistance, reduce the costs of crop nutrient inputs, retain the value of on-farm resources, regenerate natural systems, and develop new co-products that can be used on the farm and elsewhere. For example, integrated crop-livestock systems use materials that are considered as 'waste' to increase yields and the nutritional

value of crops and improve soil fertility **(see Figure 2 example)**. This system also retains the value of agricultural inputs for on-farm feed and forage and can generate biofuels along with co-products of meat, milk and other nutritious food. The recycling of drainage water, another circular practice, can supplement crop irrigation.

Another practice is planting cover crops, which can regenerate the soil, reduce soil erosion, improve soil structure and increase beneficial microbial activities. This on-farm retained value at the intersection of production systems and ecosystem services can retain the value of soil and water resources and produce forage for on-farm livestock or for neighboring producers.

To scale up circularity, research has found that bundling tools and practices can effectively increase productivity. **Bundling is a strategic practice of combining complementary innovations, technologies, practices, interventions and services to achieve multiple goals concurrently** (Agnew and Nakelse, 2024). Even minor shifts in technologies and management at these nodes can lead to major changes (Meadows, 2008; Morton and Shea, 2022; Korhonen-Kurki et al., 2024). Morton and Shea (2025) identify six questions farmers can ask to evaluate the benefits of making changes at different nodes within their current systems:

1. Will this change retain and/or add value to a farm-generated input and provide a substitute for an off-farm resource?
2. Will this change retain and/or add value to the farm or the broader landscape and maintain and regenerate ecosystem services to improve the resilience of the natural resource base?
3. Will this change expand circular approaches and biosystems networks through off-farm inputs and expand access to resources (e.g. raw materials, recycled and regenerated co-products from circular economy networks, education and training, science and technologies, and public/private infrastructures)?

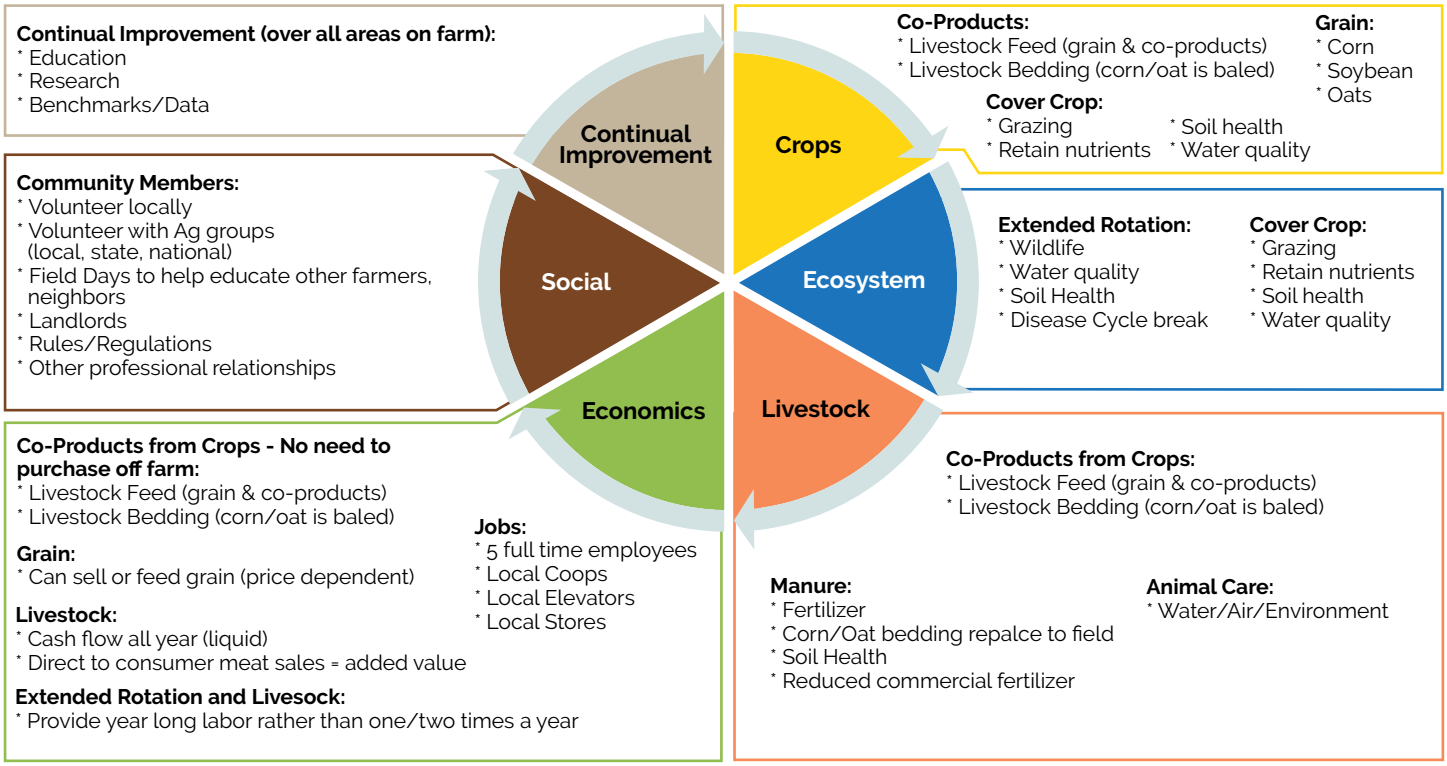

Figure 2. The Blair Farm, LLC Circle of Life, a continuous improvement process exemplifies a circular system; where adjustments and adaptations in a diversified crop-livestock system are evaluated in light of changing markets, weather, disease, soil and water resources

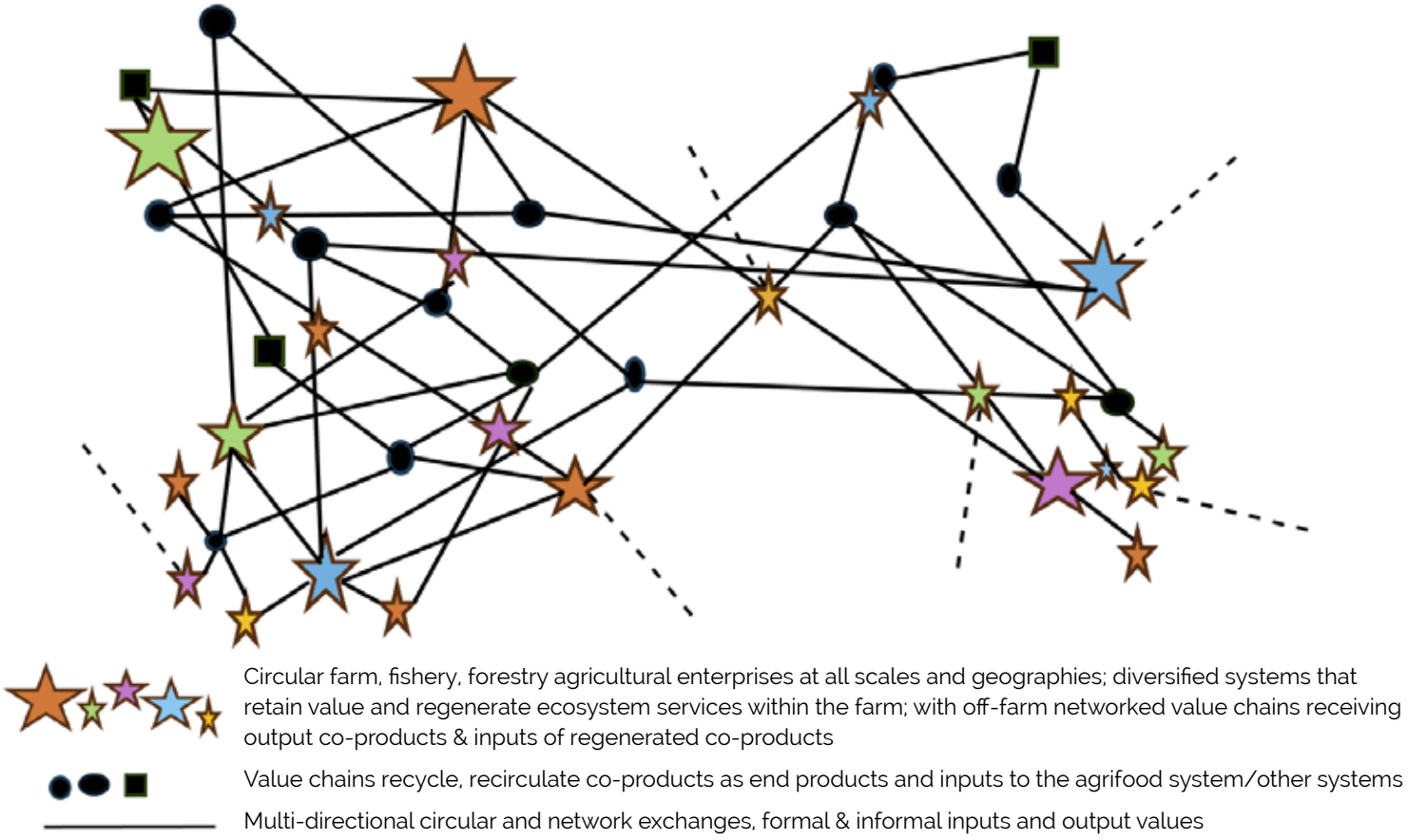

Figure 3. Agriculture and food systems circular and networked bioeconomies, where one farm's outputs and outcomes are another farm's off-farm input resources, multiplying the impacts of community and regional circularity

4. Will this change expand off-farm outputs (co-products) for consumption beyond the farm gate as consumer end-products (e.g. food, energy) and inputs to other farms and value chains?
5. Will this change lead to farm outcomes that achieve farmer goals (e.g. increased efficiencies, profitability, reduced labour time and costs, improved soil health, increased water availability and quality, and promotion of pollination, beneficial microbial activity, and biodiversity)?
6. Will this change achieve community, regional, and national goals and outcomes for food and nutrition security, biodiversity and environmental health, and more robust livelihoods and economies?

Circularity implemented for farm and community resilience arises from extensive feedback loops, cascading circularities (multiple uses, reuse, recycle, and repurpose before product end-life) and networked bioeconomies on the farm and beyond the farm gate **(Figure 3)**.

Observational and data-based monitoring systems enable continuous improvements with response systems that improve efficiencies and serve as early warning systems that can redirect potential catastrophes and restore systems under stress (Meadows, 2008). Feedback loops in networked bioeconomies enable adaptive management that improves farm and network learning. These loops can help build the capacities of producers to redesign individual systems in timely ways and encourage the evolution of circularity in the larger network (Fiskel, 2015; Tait et al., 2023).

The stories of farmers around the world that follow illustrate how farmers are leveraging these strategic nodes to implement practices that initiate, accelerate and scale-up the circular practices in their production systems. These successful circular practices are spilling over into their local communities, expanding local bioeconomies and transforming agrifood systems.

STORIES FROM FARMERS AROUND THE WORLD

Farmers are the beginning of the food system. They live with and work the lands, waters and forests daily. They manage working landscapes and juggle multiple interdependent and intersecting systems. As stewards of working landscapes producing food, fiber, energy, ecosystem services and livelihoods, twelve farmers are showcased in this report. These stories are only a small sample of farmers from different regions around the world **(see figure 4, world map)** who are experiencing local and global climate and market disruptions and uncertainties and are seeking new pathways to address these challenges. Farmers were invited to participate based on their innovative approaches, efforts to experiment and try new strategies, and leadership in transforming their farms in ways that increase their capacities to manage risk and to increase productivity and profitability with nature-positive environmental outcomes.

Selection criteria included examples of different agricultural systems and regions with a focus on:

- One or more weather/climate-related management strategies they had implemented to respond to changing conditions in their region and ways they are seeking to improve their farming, forestry and/or fishery management systems.
- Efforts to experiment with farm- and community-level circular systems that produce multi-benefit agricultural and forestry products that:
  - reuse, recycle and re-invent farm waste and byproducts into profitable co-products and healthy ecosystems; and
  - improve local ecosystem resource abundance and quality such as soil, water, air, vegetation and biodiversity while providing co-benefits to their households, farms, environment and community.

Figure 4. Stories from farmers around the world:

1. Namibia
2. South Africa
3. Uganda
4. Ireland
5. Italy
6. Thailand
7. Australia
8. Australia
9. Brazil
10. Peru
11. Canada
12. United States of America.

Photo Courtesy of Bob Lowe

1. Namibia: Drought makes farming more difficult but more crucial

Elize Eliphas

Elize Eliphas, a graduate of the Namibia University of Science and Technology, manages 4,400 hectares in the Hardap region of southeast Namibia. The land, which is semi-arid, rocky and mountainous, is much more suited for livestock production, especially sheep and goats, than for large-scale crop production. She and her four employees manage 500 sheep and goats and 40 beef cattle that graze the native range as well as chickens for egg production, a few pigs and a small garden. She takes an integrated approach in which livestock support her garden and the garden supports her animals.

Eliphas sells her livestock at local auctions or to individual buyers. She sells the produce from her gardens to a local agent who supplies lodges and hotels for tourists.

Circular approaches

Eliphas's garden is small but diverse. She focuses on planting a diversity of crops that have high yields or produce multiple harvests (e.g. spinach, beetroots, green peppers and potatoes). This sustains biodiversity and is economically sound. She rotates crops to improve the soil and control pests. For example, she may plant beans, a nitrogen-fixing crop, then tomato, then beetroot. A portion of the garden is planted in alfalfa, which she cuts to provide supplemental feed to her livestock, especially the weaker animals who need of higher quality nutrients. Her livestock, especially the chickens and goats, provide manure that she composts and uses as fertilizer for the garden. The livestock also eat garden waste. She uses empty livestock feed bags, originally purchased from local suppliers for supplemental livestock nutrition, as mulch for her garden. She also uses plant materials as mulch.

Challenges and adaptations

Climate, soil and water

Drought has been Eliphas's greatest challenge, she says. Her land did not receive rain in 2023 or 2024. In May 2024, the Government of Namibia declared a state of emergency "due to El Niño induced drought – regarded as the worst in 100 years" (WFP, 2025). The World Food Programme (WFP) reported that 1.26 million people were expected to be included in Integrated Food Security Phase Classification (IPC) 3 (crisis status) or higher during October 2024 to March 2025, with 100 000 in IPC4 (emergency status) (WFP, 2024).

Photo Courtesy of Elize Eliphas

Drought is not new in Namibia, but the rains have been increasingly irregular. "Sometimes you receive below normal, sometimes more, sometimes you receive little to nothing," Eliphas says.

Drought has dried up much of the native pastures grazed by Eliphas's livestock. This has led to nutritional deficiencies in her livestock, which has hindered their reproduction and reduced farm productivity and profitability. Eliphas has had limited success with planted pasture because the environment is semi-arid. Her primary method of adapting to drought conditions has been to sell livestock the land can no longer support. However, she has recently started participating in a program of Namibia's Ministry of Agriculture, supported by the Food and Agriculture Organization. Through this program, which launched in 2019 in response to the drought, Eliphas purchases barley seed from local shops and grows them hydroponically. After only seven days, the barley sprouts can provide good nutrition for her livestock.

"We just started in September 2024," Eliphas says. "It is very new, but the livestock like it. They are eating it well."

Because of the drought, Eliphas has become conscientious about saving water. She uses drip irrigation to water her garden and covers the soil with mulch to keep it cool.

Policy

Eliphas says agricultural policy in Namibia influences garden establishment, livestock vaccinations and the timing of crop spraying. She says subsidies should be considered to ensure they add value to the farm and enable farmers to run farms more successfully. The economics of farming is difficult, especially when confounded by drought. Food security is paramount.

Photo Courtesy of Elize Eliphas

Next steps in applying circular approaches

Eliphas is concerned about continued drought, so she is interested in building up her poultry and pork production because the chickens and pigs do not depend on pasture. She is also researching possibilities for buying raw materials needed to mix her own livestock feed to cut costs associated with buying premixed livestock feed.

Circularity in the community

Eliphas says farmers in her area may not engage in integrated farming due to lack of knowledge and not feeling empowered.

"Even if they want to do integrative farming, they may not know how to start," Eliphas says.

