CHAPTER 2

Seeking synergies for health, inclusion and the planet – in animal production systems and animal-sourced foods

Today, animal production systems and animal-sourced foods (ASF) are in the limelight because of the debate around the fear that increasing global demand for ASF could take us beyond planetary boundaries and also have nutritional impacts. There is concern about ASF production being less efficient and more wasteful than production of crop-derived foods, while land suitable for food crops is increasingly used for feed and a rising number of concentrated farm animals imposes direct environmental burdens – greenhouse gas (GHG) emissions and soil and water pollution – along with health pressures linked to zoonotic diseases and antibiotic resistance. In addition, underconsumption and overconsumption of ASF are regarded as detrimental to human health and a burden on health-care systems.

In a world with a growing population, increasing urbanization and globally rising average wealth, rising demand for ASF certainly warrants concern. That said, the implications of rising ASF production are mixed: along with its many risks, it brings some benefits. Underconsumption, as well as overconsumption, of ASF can pose health threats and impose burdens on health-care systems. So increasing amounts of ASF in diets should not be seen as a solely negative development. Further, ASF production systems and intake vary tremendously across and within regions and countries, while their effects vary by production system, ASF group and product type. Despite this, many animal production systems contribute to circular systems, recycling organic by-products and waste, providing manure to land under food crops and using pastures that cannot be used as arable land. Chicken and aquaculture-based systems are good examples of such circular systems.

This chapter develops five messages:

1. **Animal production and ASF intake increase sharply with population growth, urbanization and rising incomes – creating environmental burdens that differ by animal group and production system type.** Animal production is generally less efficient (output per unit of input) than plant production, potentially putting a large burden on land and water resources – but efficiency ranges considerably across animal groups and production systems worldwide.
2. **Consuming ASF has important health and nutrition benefits, particularly for young children, but in excessive amounts it can also harm health.** Both insufficient and excessive ASF intake pose disease risks and can burden health systems.
3. **Animals are part and parcel of rural livelihoods, with meanings beyond food production.** The significance of keeping animals varies in ways that reflect and have implications for gender roles. Kept animals need care throughout the year, can provide income throughout the year and have socio-economic and cultural significance.
4. **The expansion of ASF production systems contributes to major global environmental worries through food-feed competition, land and water degradation and pollution, and rising GHG emissions – yet these concerns are not chiefly associated with rural smallholder production.** Small-scale animal farming households are not a principal environmental threat.
5. **Depending on the animal group and production system, certain farm animals, fish and ASF – including novel proteins – show great promise as drivers of circular food systems.** In particular, developing and scaling novel proteins can help meet increasing global ASF demand.

Can the world keep up with increasing ASF intake?

ASF intake varies widely across countries and regions (**BOX 2.1**). Rising ASF demand has three main drivers: population growth, urbanization and rising incomes. The elasticity of ASF demand to income is relatively high: in low- and middle-income countries, even slight income gains from low initial levels tend to shift dietary composition in favour of ASF.

BOX 2.1 CLASSIFYING ANIMAL GROUPS FARMED FOR FOOD – AND TYPES OF ANIMAL PRODUCTION SYSTEMS – IN LOW- AND MIDDLE-INCOME COUNTRIES

Animals raised in low- and middle-income countries belong to four food groups:

- **Cattle** are kept for meat production (beef cattle) or for milk production, but also as a "mobile bank account". They have many additional functions: they provide draught power for land preparation, they produce manure for crop fertilization, they are kept as capital assets and for insurance, and they signify social status (Moll, Staal and Ibrahim, 2007; Oosting, Udo and Viets, 2014). In South and South-East Asia, water buffalo are as important as cattle for milk production and for tilling rice fields.
- **Sheep and goats**, together referred to as small ruminants, are important livestock species for poor people (Udo et al., 2016. The income derived from keeping goats and sheep is, however, relatively low. Goat and sheep populations are growing in Africa and Asia by about 2.5-3.5 per cent annually for goats and 1.1 per cent annually for sheep, which is slightly higher than the growth in cattle populations on both continents (Mazhangara et al., 2019). Goats and sheep are kept for meat, have a key role in religious festivities and are a small capital asset to be sold for cash.
- **Pigs and poultry** are monogastric, implying that they need higher-quality feed than do cattle, sheep or goats. Pigs and poultry are kept either in backyard systems, where they scavenge their own feed supplemented with household waste, or in intensified systems, which require investments in housing, feed and disease control. In low- and middle-income countries, intensive pig and poultry production is the fastest-growing livestock sector, and it is seen as the major supplier of ASF of the future (Herrero et al., 2013).
- **Aquaculture**, or fish farmed in ponds, encompasses three types of species: herbivore, omnivore and filter-feeding. All types allow for the inclusion of plant-based by-products in feed (Hua et al., 2019). Ponds are production systems, but they are also complete ecosystems in which algae grow on nutrients from waste streams such as livestock manure, kitchen waste and supplementary fertilizer (Pucher and Focken, 2017). Sediment from fish ponds may be used as a fertilizer.