She sees sharing information and giving farmers the opportunities to gain exposure to what others are doing as the way to overcome these challenges. She points to events that have been sponsored by government and non-governmental organizations that have brought Namibian farmers together as a way for farmers to learn from one another.

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2. South Africa: Turning food waste into feed for chickens

Maya Zaken and Jason Fine

Business partners Maya Zaken and Jason Fine are very aware of the issue of food waste.

Nearly one-third of all food produced globally is lost or wasted across the entire supply chain. Not only does food waste and loss take away from food security; it is economically and environmentally costly, generating losses of USD 1 trillion annually and 8-10 percent of annual global GHG emissions (UNEP, 2024).

In August 2022, to reduce food waste and contribute to greater local food sustainability, Zaken and Fine came together to launch their company, Philafeed. Philafeed uses food waste to raise black soldier flies, whose larvae are a protein-rich source of livestock feed.

Black soldier flies have a six-week life cycle. The adult flies, which live for only six days, lay eggs near a source of waste. When the eggs hatch, the larvae (maggots) feed off the waste before going dormant and transforming into flies.

Since feed makes up the largest costs of livestock production, Zaken and Fine could see that recycling food waste by raising black soldier flies could deliver a wide range of benefits.

"I was quite sold by the circularity of the black soldier flies," Zaken says. "It met all three of those [sustainability] areas [environmental, economic and social], which I really love."

Philafeed started by growing black soldier fly larvae to sell to livestock producers. They experimented with greenhouse production but settled on growing in climate-controlled shipping containers. The containers are good for any geography, and they keep the flies at their preferred temperature: 28 degrees Celsius, which South Africa naturally achieves in the summer but falls short in the winter.

Philafeed recently changed its business model to focus on selling the growing systems directly to livestock producers. Zaken and Fine have also added laying hens to their operation to add another layer of circularity.

They have set up a 12-meter container for growing black soldier flies in Citrusdal, about 160 kilometers north of Cape Town, South Africa. The container can hold up to 1 tonne of food waste per day and produce enough larvae to feed 4,000 chickens. Half of the chicken feed is made from black fly larvae.

Circular approaches

Philafeed delivers reusable blue drums for collecting food waste to partnering local restaurants and farms. Philafeed puts the waste in the climate-controlled shipping containers where the black soldier flies lay their eggs. The flies are harvested in the larval stage and used to feed laying hens. The hens lay eggs, which are sold back to the restaurants. Both the flies and chickens also produce waste, which can be used as fertilizer for the land.

Challenges and adaptations

Markets and local conditions

When Philafeed started, Zaken and Fine's aim was to sell black soldier fly larvae to livestock producers as a protein-rich feed ingredient. There was a lot of interest among poultry farmers, but Zaken and Fine realized this approach did not have an economic impact for the farmers.

Fly larvae have the potential to be a cheaper protein source for farmers. However, their focus on producing larvae to sell to farmers made it difficult for Philafeed to make a profit. Zaken and Fine needed to sell the larvae at about the same price that farmers already pay for feed. That's why they shifted to selling their container systems so farmers could grow their own larvae from food waste as chicken feed. The containers come with an application that farmers can use to virtually manage the process and track their data.

Load shedding, or power cuts, pose a challenge to the budding soldier fly industry. This situation, along with other local conditions, have created investor fatigue.

"Black soldier flies are marketed as the cheap solution, but it is not necessarily cheap in the beginning to get infrastructure properly in place," Zaken says.

Photo Courtesy of Maya Zaken

Fine points out it is difficult to monetize anything in the waste industry because there is little incentive for businesses to handle waste well.

"If things were handled correctly, it would make circularity a lot easier, down to the simple idea of sorting waste at the source," Fine says. "If waste is sorted, it solves most of the problems of waste management. There is no or less contamination, and the environment is healthier."

Heating the climate-controlled containers is the most expensive element of Philafeed's growing systems. Zaken and Fine continue to look for ways to improve this system. Solar power is an option they plan to offer in their container systems. However, solar power is limited in some locations where mountains block the sun. Financing the conversion to solar power is also a challenge. They plan to connect to solar power themselves when funds allow.

Africa's tropical climate is great for growing flies. "The warmer the better," Zaken says.

Policy

Zaken and Fine have heard regulations are coming to the black soldier fly industry, but what they will entail is yet unclear. They say the regulations that cover their production system are outdated. There is a great deal of bureaucracy to complete the necessary registrations. They are watching to see how regulations shape up because that may determine shifts in how they do business.

One area of concern is how future regulation will view food waste. The European Union (EU) has strict regulations prohibiting the use of post-consumer food waste, which means companies that export to the EU from South Africa cannot feed fly larvae with food waste. If South Africa

Photo Courtesy of Maya Zaken

matches this EU requirement for domestic production in its legislation, it is possible that Philafeed may not be able to use food waste to feed fly larvae.

"It would be such a waste if we were not able to process post-consumer waste," Fine says. "There is so much value that is getting lost, and we have a way of recapturing those nutrients. So, for now, we are just waiting to find out what happens."

Zaken says education is key.

"A lot of people are disconnected from the food system, myself included up until about three years ago," Zaken says. "I think circularity within agriculture can only really be achieved if people understand their role within their food system and why food waste matters. People are getting more in tune with where their food comes from, but there is that missing link of food waste, which is not really waste; it is just all grouped under waste."

Next steps in applying circular approaches

Selling eggs is Philafeed's next area of priority. Beyond that, Zaken and Fine are interested in buying in bulk or looking at reusable and returnable packaging to reduce plastic and other dry wastes. They are also considering getting a rain tank to collect water, and they want to improve upon their energy use in the containers.

Circularity in the community

Zaken says she sees circularity as part of South Africa's farming culture, especially in the Garden Route along the southeastern coast of South Africa where they previously farmed.

"Farmers are generally getting the short end of the stick in the food system, so if they are going to have to pay for an additional product that is more sustainable or circular, they are not," Zaken says. "But I would argue that a lot of farmers cannot afford not to be circular."

She says it is common for farmers to sell their livestock manure, and she points to local wine producers who compost because they know the value of their byproducts.

"I would say there is a lot of collaboration amongst farmers in the area," Zaken says, though she adds that agricultural waste is still a problem for many farmers. "We have worked together in ways that are mutually beneficial. If anything is hindering it, it is money and time. Do they have additional time to add value to that product, or is it worth it just to discard it?"

3. Uganda: Two circular stories - pigs support crop production

Ngonzi Tape and Bangi Robert

Ngonzi Tape and Bangi Robert are two Ugandan farmers from different villages in the Kamuli District of Eastern Uganda. Tape, a widow who cares for her grandchildren, raises pigs and chickens and tends a garden. Robert also farms with his family. He has two gardens: one of amaranth and the other of cacao. Each of Tape's and Robert's gardens are 1.2 hectares and produce food for their households and to sell at local markets. Tape has been farming for 38 years and Robert for 20. In 2024, both started working for farmer training programs offered by the Center for Sustainable Rural Livelihoods (CSRL), which was established by the Iowa State University - Uganda Program (CSRL, 2025).

Circular approaches

Tape feeds her 15 pigs with food and garden waste as well as a blend of maize and soy. She dries the pig manure, which attracts flies that produce maggots. She feeds the maggots to her 30 chickens, which produce eggs and meat for her family. She also sells eggs, chicken and pigs at the local market to produce an income for her family. She puts the chicken manure back onto her garden as fertilizer. In her garden, she grows sweet potato, bananas and grass utilized by the pigs.

Robert grows cacao in an orchard (1.2 hectares). Three or four years after planting cacao, he can harvest the pods. From the pods he gets juice and seeds. He sells the juice and some of the seeds at the local market. When splitting the pods, he saves some of the fresh juice for his family. He ferments the rest of the seeds for six days and dries them, which he uses to create a liquid that he applies as a pesticide in his gardens. The dried seeds are sold to community venders who then sell to exporters.

Dried cacao pod hulls are burned as fuel. The ash is used as a fertilizer under his cacao trees. In 2024, Robert introduced three pigs into his operations. The pigs forage beneath his cacao trees, and their manure fertilizes the soil. The pigs also consume waste from his amaranth garden. He sells amaranth to the CSRL, where it is used in a supplemental feeding program for pregnant women, breastfeeding mothers and their babies, and children at risk for malnutrition. The program, which has created a cash crop market for farmers like Robert, concentrates on a child's first 1,000 days to give that child a good nutritional start to life.

Challenges and adaptations

Climate, soil and water

Robert says drought has always been an issue in his area, but it's getting worse.

"The climate is not good," he says. "The rainy season brings some rains but not enough."

To adapt to the drier conditions,

Photo Courtesy of Mbeiza Moureen and Ngonzi Tape

Photo Courtesy of Mbeiza Moureen and Bangi Robert

Robert built an underground well. In dry seasons, he draws the water by hand to water his gardens. He would like to install a solar-powered pump. Robert also started mulching his cacao trees to keep the soil moist. For mulch, he uses sugarcane leaves that he buys from local farmers after the cane has been harvested.

Increased termite activity is associated with increased drought. His cacao-based pesticide does not work on termites, so he currently purchases a more effective chemical pesticide but wants to find other solutions.

Markets and local conditions

Access to markets and infrastructure that would support those markets (e.g. reliable cellular and internet connection, electricity, running water and other utility services) is limited. Uganda's food and nutrition insecurity levels are classified by the 2023 Global Hunger Index as 'serious', with 25 percent of children under five years old stunted and 31 percent malnourished (WFP, 2023).

Tape notes that before working with the farmer training program at the CSRL, she did not have money to pay for her grandchildren's school fees. She says limited resources are a major struggle for Ugandan farmers.

Policy

Tape describes Uganda's agricultural policy as flexible. It enables farmers to implement the practices they have learned. Robert and Tape also say the Ugandan government has provided incentives to farmer cooperative groups, as loans are available to farmers through established groups.

Next steps in applying circular approaches

Tape and Robert believe that knowledge is the greatest need among Ugandan farmers. Both say the CSRL has been a major benefit to them and their families. In 2006, Tape started planting maize and soybeans in rows in 2006, which improved her production. Robert and Tape both are part of their local farmer groups where farmers learn together and raise and harvest a crop together. They sell their collective harvest, and the income supports the whole group. For example, Robert's farmer group recently purchased a motorcycle with profit they earned from selling amaranth grown as a group. They rent the motorcycle out to a local motorcycle taxi driver (boda-boda driver) with proceeds returning to the farmer group.

"Knowledge. That is the key," says Tape, adding that the farmer groups are a good way for the community to learn together. "If someone does not know how to work, he can see and gain knowledge to improve."

Robert adds that the groups are an efficient way for individuals to learn.

"If you want people to learn, they must come together," Robert says. "When they come together, they get knowledge and they have used just a few minutes."

Circularity in the community

Tape says it is lack of knowledge and resources that prevent other farmers in Uganda from diversifying or improving their farms. Non-governmental organizations like the CSRL have helped farmers like her access resources, she says.

Community networks and value chains are essential in the bioeconomy. In the case of the CRSL, local Ugandan farmers receive training through the Iowa State University - Uganda Program and from local specialists on how to improve crop and livestock production and reduce post-harvest loss. The CSRL also works with the community to address malnutrition, improve access to clean water, improve access to quality crops and livestock, and foster entrepreneurship and life skills practices. Children and mothers receive nutrient-dense porridges, composed of millet, grain amaranth, soybean, maize, silver fish, milk and sugar. Grain amaranth offers one of the richest plant forms of protein available, with all amino acids, as well as fiber, magnesium, phosphorus, manganese, calcium, zinc, copper, selenium, vitamin B6 and folate. Mothers are also trained and given seeds to grow the ingredients for the porridge after they complete the program.

Tape adds that it is important to continue encouraging farmers to work together in groups to learn and improve their economic situation.

4. Ireland: Grass-based dairy faces climate change

Karol Kissane

Karol Kissane farms in County Kerry, in southwest Ireland, near the Atlantic Ocean. The land is located on a hill overlooking the Shannon Estuary. The climate is temperate, rarely dipping below 5 degrees Celsius in the winter and reaching 18-19 degrees Celsius in the summer. The land is unsuitable for growing crops, but it is perfect for grass.

Kissane manages about 52.6 hectares of grassland, which supports 100 dairy cows. Cows calve from the first of February to the first of April, with most calving taking place in the first three weeks of February. Grass typically starts growing around the end of January to February. The cows graze from mid-February to about the second week of November, when grass growth has almost stopped and the land is usually too wet for grazing animals. Cows typically milk through the summer when they are getting peak nutrition from grazing the grass. They produce about 7,500 litres of milk on the grass-based diet. The cows are housed through the winter, from November to February, and fed farm-grown grass silage.

This is the typical grass-based system that Kissane has been using "unless the climate is going crazy, which it has been over the last couple of years," he says.

Circular approaches

Cows graze approximately nine months of the year while in peak milk production. They are moved every day to a new paddock to allow for optimum grass growth and regrowth, returning to each paddock after about 21 to 23 days. They are brought to the milking parlor twice daily. The water used in milk coolers is recycled back into tanks and used to wash down the farmyards. The wastewater is then spread out on the land as fertilizer. Kissane has planted clover in his perennial pastures to fix nitrogen in the soil and build soil carbon. Allowing chicory (Cichorium intybus L.) and plantain (Plantago lanceolata L.) to grow has also further improved soil structure and overall health, which promotes carbon storage and makes the soil more productive and resilient. He minimizes tillage, mostly using no-till practices, to keep soil in place and further promote soil health and carbon sequestration.

Kissane is conscious of antimicrobial resistance. He monitors his cows throughout the year and only treats them when necessary and with the right antibiotic. He does not use classes of antibiotics that are human critical. He estimates 60 to 70 percent of the cows do not require or receive antibiotics. Because the cows graze, they are also at risk for parasites. Again, he regularly monitors the cows' milk and feces for problems. He has encouraged the presence of dung beetles on the farm by reducing maintenance drenches of cows (for example, drenches to deter flies). The dung beetles feed on parasite larvae, breaking their life cycle, which improves animal health. Continual monitoring quickly alerts Kissane to an animal who may be getting sick. He can then treat the animal with an anti-inflammatory to address the issue before antibiotics are needed.

Kissane sells milk to a local processor who uses it to make powdered milk and cheese. The small amounts of milk that are "waste" at the processing facilities are returned to local farms. When the milk is mixed with lime it becomes an excellent soil conditioner.

Challenges and adaptations

Climate, soil and water

Weather patterns are changing quickly. "Even in the last five years, the differences are just unbelievable," Kissane says. Usually, rainfall is spread out throughout the year, with a couple of dry days then a damp day. In the last couple of years, Kissane's region has seen six weeks to two months of absolutely no rain followed by months of rain. During the drought period, the grass stops growing. Then, the land gets soaked.

In 2023, the rains started toward the end of June and did not let up until early June 2024. "And when I say rain, I mean every single day was wet," Kissane says.

The waterlogged land meant farmers in the area put their animals inside early, in the autumn, when they typically would be out grazing, and they stayed inside longer than usual in the spring.

"That put huge pressure on the system," recalls Kissane. Farmers typically plan to feed grass silage for three to four months of the year and now needed six- or seven-months' worth of feed.

"Last year, we had huge amounts of feed moving around the country, but the prices were very high," Kissane says.

The wet spring also delayed planting and harvesting for crop farmers in different parts of Ireland.

"It is squeezing us at both ends," Kissane says. "We operate in a system

where the idea is the animals are on the land for nine months. The whole system is under pressure due to the changes in weather patterns."

Kissane says farmers have realized they must make sure they stock more silage in the yard because they do not know how long winter will be. It is adding to expenses, but not as much as they would have if they found themselves in need and without.

The changing climate is making Kissane wonder if the grass-based system will continue to work in the future.

"We could end up having to change systems, something the majority of farmers in Ireland do not want to do" Kissane says.

Markets and local conditions

Kissane, a Nuffield Farming scholar (2018) is concerned that many people in the area have stopped farming. He thinks there are several reasons. Farmers are getting older and do not have anyone willing to take over their farm. Production costs are also increasing. However, he believes the climate is making the situation worse.

"The stress that people were under these last 12 months (2024) was just absolutely crazy," Kissane says. "People could not function because they were just worried where the feed was going to come from tomorrow to feed their cows."

Land prices are still high because people are buying land, but many of those buyers are not farming themselves. They may rent the land to farmers hoping that the next few years will bring a better farm economy with carbon credits.

"The actual number of people living in the area who are farming is reducing every year, which hits at the entire community as well, which isn't great," he says.

Photo Courtesy of Karol Kissane

Policy

Kissane says regulations are typically put in place with good intentions, but they are not always helpful in practice. For example, an EU rule regulates the percentages of organic and inorganic fertilizer that can be used on the land. Many farmers have the capacity to fertilize their land almost completely with organic sources made from the slurry their cows produce, but they cannot do so legally.

"The excess has to be put on a different farmer's land, and the farmers exporting the slurry then need to go buy chemical fertilizer," Kissane says.

He also says recent policy favors smaller farmers, but the help may have come too late.

"Favoring the smaller farmer means the medium farmer is now going out of business, and everything is getting bigger and bigger," Kissane says.

He encourages policy makers to take a step back and look at the bigger picture. He advocates for policies that keeps current farmers on the land and makes farming more attractive to future generations. He wants to see farmers get a fair price at market.

Next steps in applying circular approaches

Kissane is continuing to improve his soil health by increasing the diversity of plant species in his pastures. Continuing to build soil health will help the soil capture and hold more water, which is essential to help him adapt to the changing rain patterns.

Circularity in the community

The agricultural community in Ireland needs positive support from the public, Kissane says. The country aims to reduce GHG emissions by 25 percent by 2030. Since Ireland is an agriculture-based country, the focus has been on reducing emissions from agriculture. The negative attention in the mainstream media and social media is taking a toll on Irish farmers. They are working very hard in changing conditions while struggling financially, but they are being painted as the problem rather than the solution. Kissane points to programs that connect school children with farmers so that young people can learn about farming. With an aging farming population, it will be important for Ireland to attract the next generation of farmers who can produce a domestic food supply even as the climate changes.

Kissane points to Ireland's rich tradition of farmer-owned cooperatives as an avenue for adaptation and community-based success. Individual Irish farms may be too small to afford anaerobic digesters that turn animal waste into biofuel, but perhaps there are avenues for multiple farms to form cooperatives that could take advantage of this technology.

"There are ideas like this happening here in Ireland at the moment," Kissane says.

5. Italy: Regenerating the soil for resilience to climate change

Marco Pasti

Marco Pasti farms in the northeastern part of Italy along the Adriatic Sea, about 40 kilometers northeast of Venice. His grandfather's family were the first to come to the land, which, until 110 years ago, was underwater. The land was reclaimed by Italy out of a need for more farmland to feed a growing, hungry population.

Today, the soil is on average two meters below sea level. Excess water must be pumped out. This is usually done in winter when the rains are heavier and cooler temperatures mean less evaporation. However, climate change is affecting the timing of the rains, and this is changing things on the now-1,000-hectare farm.

Pasti grows maize, soybeans, wheat, barley, sugar beets, wine grapes and walnuts, as well as feeds out beef cattle. He also has a biogas plant that produces renewable energy. His focus is on regenerative agriculture (i.e. building up the soil's health and resiliency), which he believes is key to adapting to climate change.

Circular approaches

Pasti grows a wide variety of annual crops as well as maintains perennial orchards of grapes and walnuts. He builds soil health by minimizing tillage and keeping the ground covered as much as possible with living roots through this diverse cropping system. He also cultivates cover crops, which are not sold commercially but add biodiversity and keep the soil in place when heavy rains come. In his orchards, he leaves pruned plant materials on the ground and sometimes plants cover crops of rye, black oats and/or clover as a mulch to keep moisture in and build up soil organic carbon.

He purchases beef calves and feeds them for about eight months on a special diet of grains he grows, (such as soybean and maize), silage grown on-farm and sugar beet pulp leftover from the sugar extraction process of the local sugar factory. Slurry wastes from the cattle are used to feed his biogas digester, which is also fed with silage from the first and second crops. The power generated is sold into the grid. The biogas digester also produces a nutrient-rich slurry he uses to fertilize his fields.

Challenges and adaptations

Climate, soil and water

Normally, Pasti's region gets 500 to 1,000 millimetres of rain per year. Typically, that rain has come mostly in the winter, with light rains falling throughout the year. Under these typical conditions, excess water is pumped off the land into channels that feed into rivers from November to March and occasionally in the summer. However, in recent years, most notably to Pasti in the past five or six years, the rains have become less predictable, with heavier rains coming in shorter periods followed by months without rain.

In early September 2024, for example, Pasti said they got 170 millimetres of rain in a week, which necessitated off-season pumping. They also had an exceptionally rainy, wet winter and spring in 2024. In May, they received 300 millimetres of rain, half of what typically arrives in a whole year. Then from late June until the end of August, they did not receive any rain, and they had continuous high temperatures that caused heat and drought stress to the crops.

"It was very hot, so the soil was completely dried out," Pasti says. "Before, we had some hot days and some cooler days, some dry days and some more wet days. Now what we see is a lot of heavy rain in a certain period of time, then we have maybe three months without a drop of rain. We get more or less the same amount of rain, just in a shorter amount of time."

Pasti is also noticing higher temperatures. He says summer months are three degrees Celsius warmer on average than they were in the 1990s.

"This is difficult because the crops are very stressed by the heat," Pasti says.

Higher nighttime temperatures have led to increased insect activity. He sees more European corn borer activity and damage. He has also observed more problems with aflatoxins caused by the fungus *Aspergillus falvus*, which needs higher temperatures to develop. He recalls aflatoxin problems in 2003, 2012 and 2022.

"So, it was like every 10 years, more or less," Pasti says. "This year [2024], we already know it is a very bad year for aflatoxins again, just two years after 2022."

To adapt to a changing climate, Pasti focuses on regenerative techniques, building up the soil so his land can be more consistently productive under increasing climate variability. Building soil health is important when rainfall is inconsistent. Healthier soils can capture and hold more rain when it falls, preventing water from pooling on the surface and washing the soil away. Conversely, soils that hold more water are also more resilient for crop production in times of drought.

Policy

The tool Pasti would like to use to adapt to climate change, biotechnology, is currently unavailable to him due to EU policy.

"Bt corn would be very useful to avoid this problem of mycotoxins, especially aflatoxins, but also others that affect food-grade maize," Pasti says. "Unfortunately, Europe has completely closed the door not to the import but to the cultivation, so it is a very sad situation because we are facing international competition from farmers who can use biotechnology. We are buying genetically modified corn or soybean meal from abroad, but we cannot grow it. This is very unfair to me."

Pasti would like to see at least experimental plots of biotech-produced improved seed varieties planted and studied so that people could see how much fertilizer, chemicals, water and energy it takes to grow Bt corn versus conventional seeds currently used. He says the policy is based on consumer demand that is influenced by fake information rather than science and is weakening Italian agriculture.

He also highlights policies that prevent farmers from installing solar panels on their land, limiting their ability to diversify their income.

"I do not think it makes sense because we are having such low income in the next years because of climate change, lower subsidies for cultivation, and international competition and we cannot use biotechnology," Pasti says. "I expect more and more land will be left without crops. On the one hand, they tell us you cannot put solar panels on the land because we need to keep up farm production, but on the other hand they do not give us tools to boost production."

"lack of improvements in agronomic genetics has stagnated crop production"

Markets and local conditions

Pasti says lack of improvements in agronomic genetics has stagnated crop production, which has reduced Italy's capacity to compete globally. Italy once produced more than 10 million tonnes of maize but is now producing about four million tonnes, and probably less this year, he says.

"We lost seven million tonnes in the last 15 years because of climate change and because we are not allowed to use biotechnology," Pasti says.

It is now less expensive to import corn and soybeans, so imports are increasing while the domestic market is suffering as a result. "Italy is making more value-added, processed foods, like wines and pasta," Pasti says. "The food industry is growing a lot, but farm production is shrinking a lot. We need to gain back competitiveness, and we need to improve productivity. We have not improved productivity in the last 20 years. We are still applying the same amount of fertilizer to get the same amount of production. In other countries, they apply less fertilizer and get more production because of improved genetics."

Pasti recalls a huge development of farms in Italy from the 1960s to 1980s because of hybrid corn. Local crop farmers were able to produce the feed needed for neighboring livestock farms, which created a circular system where livestock manures would fertilize the crop fields where their feed was produced. That is no longer the case, as more and more feed grains are now imported.

Next steps in applying circular approaches

Pasti is continuing on his regenerative agriculture journey. He began no-tilling 20 years ago and still finds his yields, on average, are not as high as they are with conventional tillage. However, he has seen improvement over time and believes it is his best tool for ensuring production and keeping soils healthy as the climate changes. He will continue to make progress in continuous cropping and in adding more diverse cover crops.

Circularity in the community

Circularity could return to Italy with a strengthening of domestic agriculture industries, Pasti says. This would include making biotechnology accessible to farmers, which he says will require science-based education and demonstration. For his part, he also hopes to purchase slury wastes from neighboring livestock farms to feed his biodigester and to help his neighbors reduce their carbon footprint.

Photo Courtesy of Marco Pasti

6. Thailand: Farmers from two different regions of Thailand aim to model circular bioeconomy

Pradtana Muang Ngam and Wichai Kamnerdmongkon

Pradtana Muang Ngam grows Riceberry (a type of purple rice) and mango on approximately 12.8 hectares of land owned by her family. The land is located in Suphan Buri Province in the irrigated area of Thailand's Central Plain. She holds a master's degree in agriculture and owns a company called Chok Anan that grows, mills and markets Riceberry and Riceberry products, including teas and snacks. She uses social media to market her products and sells at local organic markets and restaurants. She is passionate about growing quality agricultural products, taking care of the environment, and inspiring young people to find success in agriculture.

About 600 kilometers north, in Nan Province, Wichai Kamnerdmongkon grows coffee and strives to encourage the farmers in his community. In 2012, after earning his bachelor's degree in food sciences technology, Kamnerdmongkon returned to his hometown, where his parents grow cabbage and ginger. He wanted to help people in his community recognize the importance of the forest. Nan is a northern highland province in Thailand that has experienced deforestation. According to Zeng, Gower and Wood (2018), forest cover in Nan Province decreased by 66,072 hectares from 2001 to 2016. In the process, Kamnerdmongkon decided to grow coffee in the shade of native trees as a way to show local farmers how they can earn additional income while also supporting healthy forests. He grows coffee on 1.28 hectares. He sells coffee mostly online via Facebook as well as in a local coffee shop.

Photo Courtesy of Wichai Kamnerdmongkon

Circular approaches

Muang Ngam plants rice from seed saved from previous rice crops grown on her farm. She and her father select for varieties that are resistant to pests and disease. The harvested rice goes into climate-controlled storage that prevents temperatures from exceeding 40 degrees Celsius. This maintains quality, which is important to consumers. It is also important for Muang Ngam and her family because the controlled storage ensures these seeds will germinate and grow well, which increases production. Residue from the rice in the field is allowed to ferment and used as a mulch to cover soil in the mango orchard. Mangoes that spoil or are otherwise unmarketable are juiced, and the juice, along with fermented rice straw and pig manure, is used as a fertilizer across the entire farm.

Kamnerdmongkon began planting native trees in 2012, which led him to plant coffee. He grows Arabica coffee varieties, such as Geisha, Catimor, Tipika and Java. The native trees provide nutrients and shade to his coffee plants and deliver environmental benefits (e.g. carbon sequestration) and improve the overall forest ecosystem. He sells his coffee online and to a local coffee shop, which returns the coffee grounds to him. He mixes the grounds with other coffee plant waste and chicken and cow manure to make a compost, which feeds the soil of the coffee plantation.

Challenges and adaptations

Climate, soil and water

Muang Ngam says she does not have major challenges with the weather in Central Thailand, but Kamnerdmongkon cites climate change as one of his biggest concerns. His northern region experiences all types of weather extremes: heat, cold, wet and dry. These extremes affect the quality and yield of coffee and are detrimental to production, processing and overall profitability. For example, coffee cher-

Photo Courtesy of Pradtana Muang Ngam

ries that are beginning to ripen crack and fall in winter rains, and the rain increases risk for mold in harvested fruits. Kamnerdmongkon describes the situation as hopeless because there is little he can do to stop climate change. However, he strongly believes that encouraging forest conservation and the planting of more forest trees is a solution and aims to be a model to farmers in his area of how agriculture and forests can coexist.

Markets and local conditions

Kamnerdmongkon says it has been challenging to be the first in his family and community to grow coffee. He stays the course because he believes it is important to conserve the forest and tries to foster acceptance by being open to farmers' questions. He invites them to his farm to see what he does in the hope that seeing his success will encourage them to try to grow more coffee. Currently, the only crops grown are traditional vegetables and ginger, which require lots of sunshine. Adding a coffee crop is a way to diversify, increase farm income and protect the environment.

Muang Ngam says her greatest challenge is the income discrepancies she experiences by using organic practices compared to conventional. She plants and harvests rice twice per year compared to the five times per year that conventional farmers in her area produce. It takes time to ferment the rice residue in the field, which is a major source of fertilizer for her since she does not use chemical fertilizers. She receives a premium of about 20 baht (USD 0.61) per kilogram of rice (100 baht for organic compared to 80 baht). The fermented rice straw cuts costs by about 50 percent, and she sells some straw bales for additional income. She also uses technology to reduce costs on the farm and in marketing. For example, she can sow seed by drone for 50 baht/rai (9.6 USD/hectare) compared to the cost of 80 baht/rai (15.3 USD/hectare) for two labourers to do the same job.

Policy

Kamnerdmongkon suggests better financing and knowledge support are needed because obtaining the organic certification is difficult and awareness of its value among Thai consumers is relatively low. She would like to see higher prices for organic practices and a certification for circular bioeconomy practices so that farmers have an incentive to adopt these practices. The average age of Thai farmers is increasing, and it is important, she says, to attract young people to agriculture. She believes improved farm incomes would create opportunities for young people to stay in their rural hometowns and make a living instead of moving to the cities.

Next steps in applying circular approaches

Muang Ngam wants to continue to develop from "a grower to an entrepreneur" by improving the use of resources on the farm and adopting environmentally friendly practices. She wants to open a café and restaurant, continue to enhance her compost and food-waste recycling processes, develop a recirculating water system and drip irrigation, and produce biomass energy.

Kamnerdmongkon would like to find new ways to use the waste from coffee production other than in compost. Adding value to this waste would increase his farm income and further encourage farmers in the area to produce shade-grown coffee and promote forest conservation. He also wants to explore options for maintaining coffee quality amid weather extremes. Producing quality coffee requires quality agricultural raw materials from the outset, breeding or selecting appropriate varieties, using technology, cultivating and managing farms efficiently, adapting to local conditions, and quality processing.

Circularity in the community

Both Kamnerdmongkon and Muang Nang value their communities and want to see farmers increase their incomes. In 2019, the average annual household income from farming was estimated at USD 2,394 nationally, or about three times lower than the average annual income from wages and salaries from non-farm business (World Bank Group, 2022). As innovators in their field and supporters of their community, both farmers open their farms to anyone who wants to learn. They both say demonstrating good practices and fostering community relationships are keys to promoting circular bioeconomies among farmers.

7. Australia: Circular opportunities in aquaculture

Dan and Tarun Richards

Both Dan and Tarun Richards grew up with fathers who were pioneers in Australia's aquaculture industry. In 1993, their father started Humpty Doo Barramundi, an aquatic farm in Australia's Northern Territory on a site along the Adelaide River that had been left unused for 45 years after a rice farming project had failed. Their small family venture began by supplying six kilograms of Barramundi fish per week and their output has grown 20 000 times that. Today, Humpty Doo Barramundi is the largest Australian-owned fish farm in the country. The company employs 150 people and focuses on delivering quality protein.

"Our mission is to responsibly produce beautiful Australian Barramundi while demonstrating our genuine care and commitment to our people, our fish, our environment and our partners," says Dan Richards, Humpty Doo Barramundi CEO.

"Our people," he adds, refers to the whole community: internal employees, the broader community, which is made up largely of indigenous people, as well as animal welfare, the environment, and the natural resources they all depend upon.

They maintain supply contracts with Australia's largest retailer, Woolworths; Costco; and PFD Foods, Australia's largest food service distributor; as well as supply to other businesses, from major food service chains and airlines to some smaller boutique restaurants.