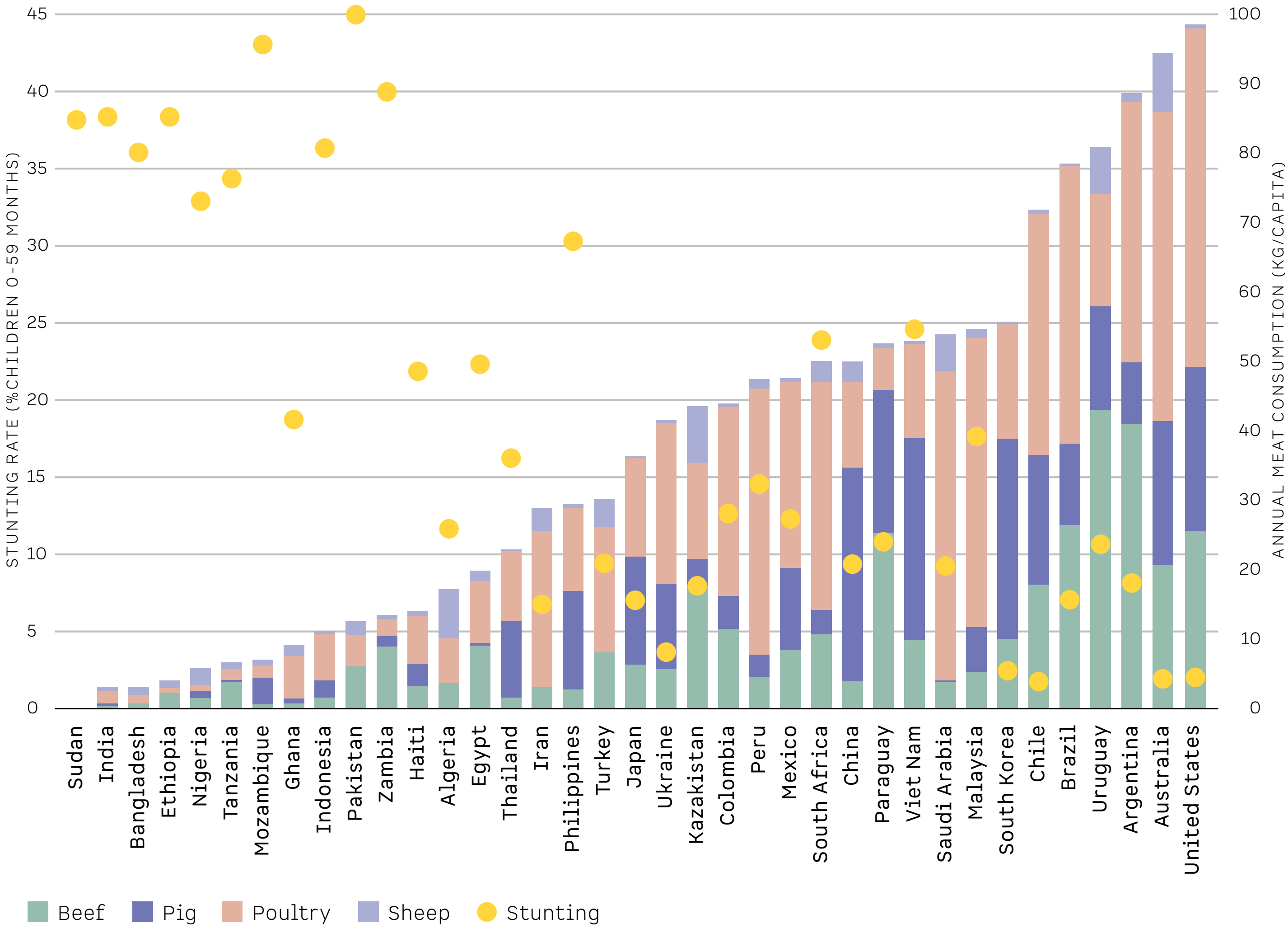
Four types of animal production systems can be broadly distinguished:

- **Dryland grazing.** In dryland regions, mobile grazing systems with pastoralists herding ruminants are dominant. Dryland regions are too dry for crop production, and herding is the only agricultural activity supporting livelihoods. Traditionally, pastoralist systems exist in symbiosis with crop systems, in part because of the exchange of food obtained from sedentary agriculturalists but also because pastoralists require grazing on crop residues during the dry season, whereas crop farmers benefit from manure deposited during grazing.
- **Semi-arid to semi-humid grazing.** In regions with semi-arid to semi-humid conditions, animal rearing is generally limited to grazing ruminants for meat production. These regions could potentially be used for crops: some were once covered by forest. In some areas, deforestation and use as cropland has depleted the soil and left extensive ruminant production on grassland as the only possible economic activity. Meat production is often a two-stage activity: the first consists of a relatively long pre-fattening period, with low growth rates on relatively poor pastures (and thus with relatively high GHG emission intensities), followed by a second stage – intensive fattening at feedlots.
- **Mixed crop, livestock and aquaculture systems.** Because of their relatively favourable conditions, these systems are found in relatively densely populated regions, where farms are small. High levels of integration between farm activities are observed; various species of livestock are kept to feed on residues of crop production and household waste – and on collected grass or by grazing on communal lands and along roadsides. Manure is used as fertilizer or as substrate for fish production in ponds, and pond sediment may then be used as fertilizer.
- **Industrial and semi-industrial systems.** These systems – often producing poultry, pigs, aquaculture or dairy – are found in densely populated regions with nearby markets and good infrastructure – conditions that allow feed supplies, good market linkages and limited transaction costs. Productivity is high, so GHG emission intensities are relatively low. Because industrial systems use high-quality feeds (for example maize and soybean, often as soybean meal), land and water use for industrial and semi-industrial systems compete with human food crop production.

Global ASF intake shows a wide range

Differences in ASF intake across countries, regions and incomes are staggering (**FIGURE 2.1**). Whereas high-income countries, Latin American and East Asian countries are all at or above 30 kg per capita per year, all countries in the Middle East and North Africa, sub-Saharan Africa and South Asia are below this level. Mean annual per capita meat consumption in the bottom four meat-consuming countries (Bangladesh, Ethiopia, India, Sudan) is less than one thirtieth of that in the top four (Australia, Brazil, the United States, Uruguay). Across IFAD regions, Latin America and the Caribbean consumes the most bovine meat per capita, on average twice as much as East and Southern Africa and Asia and the Pacific, and three times as much as West and Central Africa. East Asia ranks high on pig meat, Latin America on beef, and the Middle East and North Africa on sheep. Poultry is important everywhere.

FIGURE 2.1 MEAT CONSUMPTION PER CAPITA AND STUNTING RATE ESTIMATES IN DIFFERENT COUNTRIES



Source: OECD, 2018 and UNICEF, WHO and World Bank, 2017.

Aquatic foods are not included in **FIGURE 2.1**, but the world's appetite for aquatic foods is great and growing, mainly through fish farming. Consumption has doubled in the past 50 years (**BOX 2.2**).

Meat intake is inversely related to child stunting rates (see **FIGURE 2.1**). Although this association at country level cannot be interpreted as evidence of a causal relationship, it may reflect the income elasticity of some ASF, including meat. That said, it supports the hypothesis that ASF consumption benefits child growth (Headey, Hirvonen and Hoddinott, 2018; Pimpin et al., 2019).

While the consumption of ASF varies widely within and across countries and regions, the geographical distribution of livestock is also important for transforming food systems (**BOX 2.3**).

BOX 2.2 COASTAL COMMUNITY DEVELOPMENT IN INDONESIA

Millions of people in Indonesia rely on healthy fishing markets for their livelihood. Limited and inefficient fishing gear combined with poor infrastructure stifles the growth potential of the fishing industry.

An IFAD project implemented between 2013 and 2017 was designed to address poverty and achieve sustainable economic growth in 12 coastal districts. The goals included marine and coastal natural resource management. Beneficiaries were provided with improvements to fishing activities, such as motorized boats and improved infrastructure for markets, processing centres and storage facilities. Investments restored the coastline with mangrove; established rotational rules for fishing points; and supported aquaculture, ecotourism, and fish processing, packaging, distribution and marketing. The project implemented several sustainability measures, including the establishment of fish-processing groups, with the primary goal of engaging women in processing and marketing.

Fishing productivity rose by 79 per cent, market access increased by 28 per cent and post-harvest losses fell by 5 per cent. Coastal resilience efforts were designed to ensure the longevity of the market and prevent overfishing. Coastal resource governance was also strengthened, allowing the government to assume responsibility for the project.

Source: IFAD, Coastal Community Development Project, Indonesia impact assessment technical peport and policy brief.

BOX 2.3 MAPPING THE GLOBAL DISTRIBUTION OF FARMED ANIMALS

Global datasets on the geographical distribution of livestock are essential for diverse applications in agricultural socio-economics, food security, environmental impact assessment and epidemiology. Gilbert et al. (2018) presented the latest version of the Gridded Livestock of the World (GLW3) database, reflecting the most recently compiled and harmonized subnational livestock distribution data for 2010. That version provides global population densities of cattle, buffalo, horses, sheep, goats, pigs, chickens and ducks in each land pixel at a spatial resolution of 0.083333 decimal degrees (approximately 10 km at the equator).

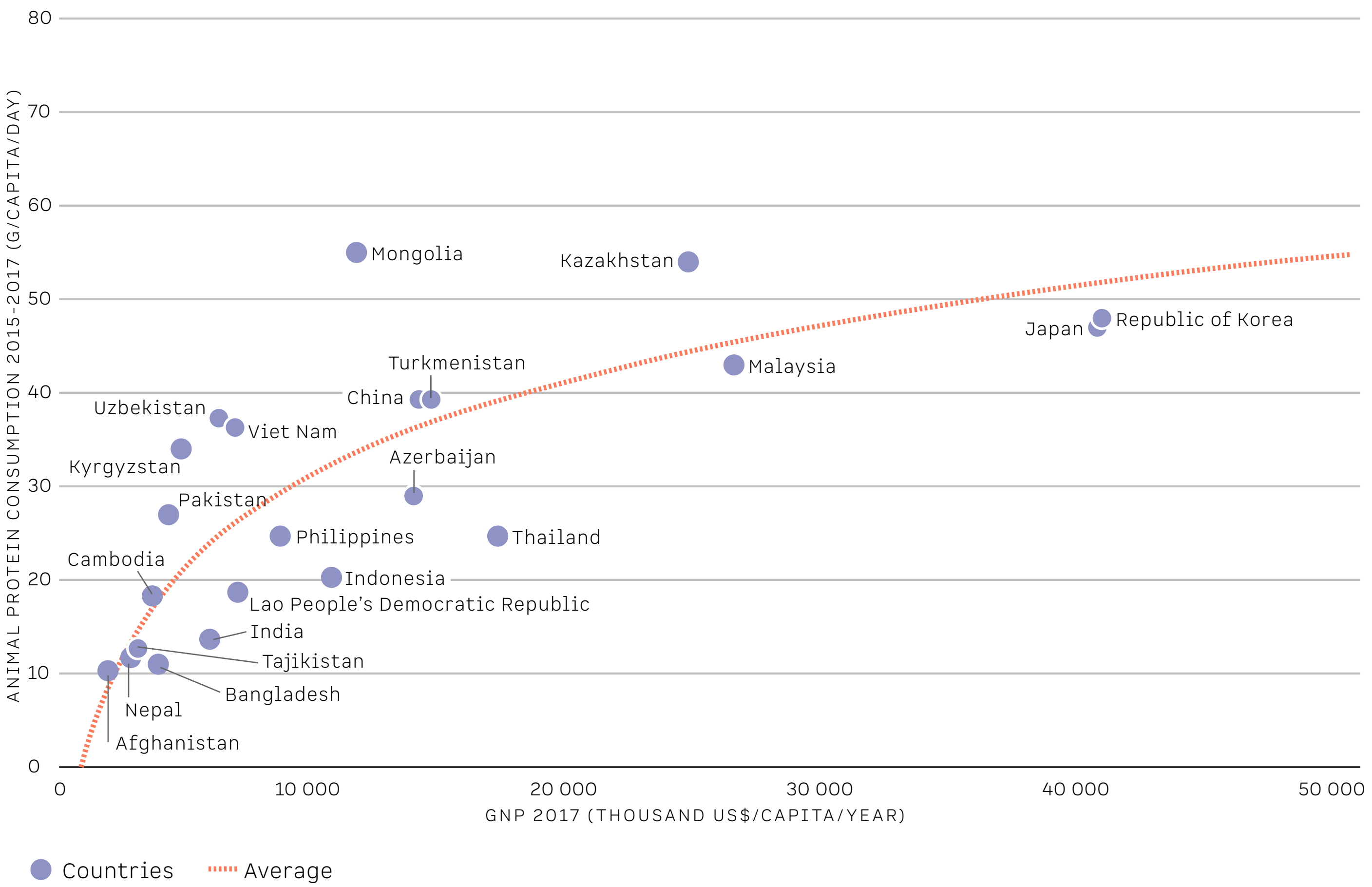
Note: Regional development of ASF demand and intake is mapped and reported by FAO in its *World Agriculture Towards 2030/2050* series.