"We share the vision that **aquaculture is the future,**" says Tarun Richards, who oversees business service units, including environmental compliance. "There's still a place for wild caught fisheries, but we cannot eat all the seafood we want or need from the ocean. There's a real opportunity for aquaculture to be a truly sustainable farming system."

Circular approaches

Fish are born at the farm's hatchery site as part of an on-farm breeding program advised by the food and agriculture group of Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). The fish are sorted by size and moved through different facilities before leaving the protected environment to free range in the saltwater wetland ponds at about five months of age. More than half of the farm, which covers 700 hectares, is dedicated to this saltwater wetland system, which was first built in 2002 as part of a transition from a flow-through system to a recirculating system. Salt water is now continuously recycled, being topped off only occasionally for evaporation. This allows salinity to remain stable, which is good for product quality. Microalgae and saltwater grasses in the ecosystem act as natural water filters. In an average year, they remove nearly all the nutrients (99-99.9 percent) created by the fish. Since the water circulates as part of the farming system, it does not leave the site or pollute the river. The system creates minimal waste since few inputs are used to grow the fish, which are sold whole and trucked to processing facilities. The whole fish is generally processed at the processing plant, and unused parts are sent to a factory to make gelatin-based candies. Any dead or reject fish are sent to a nearby organic farmer who uses them to make compost to fertilize mango orchards. A social aspect to Humpty Doo Barramundi's circularity is its community engagement programs, including a youth program that gives high school students work skills through internships. Of the 16 students who have completed the program, 15 have joined the farm in full-time employment.

Challenges and adaptations

Climate, soil and water

The tropical climate, which is hot and dry for half the year and hot and wet the other half of the year, creates a beautiful, wild environment that benefits wildlife. It is not uncommon to see crocodiles and other wildlife. Major flooding occurs every few years. The farm handles flooding on-site with measures that include, in extreme situations, helicoptering stock five kilometres off-site to maintain a continuous supply to the consumer.

"That works for localized events, but it is harder when you have gotten fish on the road and there is flooding or an event closer to the market," Tarun Richards says.

She says they can reroute trucks, but with only one main road out of town and limited routes to major cities, this can add a day or two to the journey.

Markets and local conditions

One of the largest challenges to Humpty Doo Barramundi's circularity is its remoteness. There are approximately 130,000 people living within about a three-hour drive. They are about 3,000 kilometers away from the nearest Australian city, which means industry and services are limited.

Photo Courtesy of Humpty Doo Barramundi

Specially formulated feed is trucked in, and fish are trucked out to larger market centers, which adds costs and limits partnerships. There is one government-sponsored recycling program, but other industrial attempts to recycle and repurpose raw materials have not succeeded. For example, a local company at one time would take, break down and pelletize plastics, but the company went out of business due to lack of market.

Partly because of limited access to markets, the Richards prioritize using the materials they ship in as well as the farm's natural resources as efficiently as possible. This includes careful logistical organization of shipments, both sending and receiving. They also emphasize projects that build up capacity in the people in their community.

Policy

The Richards are interested in using solar power on the farm and have looked into it several times. However, the government-controlled electric grid is not set up to accept renewables. The farm would have to carry all network costs and stabilize the network, which makes it cost prohibitive.

The Richards also mention their environmental stewardship and community engagement activities have earned them national recognition. They do these activities because they believe in their importance. However, they could do more if they received some financial support for this work. Though their customers (food retailers) express support for the work, their response to the Richards' desire to expand their impact is to find ways the end consumer would be willing to pay more for the product. Resource allocation available for environmental and social improvement is limited.

"If you want to do something that is radical and brave, it can be expensive or requires trials and trying to bring people on the journey and get the support to be able to do it can be difficult to resource," Dan Richards says. "We have got a really dynamic, brave organization willing to have a try of anything, but we cannot do everything and certainly financial resources can be a limit to that."

The Richards say having funds available, with "sensible criteria," might help people be brave and push them forward.

Next steps in applying circular approaches

Currently nutrients created by the fish in the saltwater ponds are consumed and filtered by microalgae and saltwater grasses. However, the Richards see potential to add filter-feeding animals, like oysters, that would consume those nutrients through the algae. This would further expand the fishery's circular bioeconomy and opportunity to offer a new protein product. Humpty Doo Barramundi is currently trialling this idea with an indigenous community and the state government.

Circularity in the community

Because industry is currently limited in the region, Humpty Doo Barramundi emphasizes programs that invest in the people of the community. People in the region, many of whom are indigenous people living semi-traditionally, have few economic opportunities. Also nearby are island nations, including East Timor, Vanuatu and Samoa. Humpty Doo Barramundi is one of the larger employers in the region, and the Richards are quick to say they offer as many opportunities as possible. It is young women who typically take them up on those opportunities, they say. More than half of their team is younger than 35 and one-third are women. They work with local schools and indigenous colleges to bring students into a structured internship program with opportunities to obtain full-time employment. They also offer a program for international residents to come work for nine months of the year.

"What they can make in that time is like 10 years of income at home, so they are taking that money back and transforming their communities," Dan Richards says.

More recently, an aboriginal community one hour away by small plane asked Humpty Doo Barramundi for assistance in developing their own aquaculture venture. The Richards and their team developed an exchange program in which members of the aboriginal community come to Humpty Doo Barramundi to learn fisheries enterprise skills, and Humpty Doo Barramundi employees visit the community's site to provide practical advice and guidance. Humpty Doo Barramundi also has personal and professional relationships with the traditional owners of the land they now farm. They host cultural tours and bring in chefs and customers to the Northern Territory to share the story of the land and its people to foster and show respect.

8. Australia: Crisis leads to change

Nigel Corish

Nigel Corish is a fourth-generation farmer based in Goondiwindi, on the border of Queensland and New South Wales, about four hours west of Brisbane, Australia. Several members of his family operate the farm, a mix of 4,000 hectares of dryland, rain-fed cultivation and 450 hectares of irrigated cultivation. Cotton is the family's primary crop on the irrigated land, and they grow wheat, barley, chickpeas and sorghum in rotation on the rain-fed land. Corish came home to the farm after his university studies in 2004, a few years into the Millenium Drought, the worst drought on record for southeast Australia, which lasted from 2001 to 2009.

"Drought is like a cancer," Corish says. "It just slowly grows on you and suddenly you find yourself in quite a depressive state. It is very stark to see the whole farm brown, dry and very underproductive."

There were years when nothing grew on the farm. The family had to go to the bank to refinance loans on their facilities and ask for bridging loans to sustain the business through the drought. The drought also took a toll on the family's mental health. Corish recalls the questions that kept him up at night: "Is it ever going to rain again? How are we going to get through this?"

He knew it would not be by continuing to do what the family had always done. Without change, there would be no future in farming.

The family conserved water by not growing irrigated crops for two or three years. They began capturing and storing rainfall and trying to get the best efficiency and productivity out of every drop of irrigated water they used.

Corish set out to learn what others were doing and find new ways of farming that might work better for his family. In 2014, he received a Nuffield Farming Scholarship. His focus was on improving nitrogen use in irrigated cotton. What he learned from other farmers, especially organic farmers, in Europe and the United States of America, fueled his interest in adopting regenerative agriculture principles, which work in harmony with natural ecosystem processes to improve soil health and land productivity.

It has been a **10-year journey**, one **that continues to evolve** and one that has not always been easy or straightforward. However, he calls it rewarding and now wants to share what he has learned with other farmers.

Circular approaches

Today, Corish and his family use regenerative practices to build soil health, which helps the soil better capture and store water. They minimize soil disturbance by reducing tillage as much as possible, and they practice crop rotations. About five or six years ago, they went to a five-year cropping rotation on the dryland farming system. The system increases biodiversity in the soil and reduces disease. Between cash crops, they plant cover crops to cover the land with live plants year-round, which further feeds the soil and provides the soil protection against wind and rain. For example, they might plant French white millet after their chickpeas are harvested, allowing it to grow 6 to 8 weeks before termination by herbicide. Then a winter crop, like winter wheat, might be planted. Following cotton or sorghum, a cover crop of barley might be planted. Some grain harvested goes to local beef feedlots, and manure from those operations are spread back out on the farmland as fertilizer. Other biofertilizers used include seaweed-based sources.

Challenges and adaptations

Climate, soil and water

Building soil health has helped the land become more resilient in drought. In Corish's region, rainfall is highly variable. While the historic rainfall average is 550 millilitres per year, rainfall over the last 10 years has ranged from 140 millilitres to 1.2 meters, he says. The family stores rainfall to be used in irrigation systems as much as possible, and their regenerative agriculture practices have improved the soil's water-holding capacity, which means less water stands after a rain event and more is soaked into the ground where the soil uses it to grow plants in dry periods later in the season.

Markets and local conditions

Technology has been a major help to the family in using water and other resources more efficiently. Irrigation systems apply precise amounts of water. Moisture probes detect how much water is in the soil. Satellite imagery helps map out the operations

Photo Courtesy of Nigel Corish

Photo Courtesy of Nigel Corish

and its productivity. Soil tests inform the family on what nutrients are in the soil so they can fertilize appropriately.

"Data is critical to the farming business," Corish says. "Without data, you cannot show your profitability or productivity."

Data helps the family determine a three-year plan for their cropping program, which is important "because we live in an unfortunate climate that is very sporadic," he says.

Policy

Corish says Australian producers are proactive when it comes to technology around productivity and efficiency in part because they do not receive subsidies from the government. He emphasizes the importance of agricultural research, which he says Australia does a good job with.

"For every dollar the industry spends on research, the government will match that, which is very beneficial to increasing productivity of the industry from a circular economy point of view," Corish says.

He says it is important for policy makers to understand that adopting regenerative practices, while important, is a journey and cannot happen overnight. He learned this first-hand when he returned home from his Nuffield experience enthusiastic to adopt biofertilizer. He cut out synthetic fertilizer overnight and realized in hindsight that was not a good idea. In his experience, it took the soil five to 10 years to adjust and be in a healthy enough place to remove all synthetic fertilizers. Changing too quickly can result in the soil and land not responding and negative impacts to soil structure, he says.

He sees a divide in Australia between urban and rural communities and believes it is important for policy makers to have direct access to farmers so they can learn about what happens on the land. He also says education should start in schools, with children learning from a young age how food is grown and how the land is managed.

Next steps in applying circular approaches

Corish is currently trialing a new cover crop, carinata (*Brassica carinata*), a close relative to canola. This crop can also be harvested and used to make sustainable aviation fuel. As a cover crop, it uses the nutrients available in the soil and does not require additional fertilizer, which means it would have zero emissions tied to it.

Corish is also in the process of implementing a soil carbon project. He is excited about the possibility to accumulate carbon credits in the farming business to one day sell or offset his own emissions. He envisions that in the future all his products will have a net zero brand.

Circularity in the community

Corish sees many examples of circularity in his community. Some cotton farmers shred wasted cotton products, like clothing and sheets, and spread them out on fields to build up soil organic matter and carbon. Many growers use manure-based fertilizers, and he knows of one who uses human waste from a local treatment plant. Cotton gin byproducts are also reused. Cotton seed is used as cattle feed in local feedlots, and other organic waste is composted and put back on fields. There is a good market for biodiesel and ethanol, which transforms parts of the grain into fuel and leaves other parts available for livestock feed or other products (e.g. plastics and carbonation for soft drinks).

It is important to promote farmer-driven projects. Innovative farmers are willing to test and trial new ideas, and the information they gain needs to be shared with other growers to give them confidence. Making changes can be difficult, and sometimes it takes a crisis to make people willing to change, he says. Policy makers need to support cooperation among communities and build their ability to change and adapt to changing climatic and economic conditions.

9. Brazil: Sugar cane, a sweet renewable energy solution

Cocal

Carlos Arruda Garms founded Cocal in 1980 with the vision of creating jobs and opportunities for families in the western Brazilian state of São Paulo. At the time, the Brazilian government launched the Proálcool program to promote ethanol production, which led Garms to start with a biofuel plant in Paraguaçu Paulista, São Paulo. As global demand for sugar increased, the company added sugar production to its operations in 1993.

Sugar and ethanol remain Cocal's primary products, but the company has also become a leading bioenergy producer in Brazil thanks to the by-products of sugarcane. Cocal began producing electricity from sugarcane bagasse in the late 1990s and in 2008 added a second facility in Narandiba, São Paulo. In 2021, the company built its first biogas plant in Narandiba with an investment of 150 million Brazilian reais (USD 27.825 million USD based on 2021 average exchange rate).

Today, Cocal cultivates around 9 million tonnes of sugarcane per year, which serves as the raw material for all its products. The sugarcane, grown on 142,000 hectares, produces 720,000 tonnes of sugar; 400 million litres of ethanol; 9 million normal cubic meters of biomethane; and 6,500 tonnes of dry yeast annually.

Garms' children remain active as shareholder advisors on Cocal's advisory board, and the company is governed by an executive board. Cocal today employs more than 5,000 people in western São Paulo.

Circular approaches

Raw sugarcane is processed to produce sugar and ethanol, a renewable fuel. Byproducts of sugar and ethanol production include vinasse and filter cake, which are fed into an anaerobic biodigester to produce biogas. A portion of the biogas is purified to produce biomethane. Cocal uses the biomethane as a replacement fuel for diesel in its own fleet of vehicles and equipment. The company also sells the biomethane to customers who use it for their vehicles, homes and industrial activities.

The remaining biogas is converted to electricity, which powers Cocal's facilities and is sold into the grid. The surplus electricity generated is enough to power a city of 730,000 residents. After biogas production, biodigested materials, which are rich in nutrients, are returned to sugarcane fields as biofertilizers. Currently, 95 percent of Cocal's production hectares are treated with biofertilizers. More than 90 percent of the water used in all these processes is reused.

Challenges and adaptations

Climate, soil and water

Luiz Scartezini, CEO of Cocal, notes a "new normal" has been brought on by a changing climate. Drought is a major concern to Brazilian agriculture. Not only does lack of moisture hinder crop production and animal health; drought can also cause destructive fires.

"In 2024, we recorded periods of elevated temperatures across the country," Scartezini says. "Preventative planning is critical, and we conduct daily, hourly monitoring of our entire production area. The company remains on alert and is prepared to manage any type of situation."

Cocal does not practice burning in its crop production practices, but the company maintains a permanent fire brigade to perform preventive actions. Equipment temperatures, wind speeds and humidity are also monitored daily. "We have invested in water trucks, personal protective equipment, agricultural planes for firefighting, field sensors, and cutting-edge technology, such as

Photo Courtesy of Cocal

satellite imagery, to assist in decision-making," Scartezini says. He also notes that Cocal promotes awareness campaigns about preventing fires and who to contact if one occurs both to employees and the public. "Prevention is essential in this new normal."

Markets and local conditions

In 2023, the production of biomethane enabled Cocal to avoid purchasing and consuming 700,000 liters of diesel in 2023, equivalent to preventing the emission of 1,900 tonnes of carbon dioxide into the atmosphere.

"Biomethane can replace diesel and natural gas (fossil fuels) in vehicles, as well as liquefied petroleum gas (LPG) and coal in industries, homes and businesses," Scartezini says. "For the market, the biogas plant provides a versatile and clean energy source (biomethane) as a substitute for fossil fuels, while for the bioenergy sector, it adds value to the byproducts generated from sugar and ethanol production. What was once discarded is now a raw material for producing clean and renewable energy."

Producing biofertilizers as part of the biodigestion process that produces biogas has also helped Cocal reduce costs associated with fertilizer. "By using biofertilizers in our sugarcane fields, we reduce GHG emissions starting from our agricultural production," Scartezini adds.

Policy

Scartezini describes decarbonization of the economy as "urgent and essential." This requires new laws and incentives from federal agencies to provide a viable framework for the expansion of clean and renewable energies, he says.

"Every new technology, when introduced, raises doubts and concerns among business leaders about change," Scartezini says. "We need to offer attractive ways to encourage this shift and ensure energy efficiency, while also reminding them that they are contributing to saving the planet."

Scartezini says Brazil is making political progress toward clean energy. For example, the Renovabio program, an initiative focused on expanding biofuels and meeting the commitments Brazil made in the Paris Agreement, created decarbonization credits (CBIOs) that act as environmental assets and are traded on the Brazilian stock exchange. Each CBIO issued by biofuel producers and importers represents one tonne of carbon that is prevented from being emitted into the atmosphere.