Demand for ASF increases sharply as incomes rise – even where incomes are low

The income elasticity of demand for ASF is high: a rise in income prompts a considerable rise in demand (Speedy, 2003). Rising incomes thus shift consumption from plant-sourced food to ASF. Even small increases in the income of poor households lead to relatively large increases in ASF consumption.

The proportion of dietary energy from ASF varies and is often high in high-income countries (above 30 per cent) compared with low- and middle-income countries (5-10 per cent) (Dasi et al., 2019). Among low-income countries, those in Asia see an especially high rise in ASF consumption per unit increase in income (**FIGURE 2.2**). In these Asian countries, daily per capita animal protein consumption rises with GDP until it plateaus at 50-60 grams. The pattern is similar in sub-Saharan Africa, but less so in Latin America, where meat consumption is already at the higher end (Muhammed et al., 2017).

FIGURE 2.2 GNP AND PER CAPITA ANIMAL PROTEIN CONSUMPTION IN ASIAN COUNTRIES



Source: Oosting et al. (2021); derived from FAOSTAT (2020a) www.fao.org/faostat.

Where do animal production systems and ASFs fit in the health-sustainability-livelihoods triangle?

The simple answer: in every angle. Animal production systems and ASF have pronounced but varying implications for nutrition and health, inclusive livelihoods and sustainability (**TABLE 2.1**).

TABLE 2.1 SELECTED BENEFITS OF ASF FOR THE THREE FOOD SYSTEM OUTCOMES

AREAS	BENEFITS
Nutrition and health	– High-quality proteins, with adequate combinations of all nine essential amino acids (Semba et al., 2016) and with vegetarian/vegan diets requiring careful combination of foods to achieve protein adequacy (Mariotti and Gardner, 2019). – High contribution to essential micronutrient intake: high nutrient density, higher bioavailability (such as iron, zinc, calcium, vitamin A), important in preventing micronutrient deficiencies such as anaemia, which disproportionately affects women of reproductive age and adolescent girls in low- and middle-income countries (Grace et al., 2018; WHO, 2008). – Only dietary sources of vitamins B12 and D (GAIN, 2020), with vegetarian and vegan consumers showing high deficiency prevalence (Pawlak, Lester and Babatunde, 2016). – Animal proteins are 20-30 per cent more digestible than plant proteins (96-98 per cent versus 65-70 per cent) (Murphy and Allen, 2003). – ASF contains bioavailable compounds such as iron and preformed vitamin A; iron helps with blood formation while vitamin A is important in cognitive and physical development of children (GAIN, 2020; Murphy and Allen, 2003). – Milk and eggs improve linear growth in young children if provided regularly and in appropriate amounts, and meat improves cognitive development (Grace et al., 2018).
Inclusion	*Economic inclusion* – Role in rural poverty reduction: income, jobs and livelihoods – livestock-keeping is the main livelihood for around 1.3 billion people worldwide (Herrero, 2009). – Cash/bank functions – financial security for health, education, and so on. – Provision of draught power and fuel for subsistence agriculture.
	Social inclusion – Cultural beliefs, values and norms – celebrations and a sense of belonging drive tendencies to produce and consume ASF in many cultures. – Women are more likely to control the milk and eggs economy, and obtain income and assets, which are more likely to result in nutrition benefits for the family. – ASF and animals are frequently a mark of social status. – Ethnic minorities are often more livestock dependent than majority cultures. – Milk is a culturally valued component of many diets in low- and middle-income countries. – Many derived psychosocial benefits from ownership of livestock.
Environmental sustainability	– Ruminants can convert biomass unsuitable for consumption into high-quality food, so not all the land used is in competition with crop production. They can also use land that is unsuitable for crop production. – A large part of livestock's environmental footprint stems from feed production, but extensive systems in low- and middle-income countries use grass, crop residues or scavenging in backyards. – Manure from livestock can be cycled back to crop production, reducing the need for chemical fertilizers.

Source: Based on Dominguez-Salas et al., 2019.

Excess consumption or underconsumption of ASF? The health and nutrition pathways to desirable transformation

Despite much controversy around ASF, its high nutritional value contributes to nutrient adequacy. ASF is especially noted for preventing iron-deficiency anaemia in women of reproductive age and in young children, and supporting motor and cognitive development in young children (Neumann et al., 2003; Grace et al., 2018). Although human beings can live without consuming ASF, vegan diets present a challenge for a balanced nutrient supply – a challenge that requires special knowledge and access to a diverse food basket. Because poor people often lack this knowledge and access, many countries have included ASF in their national dietary recommendations (NDRs; FAO, 2018; **BOX 2.4**).

Protein consumption from ASF is close to 60 grams per capita per day in high-income countries, but the global average protein consumption from ASF under the NDRs of individual countries is in the order of 30-40 grams per capita per day (Matena, 2018). Despite the direct benefits of ASF intake for poor people, in specific circumstances ASF can also be overconsumed:

- In Africa and in Asia, poor strata consume considerably less than the NDRs.
- In Africa, rich strata consume roughly the NDRs, with overconsumption in some countries.
- In all other continents, rich strata overconsume, with consumption higher than NDRs (Matena, 2018).

Overconsumption and underconsumption of ASF can coexist within countries, so meeting NDRs is partly a matter of distribution. Overconsumption of ASF from terrestrial livestock is unhealthy, because the fat in ASF is rich in saturated fatty acids, and high ingestion of such saturated fatty acids may cause hypercholesterolaemia and cardiovascular disease (Brouwer et al., 2021; Oosting et al., 2021).

Foodborne diseases (FBDs) are also relevant when it comes to ASF (Grace, 2021). Meat consumption is a strong predictor of FBD mortality. In a cross-country study, for every additional metric ton of meat consumed per 100 people, FBD mortality increased by 6 per cent (Hanson et al., 2012). Food consumption is determined by culture, religion, values and beliefs, and the riskiest foods are often the most nutritious and the most societally valued. In

BOX 2.4 NATIONAL DIETARY RECOMMENDATIONS AND ANIMAL-SOURCED FOODS

National dietary recommendations (NDRs) are country-specific dietary guidelines addressing public health and nutrition priorities and accessibility of foods. Nutritional reasons to include ASF in NDRs include providing proteins with a high bioavailability and an amino acid profile that meets human requirements (Elmadfa and Meyer, 2017). ASF constitutes important sources of micronutrients such as zinc, selenium, iron, vitamins A and B12, and folic acid (Biesalski, 2005). Aquatic ASFs are also a good source of highly unsaturated fatty acids.