He also considers the approval of the Future Fuel Law to be a significant milestone for Brazil's energy transition. The law promotes the increased use of ethanol in gasoline and biodiesel in diesel. It also establishes the regulatory framework for carbon capture and storage and national incentive programs for biomethane and sustainable aviation fuel.

"We must continue on this path," Scartezini says. "We need contributions from all stakeholders — companies, governments, NGOs and society at large — working together to reduce carbon emissions."

Next steps in applying circular approaches

Cocal is in the process of expanding its circularity, and potential for reducing carbon emissions, in several directions. In 2023, Cocal launched its first photovoltaic solar plant and has plans to expand in the coming years.

Cocal is currently building a new biogas plant exclusively for biomethane production with a 216 million Brazilian reais (USD 39 million) investment. This plant, expected to begin operations in April 2025, will be able to produce up to 60,000 cubic meters of biomethane per day during sugarcane harvest season. Cocal is testing additional raw materials, including sugarcane straw, animal manure and urban wastes, as feedstock for this new plant.

Cocal is also entering the sustainable aviation fuel market. Cocal's units in Paraguaçu Paulista and Narandiba received the International Sustainability and Carbon Certification (ISCC) Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Plus certification, enabling the company to supply its ethanol for the production of sustainable aviation fuel.

"Our goal is to continue growing within this ecosystem, offering the full potential of green products to our customers and contributing to the decarbonization of Brazil's energy matrix," Scartezini says.

Circularity in the community

Scartezini says it is important to note Cocal is not just producing biomethane, it is producing sustainable regional development.

"Our biomethane strengthens the national industry, generates income and new jobs in western São Paulo, reduces external dependency on chemical fertilizers, and decreases our carbon footprint," he says. "At the same time, we promote several social projects aimed at building the skills of the workforce and encouraging more young people to work in the bioenergy sector, bringing fresh ideas and perspectives into the business."

Cocal also maintains regular dialogue with partner companies that are seeking new technologies that combine energy efficiency with sustainability.

"We are all working together towards the energy transition," Scartezini says.

10. Peru: Heritage and tradition meet innovation for climate resilience

Evelyn Díaz

Evelyn Díaz and her husband, Oscar Vilca, are both veterinarians. They work with Díaz's parents, Maximo Diaz and Felicitas Salas, on the *Ganadera el Nevado* in Puno, Peru. The 2,500-hectare farm, which was started by Diaz and Felicitas in the late 1980s, has about 2,500 alpacas and 500 llamas. Situated at an elevation of 4,000 to 5,000 meters above sea level, the farm is in a very remote area. Díaz's parents built the first road to the farm to allow for better, although still rudimentary, transportation of animals and supplies.

The farm has four production units: one with alpacas of different colors; two with llamas; and one with both alpacas and llamas. The production units are broken down into smaller groups with each one having 300 animals on average. The units contain different types of animals: breeding adult males, breeding adult females, females that have not yet been bred or did not get pregnant after breeding, and young animals, which are typically born in January or February.

Because llamas are well-adapted to the high elevation and their meat has relatively higher nutritional value compared to other meats, llamas have become an important part of Peruvian culinary traditions. They are a major source of meat for the family at *Ganadera el Nevado.*

Llama fiber is used to make ropes and some clothes. Alpacas are prized for their high-quality fiber. The family sells alpaca fiber directly to national companies. They also sell llamas and alpacas for breeding stock on national markets and sometimes on international markets. They occasionally sell meat.

Circular approaches

The llamas and alpacas depend on native, high-elevation pastures for most of their nutrition. Some supplemental feeding is provided, especially from December to April. Oats, which are cultivated at the farm's lowest elevation, are a major source of supplemental feed. The oats are primarily given to young or pregnant animals that require higher energy rations. Manure from the alpacas is used to fertilize the oat fields. The manure is collected from permanent shelters that house some of the animals at night. Animals grazing pastures sleep under a temporary circular shelter for protection from predators and the natural elements. These shelters are moved approximately every 15 days to areas the family notices are dry or need fertilization to improve forage production. They also use vermiculture (raising of worms) to compost and create a highly nutritious soil. They sometimes collect stones to clear the land and add this compost to begin creating more pasture.

Challenges and adaptations

Climate, soil and water

The region has been experiencing drought, and water is a concern. The few rains that come are very erratic, Díaz says. It is also hotter, which puts stress on the animals and can lead to the death of the llamas and alpacas. They have some wells and underground water on top of the mountain. The water flows from the higher ground to lower areas of the mountain and is used on the farm and for the family. But drought is jeopardizing the water supply. Less snow also means less nutrients going into the soil, which makes the pastures less fertile, Díaz says. "Everything depends on water." Loss of biodiversity has resulted in some desertification, which

Photo Courtesy of Evelyn Diaz

she links back to changes in their climate. Díaz has been experimenting with ways to improve soil health by planting mixes of legumes and adopting other soil management strategies. Diaz says there should be acknowledgement of the role grazing animals play in maintaining more resilient landscapes, especially as changes in climate escalates, and sustainable livestock production should be supported to protect these ecosystems and keep people on the land.

"Without the animals, there are no people," Díaz says. "There are pasture, animals and people - three elements together that make the living. Without one of them, the others would not live or exist."

Markets and local conditions

Díaz says current farm income does not cover costs of production, particularly for fiber production. They can harvest fiber once per year, and the current market only pays enough to cover 55 to 60 percent of production costs. At one point in the past, there was a ministry dedicated to camelids, which Díaz appreciated. She says it helped provide price incentives for high-quality products and opened international markets. However, now, she says there are no "sincere and transparent markets." Farmers are unable to negotiate prices, which makes it very difficult to make a living. International markets sometimes open up, but they are not consistent. Díaz and her family rely on the national market. It would be helpful, she says, if long-term policies would support the selling of camelid meat. Currently, the price of camelid meat is 55 percent lower than beef.

Policy

Díaz and other highland producers live in very rural, remote areas, and she says there is very little awareness in policy on the actual problems of the people living in these areas. Roads have been built by individuals in these areas, and the infrastructure is very basic. In the past few years, there have been some programs started by local governments and municipalities, but Díaz says there are barriers to development, access to education for her children, health services, and water and electric utilities. Indigenous communities in the highlands area face extreme poverty, and, while there are some social assistance programs, Díaz says they are limited.

Next steps in applying circular approaches

Díaz and her family began growing oats only seven years ago. They are now exploring other grasses and crops that could improve livestock nutrition and make their farm more resilient to climate change. They are particularly focused on establishing a protective microclimate through agroforestry practices to mitigate the impacts of drought. They would also like to strengthen the value chain for llama meat, particularly dried meat, to generate larger and more stable revenues.

Circularity in the community

Díaz says it is important for members of the community to support one another. The area is also being used for mining, which displaces farmers and makes it difficult for them to return once the area has been mined and abandoned. Farmer associations are important for raising the voices of farmers and ensuring that their concerns and ideas are heard. This is important not only in Peru but in the other countries in the region, Bolivia (Plurinational State of), Chile, Columbia and Ecuador. Díaz would like to see the establishment of an international camelid centre that could channel investments into research and education and boost demand for camelid fiber and meat. This would help keep camelids and farming families on the land.

Photo Courtesy of Evelyn Diaz

11. Canada: Beef cattle play important roles in a circular bioeconomy

Bob Lowe

Bob Lowe's great-grandparents on both sides of his family came to Alberta, Canada, in the 1880s. Generations of his family have farmed and ranched there ever since, and now it is Bob's and his brother Don's turn.

The brothers grow crops and manage beef cattle operations with various family members about 65 kilometers south of Calgary. From his home, Lowe looks east and sees the prairie. To the west, the foothills begin. The family grows crops on nearly 10,000 hectares; manages about 1,000 mother cows; and operates a 6,000-head beef feedyard. Much of the land is over 900 meters above sea level, but, in the summer, the cows graze in the mountains, between 1,200 to 1,800 meters above sea level.

Circular Approaches

The Lowes grow barley, wheat, peas, canola and some lentils. Grains are harvested and sold mostly into commodity markets. Cows graze native pastures and are supplemented with hay and grain through the winter and spring. They graze mountain pastures in the summer and return in the fall to graze the residues from harvested crops. For the last 25 years, Lowe has experimented with managed, rotational grazing systems that boost soil health and productivity. Crop residues are also baled and fed to cattle in the feedyard. Most of the feedyard cattle are backgrounder cattle and are fed to 800 to 900 pounds (360 to 400 kilograms) before being sold, but some are fed out to finished-market weights and sold to a global agricultural company about 32 kilometers down the road. Manure from the feedyard is spread out onto crop fields as fertilizer. The manure has close to USD 218,700 in value in terms of nutrition alone, not including the benefits in soil health resulting from improved moisture retention. Lowe says the manure-fertilizer has helped them turn marginal land into exceptionally good land.

Challenges and adaptations

Climate, soil and water

The farm has experienced drought for the last 10 years, although there have also been extreme rainfall events. Lowe recalls a retired meteorologist saying, "If it is not raining, it may never rain again. And if it does rain, it may never stop raining." That is exactly how the situation feels, he says. The family moved up its calving season to the middle of January and through February from spring for a different reason: to ensure cows are bred before going into the mountains. The shift has also helped them adapt to the changing climate as spring calving season is increasingly wet and muddy. The weather is colder in January, but it is also drier.

Lowe adds that more people from his area are looking at expanding into northern Alberta. Historically, that land has been wet and difficult to farm, but it seems to be drying off. There may be opportunities for more predictable weather patterns there than in southern Alberta, he says.

Markets and local conditions

When the brothers began their careers on the family farm in the late 1980s, they knew they needed to expand in some way to bring in more income to support more families. The cost of land was prohibitive, so they built a feedyard. An added bonus of the feedyard, they later realized, was creating new opportunities for reusing and recycling resources.

"I had never heard of 'circular economy' until the last two or three years," Lowe says.

He says straight, cattle-only and grain-only farming systems have been productive, but combining cattle and grain systems offers more opportunity for retaining value and reducing off-farm inputs.

"When you throw the feedyard into the mix, you can really make these circular economies work," he says.

Policy

Organizations including the World Wildlife Fund and National Fish and Wildlife Foundation consider the Northern Great Plains one of the most threatened and least protected ecosystems in North America (WWF, 2025; NFWF, 2025). The ecosystem covers more than 180 million acres (72.8 million hectares) across five US states and two Canadian provinces, including where the Lowes farm and ranch (Mitchell, 2022). Lowe can understand the concern. Land use, he says, is determined by economic value. Grasslands are becoming fragmented. Cities expand as populations grow. Natural amenities become tourist attractions, and competition for agricultural lands increases for economic reasons (i.e. the potential for greater profits).

"If we have any native grasslands left, it is because of the cattle we have," Lowe says. "They are grazing and doing what they do best, keeping grasses growing lush, keeping it a thriving ecosystem where bugs and wildlife coexist."

Photo Courtesy of Bob Lowe

Beef cattle spend most of their lives on pasture. Their unique ruminant digestive systems turn vegetation humans cannot eat into nutrient-dense protein. Livestock also play important roles in grassland ecosystems. The Great Plains evolved under extensive herds of grazing buffalo. Today, **cattle help control woody plants and many invasive plant species, enabling native grassland species to thrive.** They naturally fertilize the land and stimulate biodiversity overall, which also helps the ecosystem cycle water and sequester carbon.If cattle producers were compensated and acknowledged for the ecosystem services they deliver, grassland stewardship would be incentivized and protected.

Next steps in applying circular approaches

For the last two years, the Lowe family has been trialling a seaweed-based feed to inhibit methane production in the feedyard.

"It looks really good," Lowe says. "If we can keep these results up, it will be a game changer for the global cattle industry."

The Lowes are also trying out new technologies. Everything on the farm, he says, runs on computers. Crop fields are mapped using GPS technology overlaid with historical production data so the tractor plants, fertilizes and sprays only as much as needed and where the best outcomes are most likely. The cattle crew may be saddled up on horses calling cows up out of the field, but they each have smartphones in their hand and can pull up an individual cow's entire production and health history with a few clicks in an app.

Circularity in the community

Diversification opens up opportunities to work with community members. Lowe recalls a wet fall a few years ago when a neighbor could not harvest his barley due to high moisture levels. The crop would have been a loss to the farmer, but Lowe made a deal with him. The farmer harvested a truckload of high-moisture barley each day, and Lowe was able to feed it to his feedyard cattle the same day.

Several years ago, Lowe had a contract with a vegetable wholesaler in Calgary. They fed 25 to 50 tonnes of vegetables and fruits that were still good quality but did not meet market criteria. The bulk of it, about 70 percent, was potatoes, which are highly nutritious for the cattle. Under the guidance of a nutritionist, they could replace barley with potato almost one-to-one as an energy source. The story made national news, and someone made a deal with the wholesaler to buy the culled potatoes to make frozen French fries. Without the potatoes, the Lowes could not justify buying the leftover produce from a nutritional or economic sense, so they ended that practice. However, Lowe was not upset.

"It is absolute insanity that we are feeding perfectly good food to cattle because we as humans will not eat it," Lowe says.

According to Second Harvest, Canada's largest food rescue organization, more than 46.5 percent of all the food produced for Canada is wasted (Nikkel et al., 2024). More than one in four children in Canada lived in food-insecure homes in 2022 (Statistics Canada, 2025).

"Those two numbers mean something's very, very wrong in the system," he says.

Other examples of circularity Lowe sees in his community are feeding beef cattle the leftovers from making ethanol (distillers' grains), and, ironically, the leftovers from the processing of peas used to make Beyond Meat plant-based burgers at a Manitoba facility.

"It is going to take everything to feed everybody," Lowe says. "Cattle are a pretty amazing thing in making the world go round."

12.United States of America: Livestock feeds the soil and fuels everyday life

Iowa Select Farms

Jeff and Deb Hansen entered the hog business in the late 1970s. They started in an old barn where they farrowed pigs from three sows purchased at the local sale barn. Over time, they grew their operation and, in 1992, started what is now known as Iowa Select Farms.

Today, Iowa Select Farms, which remains privately owned by the Hansens, is the largest swine operation in Iowa and ranks among the top five nationally, with 250,000 sows. Iowa Select Farms employs or contracts more than 1,850 people on more than 800 farms sites across Iowa and one farm site in Nebraska.

Iowa is conducive to the hog business because of its proximity to feed sources. Iowa is the country's top corn-producing state, followed by neighboring states Illinois, Nebraska and Minnesota. Iowa Select Farms has leveraged relationships with its crop-farmer neighbors to recycle hog manure as a natural fertilizer. Inspired by the dairy industry, Iowa Select Farms has become one of the first hog producers in Iowa to use anaerobic digesters to reduce GHG emissions.

Circular approaches

Manure from hogs is collected in one of two types of manure storage systems: lagoons or deep pits. The older farms typically have lagoons. Deep pits, which can capture more concentrated nutrients, are a more recent approach. Iowa Select Farms contracts more than 850 custom manure applicators across the state. They have all undergone training with local authorities, including the Iowa Department of Natural Resources.

The applicators spread the manure across more than 64,750 hectares of land operated by more than 1,700 row crop farmers. Many of the row crop farmers sell corn and soybeans to local cooperatives, from which Iowa Select Farms sources its feeds. Beginning in 2022, Iowa Select Farms began covering its lagoon storage systems to capture methane, which is converted into biofuel by anaerobic methane digesters and sold into the grid. In 2023, these digesters captured enough methane to fuel 2,500 homes, an amount equivalent to the emissions produced by 3,000 automobiles.

Challenges and adaptations

Climate, soil and water

Jamie Horbach, director of public affairs for Iowa Select Farms, notes that fluctuating weather patterns in Iowa along with the susceptibility of swine to diseases were significant factors for moving hogs indoors. Climate-controlled barns protect animals from extreme heat and cold are common in Iowa, but hog farms remain vulnerable to damaging winds, tornadoes, snowstorms and other severe weather events. Horbach says the winter of 2023-2024 was relatively mild, but there was a three-week series of snowstorms that brought risks of power outages and dangerous roads.

Photo Courtesy of Iowa Select Farms

"That is when we really go into crisis mode," Horbach says. "If anything, we overprepare."

The farms have backup generator power, and staff work closely with local suppliers to ensure they will have enough feed to get through storms. If especially severe weather is forecasted, some staff sleep on-site to ensure animal care is not interrupted. Horbach also praises their maintenance team for keeping farm roads, and sometimes even public highways, clear of ice and snow so that employees can make it in safely to work.

Markets and local conditions

Since the 1989 farm crisis, 2023 was one of the worst years for American hog producers. At the same time, inflation has increased the production costs, especially for feed and energy. Farmers are constantly looking for ways to be more efficient.

"Our focus was on production and making it through this tumultuous time," Horbach says.

Policy

Consumer-driven policies have challenged the hog industry. Most recently the popular ballot initiative 'Proposition 12' in California set minimum space requirements to 24 square feet of usable floor space per breeding pig. Pork producers who sell pork into California, including those across the U.S. and beyond, must now be certified as compliant. Preliminary data show that the price of pork products impacted by 'Proposition 12' has risen on average 20 percent, depending on the cut, with loins most impacted with a 41 percent increase in price (Hannah, Arita and Meyer, 2024).

"No one knows their animals and land better than the farmers themselves, so the more that government can be open to supporting farmers and giving them the freedom to operate as much as possible, the more our food supply stays secure," she says.

Horbach adds that, in terms of policy, it is important to promote good relationships and open lines of communication with countries around the world to support successful global markets.

Next steps in applying circular approaches

Iowa Select Farms participates in the National Pork Board's Pork Cares Farm Impact Report annually, which gives them a picture of **their carbon footprint** and how they can decrease it. Their baseline study in 2021 showed that 58 percent of their footprint comes from feed and **29 percent from manure storage, which motivated them to invest in the anaerobic digester technology.** Horbach anticipates Iowa Select Farms will continue to invest in these systems based on the initial success. She says they have also had conversations about how to improve efficiency in terms of trucking feed onto the farms to reduce fuel use. She says they will continue to work with Iowa State University and NGOs to see what other opportunities could be available.

"We are proud to see these metrics from reducing our GHG emissions, and I think there is just endless opportunities as we move forward," Horbach says.

Circularity in the community

Cost is a major factor that farmers must consider before adopting something like a biodigester. The investment can be in the tens of millions of USD. However, Horbach says there may be ways to scale down the system to make it affordable for all types of farmers.

Iowa Select Farms has found success working with Iowa State University to research best practices. They also collaborate with the Iowa Department of Agriculture on a smart soil partnership that encourages farmers, including those who use manure from Iowa Select Farms hogs as fertilizer, to adopt practices that build soil health and reduce runoff potential.

"We want to leave our earth better than we found it," Horbach says. "If it is going to continue to be so robust and have the livestock and crop production it does, we have to do our part."

> *"their carbon footprint ... 29 percent from manure storage, which motivated them to invest in the anaerobic digester technology."*

Photo Courtesy of Iowa Select Farms

"If the "circular" activities inherently make sense, farmers will do them."

DISCUSSION OF FINDINGS

Farmers from around the world have shared in this report their experiences with circular systems, the challenges they face, impacts of variabilities in local weather and climatic changes, uncertainties in their supply chains and markets, and their adaptation strategies. Many farmers discussed the impacts of local and national policies, the rules and regulations that help or are barriers to successfully implementing a viable, profitable bioeconomy in their country. They talked about their efforts to experiment with circular systems on their farms and in the wider community to produce agricultural and forestry products that reuse, recycle, and re-invent farm waste and by-products into profitable co-products and healthy ecosystems. All were concerned about how to improve their local natural resource base and were especially focused on soil health, availability and access to clean water, and biodiversity. As one farmer said taking care of your resource base and improving soils just makes sense. If you do this, circularity can happen even without the "name circularity." **If the "circular" activities inherently make sense, farmers will do them.**

Social, economic and community networks were viewed as important assets. For circularity to work, many perceived there is a need to think beyond local and commented that local markets need to create and connect to regional and national networks with larger scale systems focused on national and global markets.

One farmer observed that circularity can be highly specialized and not require a lot of employees, or it can be labor intensive. Labor-intensive systems often work because of connections to the community and the availability of a competent workforce. Circular approaches in the bioeconomy can offer transitional as well as permanent employment and are investments in local communities and skills. A large-scale farmer observed that industrial farming is not factory farming; not everything is controlled and uniform in farming. There are many variations in farming systems and many challenges. Farmers do not work in sterile environments; they work alongside the natural environment managing storms, drought and invasive species. It is critical not to oversimplify circularities. Nature is not simple.

Many farmers had a history of farming as part of intergenerational family operations. They were persistent and determined to succeed, expand and innovate on the legacies of parents and grandparents. Several farmers said it was important for local and national leadership and policymakers to acknowledge the value of farmers beyond what they could produce (food, energy, feed and fiber); they are also stewards of land and water landscapes.

Farm-level circular approaches varied by farm type and size, production systems, the combinations of crop and livestock production, geography, and culture. Farmers observed that their climate, access to water and soil conditions often influenced the amount of land they managed and their choice of cropping systems. Those with poor soils in cool, often dry climates and mountainous topog-

Photo Courtesy of Karol Kissane

raphy needed more hectares of private and public lands to graze lamas, goats, sheep and cattle. Intensive rotational grazing was used to keep the vegetation and animals healthy and manage erosion. Livestock manure was central to adding fertility to soils and regenerating grazing lands. Farm enterprises of all scales found crop-livestock systems allowed them to upcycle agricultural products that could not be consumed directly by humans. These systems enabled them to produce alternative products and be profitable when heat, drought or flooding caused crop failure or when market prices were low.

Biogas from mixed crop-livestock systems is a classic example of mature circularity. Large-scale biodigesters were sources of local employment and produced many co-products, including fertilizers and energy. One large-scale company growing sugar cane with a biodigester system produces 9 million tonnes of sugar cane annually with co-products of sugar, ethanol, biomethane and dry yeast.

One mid-sized producer reminded the interviewer that biogas production might not work for everyone. Smaller farms with livestock and diverse cropping systems must work together cooperatively to build and 'feed' a biodigester.

Small-scale farmers raising livestock also demonstrated circularity. Black Soldier flies fed on food waste produced maggots, a protein-rich source of feed for chickens with meat and eggs sold back to restaurants. Another variation on this circularity was maggot production from flies laying eggs in pig manure with larvae used as chicken feed to produce meat and eggs for nutritious household food and sale at the local market.

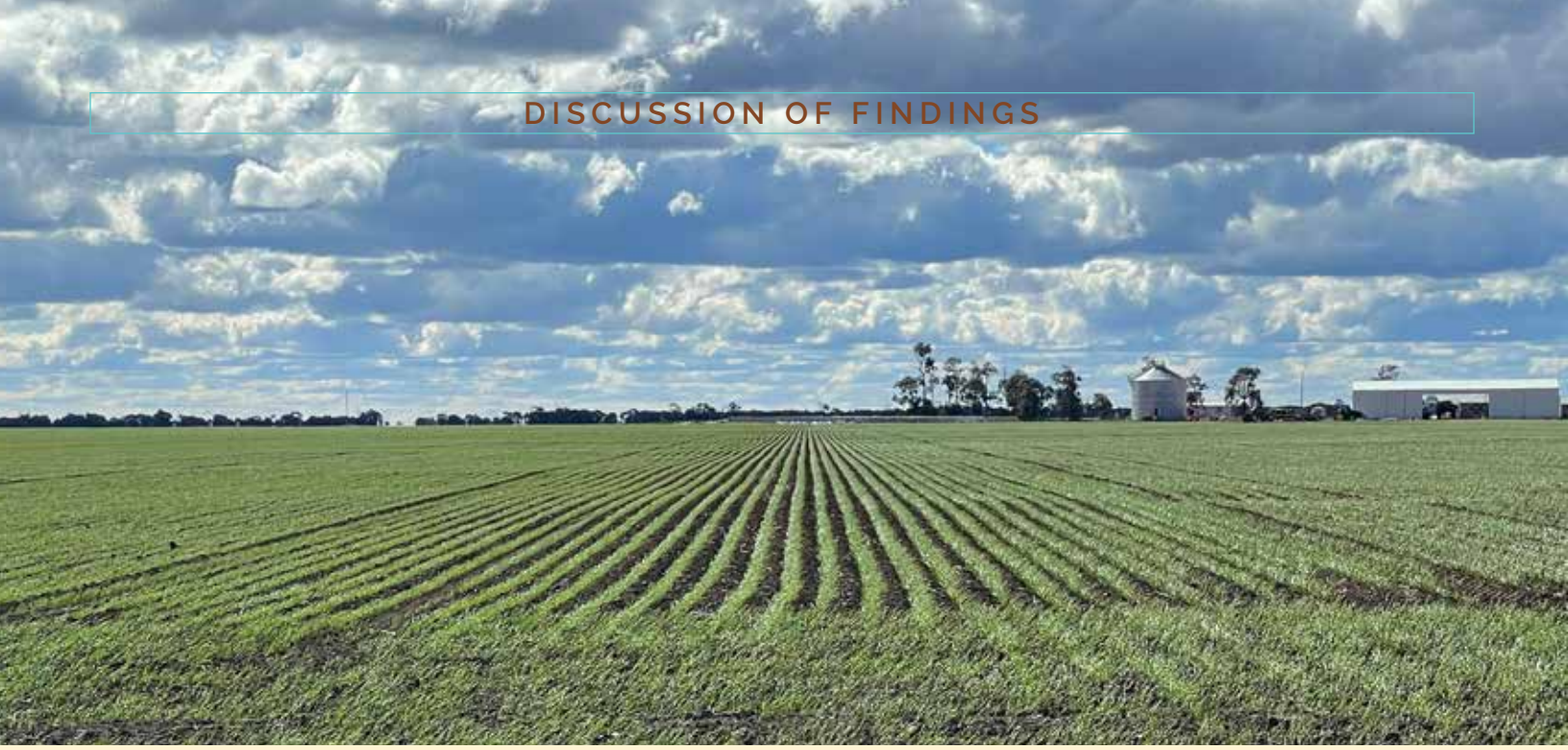
Tropical farms often produced two to three crops a year and a large diversity of vegetables and fruit, which gave the farm greater flexibility under variable weather and market conditions. Most farmers spoke about the value of the ecosystem services and biodiversity provided by their natural resource base. One farmer saw deforestation in his community and began modelling shade-grown coffee production as an alternative to traditional sun-loving crops (e.g. vegetables and ginger). His willingness to experiment demonstrated coffee and native trees grew well together, were productive, and regenerated the forest.

Survival was a word frequently used by small-scale and mid-scale farmers. These farmers were entrepreneurial and positive about the challenges of farming. However, they were clear their systems were circular and diverse out of necessity. One farmer raising llamas and alpacas on the mountain put it this way: "For animals to survive, people have to survive. Pastures and people are interdependent; when one suffers, the other suffers." Small-scale farmers discovered the key to moving beyond subsistence farming was to diversify their crops by adopting multi-species and multiple cropping systems.

Networks were important in all case studies. All the farmers spoke about their communities as sources of social support and resources. They viewed helping each other by repurposing, reusing, and sharing resources and knowledge as part of building a stronger community. Institutional support like the Center for Sustainable Rural Livelihoods (CSRL) Uganda Program and Nufield Scholars program were mentioned as helping them to be better farmers.

Photo Courtesy of Courtney Girgis

"Survival was a word frequently used by small-scale and mid-scale farmers."



"They cautioned that patience is important"

One farmer commented that CSRL helped her to be more purposeful in managing farm resources, increasing diversification and moving from rudimentary "throw out the seed," to building capacity to produce excess for selling to markets.

Community networks helped farm-level circular systems be successful. One farmer explained that his milk went to a nearby processing plant, the processor sent back the waste to the farm, and, when mixed with lime, the waste added fertility to the soil. Another farmer commented that generations ago in his region farms were more circular in their use of resources, but specialization and monocropping have reduced circularity. One of the ways farmers in his area are recreating circularity is through community cooperation, where row crop farmers purchase slurry from neighbors to fertilize their soils. "Relationships between people come first," said another farmer, explaining that many systems can complement each other. For example, one farmer may grow vegetables and sell fresh produce wholesale, while leftover vegetables can be provided as animal feed to a neighboring livestock farmer. In a remote area surrounded by Indigenous communities, an aquaculture farmer emphasized that community is essential to the success of their operation. Located close to Asian Pacific islands, the farm operation provides employment to people from those countries, creating a multicultural environment that is mutually respectful and cooperative.

Several farmers commented that adaptation and transition to different practices do not show results overnight. They cautioned that patience is important. Sometimes if you try to change everything too fast, bad things can happen. It takes time for soil to adjust. Biological systems are different everywhere; doing one thing will not give the same result somewhere else. Further, natural systems are constantly changing, and farmers must pay attention and adapt.

Drought was frequently mentioned as a common challenge. Drought intensified the vulnerability of small-scale farmers and reduced options. Poultry and pork livestock were considered less dependent on pasture, whereas cattle needed forage and grains. Drought conditions could interrupt the circularity of the farm sys-

Photo Courtesy of Nigel Corish

tem when feed had to be purchased off-farm. Other farmers talked about the importance of water technologies to prepare for the 'next' drought. Fires were the corollary to drought, and areas with dry grasses or forests were highly vulnerable to wildfires. There was recognition that farmers in the tropics experienced regular cycles of drought and monsoons. Farmers talked about the need for infrastructure to mitigate drought, with one farmer noting, this kind of 'crisis pushes you to change' and adapt to be more resilient.

Policy incentives and public investments in agriculture were on many of the farmers' minds. In one country, the government offered loans to farmers through their farmer cooperatives. This financing was particularly helpful to small-scale producers who needed seeds, fertilizers or to invest in a proven technology. One farmer was very open about farm income, government support and how helpful it was that their government promoted their farm. Another farmer was quite proud that his country's government emphasized and funded agricultural research, which was very important to the success of farmers.

Road infrastructure affected access to markets for some. One farmer commented that there was only one road to market and few options when a big rain closed the road. This was especially a problem for those who raised fish and had short windows to sell fresh fish. Access to a helicopter to take the fish to higher ground during a severe weather event was essential to ensure product quality and freshness and maintain a consistent supply to their market. Some farmers found it hard for them to compete in international markets, to sell and to acquire raw materials. One farmer expressed the concern that the cost of inputs

Photo Courtesy of ??

was higher than the market price received. Although the national market was steady, the prices were low. International markets were more sporadic but offered better prices.

Some producers were interested in using solar technology to off-set fuel costs but commented that their government was not set up to receive any excess renewable energy. Government policies preventing the use of GMO technologies or even participating in research trials were viewed as barriers in competitive markets. Other perceived barriers were policies that micromanaged the use of fertilizers and manures and governed reuse of food waste. Government policies on agricultural produced biofuels and laws governing energy transition, ethanol, carbon capture and sustainable aviation fuel were on the minds of many of the farmers with and without biodigesters. Competition for land between mining and agriculture was a major concern for farmers raising livestock and crops in mining areas. Conflicts between these two industries are a safety issue, and there is little protection for farmers.

Important messages that interviewed farmers wanted to be sure were brought forward included the importance of access to education, training and information, and the roles of and access to technologies. Multiple farmers thought there was a great need for agriculture to better connect with urban centers. Farmers are thinking about how to be sustainable in their communities. Farms have multiple dimensions and are part of a system of systems. Several farmers were especially concerned about the future of agriculture. The aging demographic of farmers combined with economic and climate challenges is pushing farmers out, and many are selling their farms and leaving their land, observed one concerned farmer. There is a need to plan for land and farm succession and have policies in place to support intergenerational management. Farmers are worried about who is going to be the next generation of farmers and the loss of the people who take care of the land. **Another strong message was that for farming to survive it must be profitable. Farmers should not apologize for profitable farm operations.**

BIOECONOMY AND CIRCULAR APPROACHES AS SOLUTION PATHWAYS

"farmers are concerned about national and regional policies and regulations that are barriers to their experimentation and adoption of circularity and climate-smart approaches and their capacities to make a living."

Policy incentives and regulations are needed for transitioning toward sustainable, regenerative agricultural approaches. Based on farmer interviews and global research, it is evident that appropriate policy frameworks are essential for creating enabling environments, removing barriers and incentivizing sustainable circularity practices.

Better understanding of farmers' challenges and their potential for the bioeconomy is needed to inform policy making and the policies needed to drive adoption of good practices and foster market access of bioproducts and sustainable trade. For instance, farmers are concerned about national and regional policies and regulations that are barriers to their experimentation and adoption of circularity and climate-smart approaches and their capacities to make a living. National regulations and policies on technologies and bioeconomy development can have disproportionate impacts on small-scale agricultural producers compared to large corporations or stakeholders with substantial resources (Albinelli *et al.*, 2024).

Below are a series of recommendations for putting into place meaningful policies that support the adoption of circular farming practices:

- **Inclusive policy design**
  Policies should be developed with the meaningful participation of farmers and other stakeholders to ensure they reflect real-world needs. In many developing countries, participatory approaches have proven effective.
  - » **Example:** In Zambia, integrating agroforestry with maize cropping, an approach developed with local farmer input, has led to higher yields and returns compared to conventional fertilizer use, supported diversified income streams, and improved soil cover.
- **Coherent policy frameworks**
  Ensuring coherence across different policy domains (agriculture, environment, trade, energy) avoids conflicting requirements. This includes harmonizing regulations at different levels of governance.
  - » **Example:** In Malawi, the government is piloting flexible e-vouchers and bundling input support with extension services to encourage diversification and soil health improvements.
- **Infrastructure investment**
  Support for infrastructure development is essential for circular systems, which encompass processing and storage facilities and transportation networks, particularly in remote rural areas. Similarly, the convergence with digitalization strategies is essential for the bioeconomy in agrifood systems. These systems benefit significantly from investments in

precision agriculture technologies (e.g. GPS and sensors) that help farmers apply water and fertilizers exactly where and when needed, substantially reducing waste while improving crop yields.

» **Example:** In Italy, the conversion of traditional fossil-fuel refineries and industrial sites into bioeconomy-based production facilities.

- **Flexible, scale-appropriate approaches**
  Different scales of operation require tailored policy responses. What works for large-scale operations may not be feasible for small-scale enterprises, and vice versa. Territorial pilot actions could demonstrate flexibility in supporting bioeconomy initiatives and serve as models for other farmers, acknowledging the need for context-specific approaches.

  » Example: Bangladesh's e-voucher system allows farmers to choose input bundles suited to their specific needs, supporting both small-scale and larger-scale producers.

- **Knowledge transfer mechanisms**
  Investments in extension services, farmer-to-farmer learning platforms, and educational programs are crucial for spreading knowledge about circular approaches.

  » **Example:** The United Republic of Tanzania's Seaweed Cluster Initiative trains women farmers in value-added processing.

Photo Courtesy of Humpty Doo Barramundi

- **Market development support**
  Policies that help develop markets for circular products and byproducts (e.g. certification schemes, public procurement, and consumer education) are essential. Blockchain traceability systems are emerging as effective market development tools that provide transparency, efficiency, and accountability across the supply chain, helping farmers demonstrate sustainable practices to consumers and reducing waste throughout the value chain.

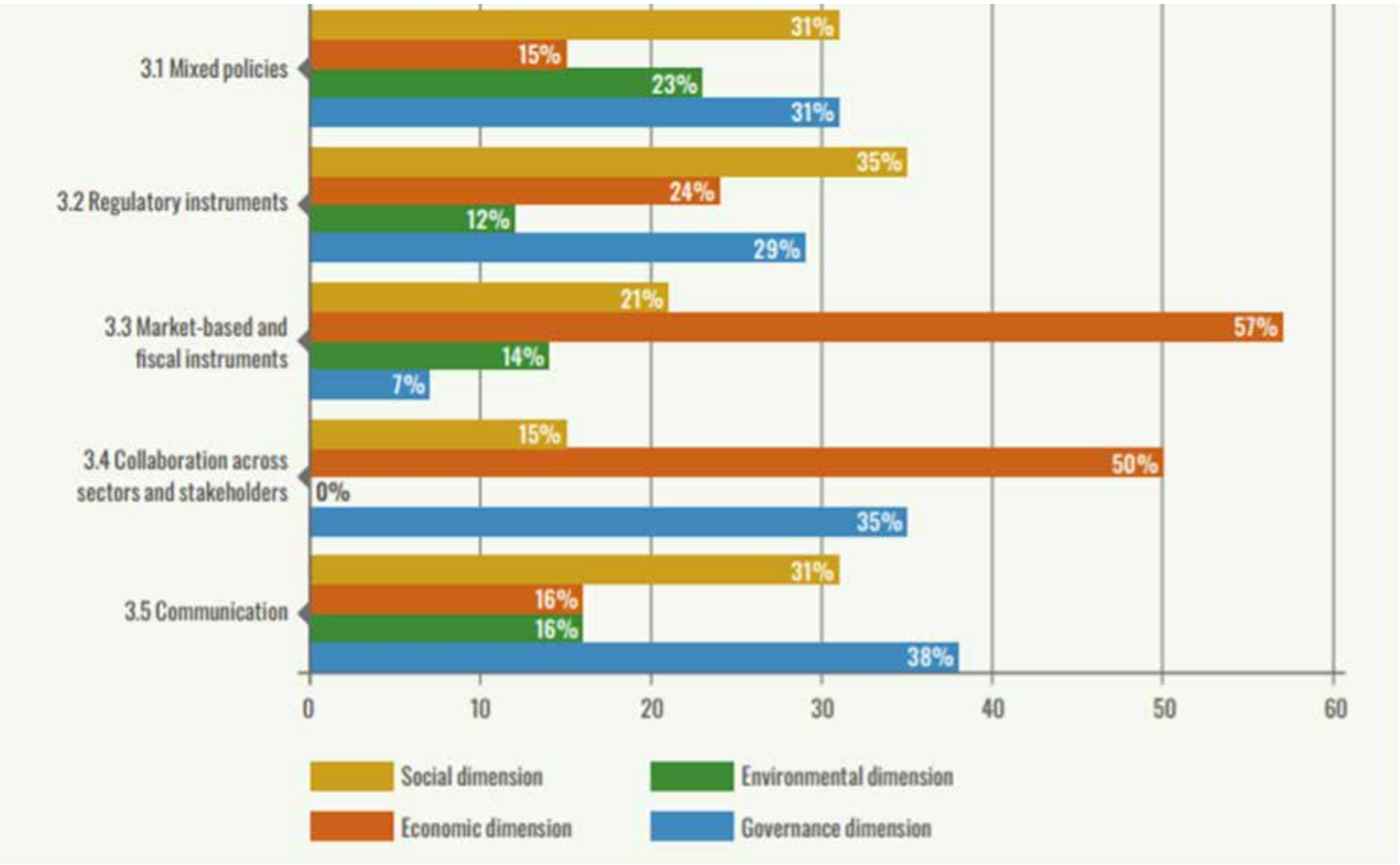
  » **Example:** In the United Republic of Tanzania, inclusive value-chain development empowers women and adds value to local resources.

Many countries have articulated proactive visions and embraced resource circularities as strategies for cleaner, greener environments, sustainable development, and lower carbon emissions (Edyvean *et al.*, 2023; IICA, 2024). **Box 1**, Implementing Effective Bioeconomy Strategies, elaborates on guiding principles and policies some countries and regions have implemented.

As shown in Figure 5, there are distinct areas of policy-making that can support these practices uptake by farmers (Gomez San Juan and Bogdanski, 2021):

- Public support for technology uptake by farmers to bridge the gap between farmers, science and policymakers in dedicated projects, platforms or public private partnerships;

Figure 5: Classification of policies that support the sustainable bioeconomy transition



Source: Gomez San Juan, M. & Bogdanski, A. 2021. How to mainstream sustainability and circularity into the bioeconomy? A compendium of bioeconomy good practices and policies. Rome, FAO.

- Education and communication including challenges in the uptake of practices as well as the solutions they provide and the benefits in the long-term;
- Commercialization of bio-based products for income diversification, including co-benefits valuation such as carbon sequestration, rehabilitation of degraded or contaminated soil, plant growth promotion, and climate change resilience; and
- Regulations, including revision of agricultural policies to include innovations and circularity practices, and other policies such as safety and the efficient use of resources.

For instance, food safety management is often designed for linear systems, and possible risks related to circular agrifood systems are not easily identified. Examples are water recycling and reuse, including monitoring contaminants in recycled water; integrated farming systems, including transmission risks of pests and pathogens; contaminants in food waste and byproducts, including those used as feed; and risks linked to reusable and recycled food packaging (FAO, 2024c).

Also, consumer perceptions of waste are important, promoting its recognition that it is a valuable resource that needs to be recycled or re-purposed. For instance, only a small portion of food lost or wasted in North America and Europe is used for animal feed, which means around 5 percent and 10 percent, respectively (Boumans et al., 2022; McBride et al., 2021), while in Japan it is around 36 percent and in Republic of Korea it is 43 percent (Takata et al., 2012; zu Ermgassen et al., 2016; Uwizeye et al., 2019). Therefore, there are countries which have developed innovative policies and regulations to collect, prepare, heat treat, and improve residual biomass traceability.

In the European Union, the Urban Wastewater Treatment Directive mandates the compulsory establishment of wastewater treatment facilities, including that the sludge arising from wastewater treatment shall be re-used whenever appropriate. Uses include organic fertilizer and more advanced resource recovery (including N) if allowed by regulations as well as technical capabilities in the sludge stabilization process and adequate disposal.

Another example is nutrient management, including better understanding of the role of soil microbiota in biogeochemical cycling and the adaption to climate change (Kendzior, Warren Raffa and Bogdanski, 2020). This includes improved knowledge of soil microbial functions to guide nutrient management strategies (Carbon, Nitrogen, Phosphorous) for crop production, ecosystem health and GHG emissions. Improving resource use efficiency, including nitrogen use efficiency (NUE) and other indicators, can be achieved by the adoption of circular bioeconomy practices that valorise unavoidable waste and optimize biomass use across the farm level (FAO, 2024d). **Figure 6** shows some of these practices for the livestock sector. FAO (2025a) explored the role of bioeconomy and circularity practices in nitrogen management and called for countries to encourage, as appropriate, the use of organic residues and waste such as biosolids to address consumption patterns to promote highly efficient fiber, food and bioenergy production. This publication also calls for more market-based incentives, such as premium prices and other instruments, to reward farmers

BOX 1: IMPLEMENTING EFFECTIVE BIOECONOMY STRATEGIES

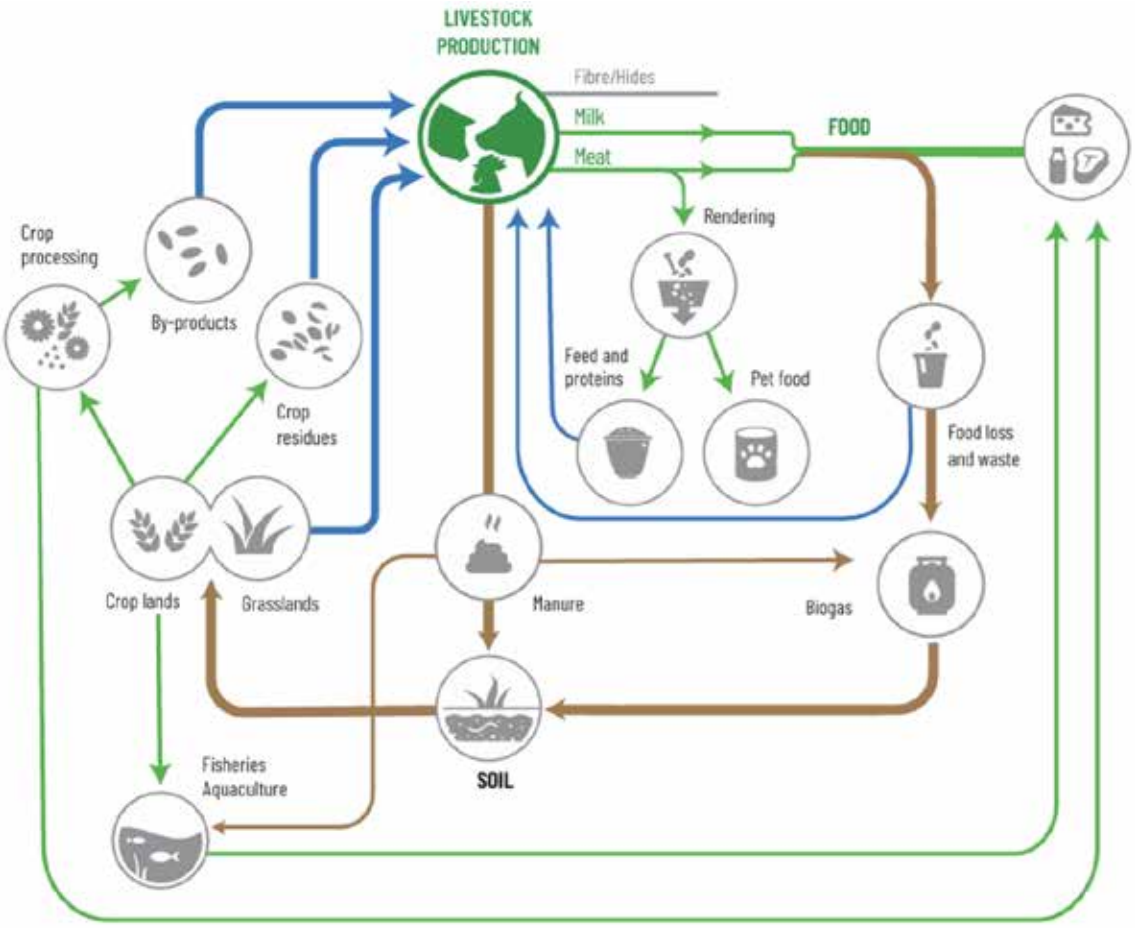
Thailand's Bio-Circular-Green (BCG) focuses on elimination of waste and use of renewable resources with the goal to create a "new normal" (Edyvean et al., 2023). This new normal focuses on biological resources and their conversion into value-added products and creation of a green economy that "keeps economy, society and the environment in harmony, resulting in sustainable development" (Edyvean et al., 2023).

The Latin American Bioeconomy Network has created a set of guiding principles in support of policy development and investment tools that promote sustainable development, use of natural resources, and the enhancement of food and nutritional security (IICA, 2024). The network reaffirmed that there is no single definition of "bioeconomy" and identified five common elements among national bioeconomies: conservation and valorisation of biodiversity and biomass; incorporation of science, technology, and innovation including ancestral knowledge; value addition and circularity; promotion of environmental sustainability; and social inclusion in rural areas.

The Italian Bioeconomy Strategy Implementation Action Plan (2025-2027) specifically calls for "territorial reconnaissance actions" to better co-design site-specific, tailored actions for restoring, regenerating, and upgrading local bioeconomy value chains with stakeholder participation (NBCB, 2024). "Living labs" in Italy serve as multi-stakeholder platforms where farmers, forest owners, advisors, researchers, businesses, policymakers, and citizens collectively develop place-based innovations, promoting aggregation of local bioeconomy actors and fostering new site-specific value chains. Likewise, the Italian Bioeconomy Strategy proposes an integrated approach combining "policies, standards, labels, certificates and emerging market-based actions, including fiscal and financial incentives" to create a comprehensive enabling environment for circular bioeconomy development.

The European Union concept of bioeconomy encompasses bio-based, green, and circularity of resources. The European Economic and Social Committee has emphasized bioeconomy-related governance frameworks that balance economic growth with environmental protection while ensuring fair access to resources and equitable benefits for all stakeholders. **Figure 7** shows a summary of the bioeconomy policies promoted under the EU bioeconomy strategy. The installation of biorefineries in rural areas have helped in the transf-ormation of biomass into useful bio-products, employed local people, and incentivized the production of biofertilizers as renewable inputs for crop production (Khan and Ali 2022).

Figure 6. Representation of circular approaches in bioeconomy for the livestock sector



Note: The green arrows represent the production of food, blue arrows represent the supply of animal and fish feed, and the brown arrows represent the recycling flows across agrifood systems.
Source: Authors' elaboration.

Source: FAO. 2025a. Sustainable nitrogen management in agrifood systems. Rome. 132 pp.

who comply with environmentally friendly practices such as circular nutrient management, as well as regulations such as to stop the discharge of manure in water bodies.

Farmer organizations can serve as valuable entry points for policymakers seeking to ensure that farmers receive accurate information about emerging innovations. Policymakers, in turn, must be well-prepared and equipped to make informed decisions about both the opportunities and risks associated with revising policies or supporting new market development.

Increasingly, policymakers are involved in creating favourable conditions for the adoption of new bio-based technologies, inclusive business models and circular practices. However, the development of a bioeconomy does not automatically guarantee sustainability or circularity. Therefore, it is important to develop and use policy indicators to assess the impact of circular practices — such as their effects on land management, soil health and GHG emissions.

Despite these efforts, several barriers remain. These include limited awareness, restrictive policies and legal frameworks, and a lack of economic incentives and infrastructure for the collection, transportation, and processing of crop residues, byproducts, and organic waste. These challenges hinder the effective valorisation of these materials. In particular, market access barriers and the "biomass premium" challenge bioeconomy economics. Bioproducts typically face a price premium compared to fossil alternatives, creating a market disadvantage that must be addressed through policy, innovation and changing consumer

expectations. Without addressing these economic challenges, many promising bioproducts will struggle to achieve commercial viability. Similarly, enforcing good practices and circularity approached in the production and processing of the biomass into the bioproducts require their own set of policies.

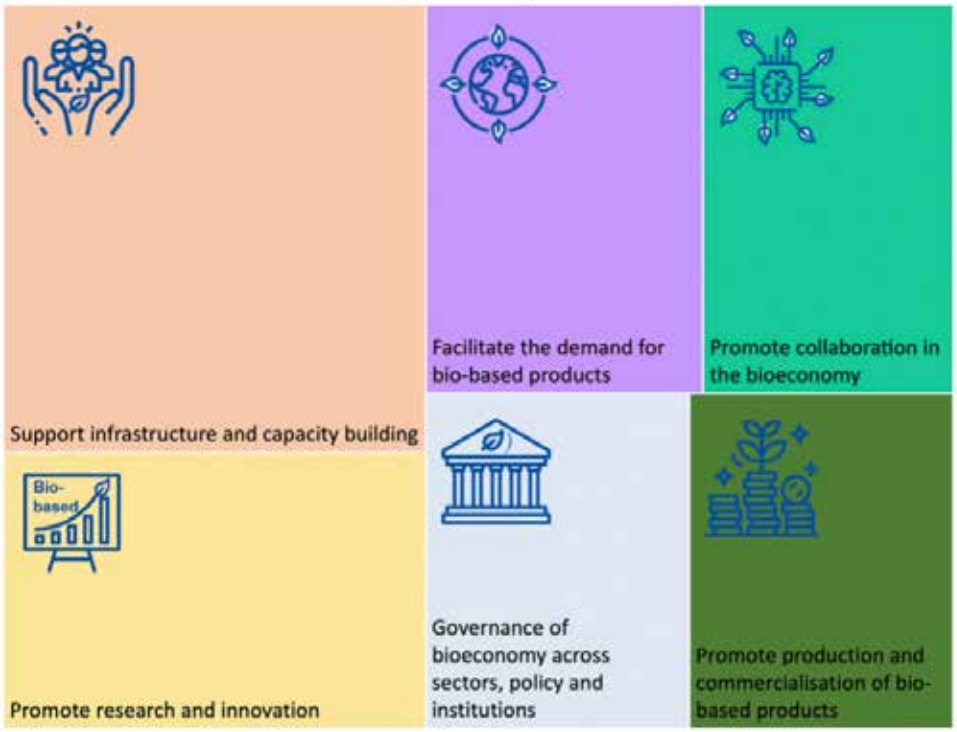
To this end, policymakers are increasingly committed to developing sub-national, national and/or regional bioeconomy strategies and programs that ensure policy coherence, and a toolbox of different policy mechanisms that valorise and efficiently use biological resources while planning and preventing trade-offs. Circular approaches and bioeconomy national strategies and plans can help countries make agrifood systems more sustainable and leverage the potential of agrifood systems that could advance the whole economy, create and connect new industries, generate decent employment opportunities, and increase social well-being (Albinelli *et al.*, 2024).

Generally, when governments or regional or local authorities develop strategies and policies to support a sustainable bioeconomy (**Figure 7**), they seek to improve the production, use, consumption and conservation of biological resources. Often, enhancing circularity increases efficiency in using and regenerating these biological resources, thus reducing pressure and competition between the end-use sectors. For instance, crop residues can be left on the soil to enhance soil structure and nutrient content and/or used for feed or as a substrate to grow food such as mushrooms and/or in pulp and paper, construction, chemicals, energy, or textile sectors.

To implement sustainable bioeconomy strategies in countries and regions, strategies and action plans must be developed over time in close coordination with government ministries, ensuring the inclusion of local and regional stakeholders and civil society throughout the process. This collaborative, inclusive approach to policy development together with farmers' perspectives will be key to realizing the full potential of circular bioeconomy approaches in agriculture, as demonstrated through successful implementations in regions like Catalonia and national strategies such as Italy's Bioeconomy Strategy.

In conclusion, effective policy incentives for circular farming practices must be comprehensive, coherent and context-sensitive. When properly designed with stakeholder input, supported by appropriate infrastructure investment, and complemented by knowledge transfer mechanisms, policy frameworks can successfully drive the transition toward more sustainable agricultural systems. Farmer voices from around the world provide valuable lessons for policymakers seeking to support circular bioeconomy development in their own regions, highlighting the importance of balancing economic, environmental, and social considerations in policy design and implementation.

Figure 7. Contribution of key policies towards the achievement of bioeconomy objectives.



Source: Korosuo, A., Borzacchiello, M.T., Giuntoli, J., Lasarte Lopez, J., M'Barek, R., Mubareka, S.B. & Camia, A. 2024. Trends in the EU bioeconomy - update 2024. Publications Office of the European Union, Luxembourg.

"It will take resources, imagination, boldness, partnerships and alliances to successfully meet present and future goals"

CALL TO ACTION

As planet earth continues to evolve and grow, the challenges and opportunities facing nations, leaders, and farmers of the world are immense. It will take resources, imagination, boldness, partnerships and alliances to successfully meet present and future goals such as concurrently increase productivity, nutrition and food security; ensure rural livelihoods and develop economic opportunities; eliminate or greatly reduce resource waste and losses; eliminate or significantly reduce environmental degradation; and increase the value of biomass carbon sources (CBSI, 2024).

While many local, national and global agri-food systems are well positioned to help meet and overcome these challenges, they cannot succeed alone. Nations and their leaders must create spaces and policies that encourage public-private partnerships within and across agriculture, forestry and food sectors, their value chains, and allied sectors to realize the full potential of bioeconomies. These partnerships must honestly assess current agrifood and bioeconomy capacities; re-evaluate what is working and what is not working in local and national food systems and economies; and strive toward the elusive sweet spot of scale between local, national and global economies. This means each nation and leaders must develop a shared vision and action plan for transformed systems that meet national needs and its people. The action plan must encompass a wide range of innovations including famer and indigenous innovation, strengthening of scientific knowledge, encouragement of experimentation and refinement of effective technologies. Farmers, ranchers, foresters, pastoralists, aquaculturalists and fisherfolk are the foundation of the food system and bioeconomy. If they fail, the whole system falters. They are key and necessary partners in building healthy, abundant and robust food systems and bioeconomies.

National and sectoral plans will need well-constructed but flexible mechanisms that incentivize finance, scientific discovery, and economic stability with system feedback loops that enable timely responses to uncertainties and changes in climate, markets, resources, and relationships.

Investments in circular agricultural approaches and local and national bioeconomies show great promise for scaling up the bioeconomy to become an "economy of economies" that can deliver the solutions that healthy, vibrant and growing nations require. While a bioeconomy-based future can supplement and perhaps someday replace or greatly reduce dependency on fossil based industrial economies, it will require a transition from linear to circular and singular to integrated approaches. This transition means changing mind sets and habits about how we use and reuse, recycle and redirect resources while strengthening capacities for innovation.

As countries and groups such as the G20, craft national, regional and hemispheric plans and strategies to achieve agendas for sustainable development, circular agricultural systems and practices can provide

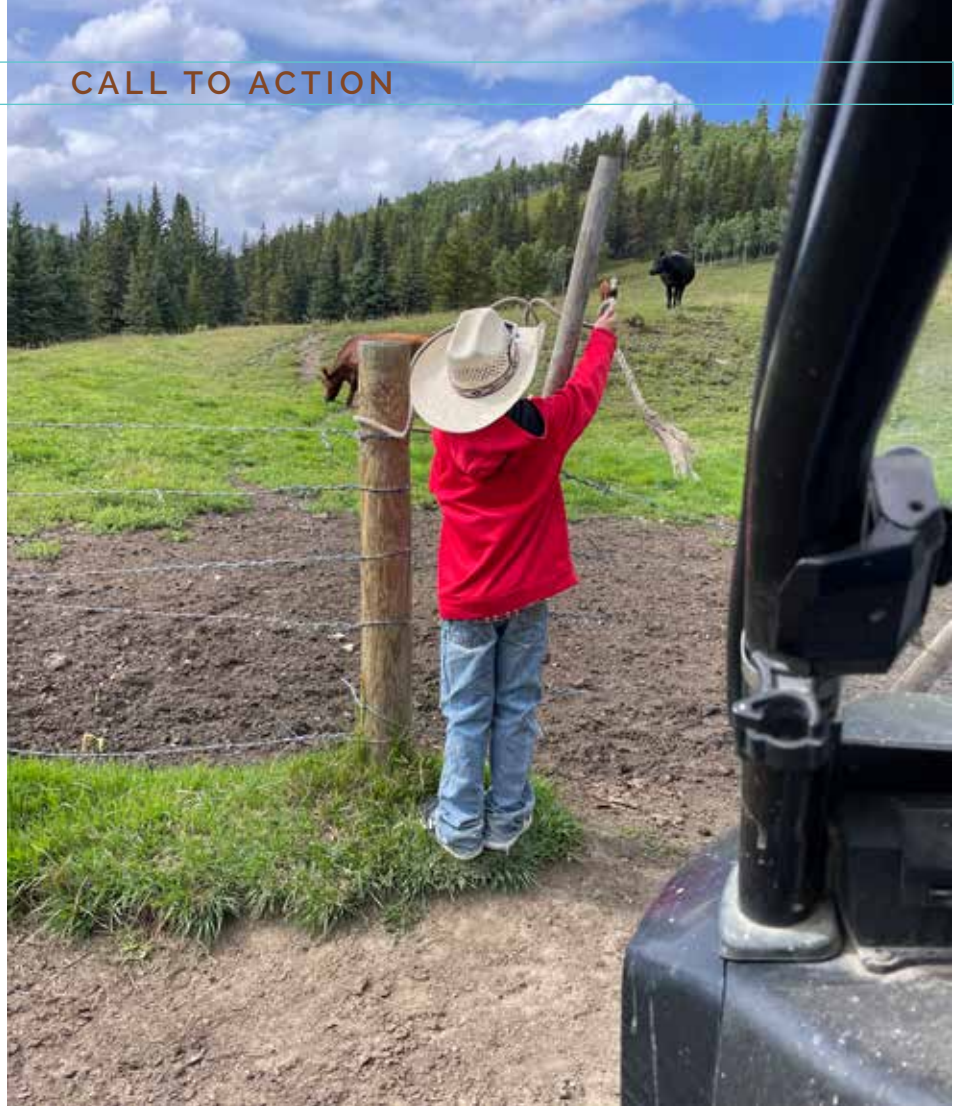


Photo Courtesy of Bob Lowe

cost-effective and valuable regenerative solution pathways to grow the bioeconomy. The interviews with farmers from different regions of the world in this report give voice to their experiences and experiments with circular approaches and bioeconomy strategies. Their observations and insights reveal a number of essential building blocks that countries can use to scale bioeconomies, including but not limited to:

- building policy frameworks and systems from the ground up not top down;
- maximizing the use of farmer-to-farmer knowledge sharing platforms and programs;
- prioritizing capacity building investments in cooling, processing and storage infrastructure, roads to transport inputs and outputs, and clean renewable energy sources of power;
- investing in innovation technology, research and development;
- guaranteeing fair and equitable land and water rights;
- constructing finance mechanisms designed to meet local needs; and
- paying farmers not just a fair price for the commodities they produce but for the ecosystems services they concurrently deliver.

Transitioning to circular approaches and scaling up bioeconomies is a journey, not a sprint. It will not happen overnight and therefore nation states need to budget adequate time to construct and implement enabling policies, programs and partnerships. The process of visioning, planning and implementing a national bioeconomy that meets multiple challenges and leverages the opportunities of uncertainty and change must begin with placing farmers and their private sector value chain partners, those who will actually be delivering the outcomes society desires, at the centre of discussions and decisions **(See Box 2)**. The evolution of 21st Century economies across the globe will require continuous monitoring, assessing progress, and recalibrating in response to real-world conditions. It also requires the adoption of guiding principles and values to construct policy frameworks that create effective enabling environments, remove barriers and incentivize sustainable circular approaches to growing bioeconomies. Solution pathways must be built from the ground-up using co-creation approaches that engage key players and pull people through planning and into implementation and action.

"Transitioning to circular approaches and scaling up bioeconomies is a journey, not a sprint."

BOX 2: PUTTING FARMERS AT THE FOREFRONT OF AGRIFOOD ECONOMIES, SOLUTIONS FROM THE LAND, "NORTH STAR"

Farmers must be at the center of all agriculture and food discussions and decision- making; significant input will be needed from a wide range of farmer, indigenous communities and producer organizations outside of established policymaking structures.

There is no "silver bullet" solution for enhancing the resilience of agriculture and food systems: policymakers must embrace farmer-centric systems approaches that recognizes the tremendous diversity of agricultural landscapes and ecosystems and enables producers to utilize the systems and practices that best support their farming operations.

Science-based decision-making, in conjunction with farmer and indigenous innovation, must be the foundation for the adoption of agricultural smart technologies and practices in the production of sustainable agriculture, biodiversity, ecosystem well-being, and food and nutrition security.

Since crops, livestock and production forestry dominate the world's land area, agricultural systems must be advanced that increase both production and production efficiency per unit of land and water; meet the food and nutrition needs of the future; and greatly enhance ecosystem health by regenerating soils, watersheds, habitats and biodiversity at scale.

All tools in the toolbox approaches appropriate to geographies, ecosystems and watersheds, cultures and a wide variety of agricultural/ forestry types and scales should be considered in the effort to achieve multiple Sustainable Development Goals (SDGs) of the United Nations outcomes, without predetermining technologies, production type or design components.

Adaptation strategies will require system approaches that utilize a combination of improved efficiency, substitution (e.g. new crop varieties and breeds), and redesign/system transformation to reflexively respond to continuous short- and long-term changes in weather and climate patterns and impacts on cultivated and natural ecosystem conditions.

Context-specific priorities and solutions must be aligned with national policies and priorities; be determined based on the social, economic, and environmental conditions at site (including the diversity in type and scale of agricultural activity); and be subject to evaluation of potential synergies, tradeoffs, and net benefits.

Source: SfL (Solutions from the Land). 2025. Guiding Principles. In: SfL. Lutherville, Maryland, USA. [Cited 6 May 2025].

Photo Courtesy of Bob Lowe

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Farmers are central to food and nutrition security, environmental sustainability and resilient rural economies. This publication features farmers from around the world who are applying circular approaches, reusing, recycling and regenerating resources, to transform agricultural systems and livelihoods. Their stories reflect how diverse circular practices, from integrated crop-livestock systems to bio-textiles production, coupled with innovation and technology, can improve productivity, reduce input costs, and restore natural resources while contributing to agricultural resilience and community well-being.

Through their experiences, the report highlights practical pathways for advancing circular bioeconomies grounded in local contexts and knowledge. It shows how farmers are building sustainable agriculture and food systems by connecting on-farm resource management with policy, ecosystem health, technology and community engagement. The farmer stories, drawn from personal interviews conducted in 2024, are their own unique perspectives and may not reflect the views of other farmers or SfL. These voices offer valuable insight into how circularity can scale from farms to food systems, contributing to better production, better nutrition, a better environment and a better life, leaving no one behind.

Photo Courtesy of Wichai Kamnerdmongkon

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