Ethiopia, raw meat is consumed. In Uganda, people consume raw eggs in the belief it will cure illness. In West Africa, pastoralists believed raw milk could not cause illness. And in South-East Asia, widespread consumption of raw, undercooked blood and raw fish leads to several zoonoses (Nasinyama, Cole and Lee Smith, 2010; Carrique-Mas and Bryant, 2013; Roesel and Grace, 2014; Seleshe, Jo and Lee, 2014).

Linkages between human and animal health are tackled through the One Health approach, a collaborative, multisectoral and transdisciplinary approach applied at different spatial levels. The aim is to achieve optimal health and well-being outcomes, recognizing the interconnections among people, animals, plants and their shared environment. IFAD, the Food and Agriculture Organization of the United Nations, the World Health Organization and the World Organisation for Animal Health collaborate to ensure that investment projects adopt this design approach and to support policy engagement for scaling up.

One challenge tackled by One Health is antibiotic resistance – when bacteria change after exposure to antibiotics and become more difficult to treat. The overuse of antibiotics in some intensive animal production systems can drive such resistance. One Health approaches have a high impact in combating antibacterial use and antibiotic resistance by combining human, animal environmental use and transmission pathways rather than treating them separately (Booton et al., 2021). They also curb the further spread of zoonotic diseases, such as COVID-19. The virus has been associated with traditional informal markets, or fresh produce markets (sometimes called wet markets). These markets sell fresh meat, fish and other perishable agricultural produce. Some sell live poultry and other domesticated animals, many sell live aquatic products (fish and shellfish) and some sell live or dead wild animals. The products can be sourced from many different places, including distant parts of the world.

There is a general consensus that informal markets can be epidemiologically risky – especially those selling live domesticated animals or live or dead wild animals and those with poor hygiene. But expert opinions differ on whether live animal markets should be regulated more strictly, upgraded gradually with buy-in from vendors, or banned completely to reduce disease transmission risk (Grace, 2021). Note that strict regulation of food has proven difficult in governance-poor contexts, where banning desired products often shifts the market underground.

Informal, traditional and fresh produce markets have many benefits for people, including low prices, ease of access, the availability of preferred fresh and traditional foods, income-earning opportunities for women, worker independence and attracting tourists. But these benefits need to be weighed against the wider costs to humanity – starting from local people – of failures to prevent disease outbreaks and global pandemics (Grace, 2021). Regulation may also support more effective protection of forest and wild species. In response to COVID-19, China is changing the Wild Animal Conservation Law to follow One Health thinking, to restrict invasions of nature conservation areas and avoid close contact with organisms spreading zoonotic diseases (Fang and Song, 2021).

Keeping animals is more than running a food store

Animals mean more to rural people than just food. They are part of livelihoods – in many different ways – and in many cases and countries, they contribute to social status. In many low- and middle-income countries, livestock is widely seen as a store of wealth, in addition to providing power for land preparation and agricultural tasks and being a source of food and income. As a store of wealth and capital, they serve as a buffer stock for bad times, when distress sales of animals can compensate for crop income failures (Dercon, 1998; Fafchamps, Udry and Czukas, 1998; Kazianga and Udry, 2006).

Gender roles in animal management are varied and have been insufficiently understood in policy discussions of ASF, as have the wider economic and cultural roles of livestock in the household and in the community. For coastal fisheries and aquaculture, studies focusing on women and gender are progressing slowly because they are not on policy agendas or in action plans and do not receive substantial resources (Williams et al., 2012). As the world's fastest-growing food production sector, aquaculture generates significant employment opportunities at multiple scales – but there is a paucity of high-quality sex-disaggregated data on aquaculture value chains, especially on the distribution of benefits in the chain (Kruijssen, McDougall and van Asseldonk, 2018).

Technical approaches have been dominant in research and development, and successful improvement has to start from smallholder livelihood realities (Hailemichael, Gebremedhin and Tegegne, 2017). For poultry to continue making positive and sustainable contributions to stable human society, it is essential that production and marketing be tailored to local conditions and associated value chains, and that they maximize nutrient cycling and the efficient use of all products, maintain genetic diversity and are accompanied with improvements to local health services (Alders et al., 2019). The Small Livestock Advantage programme offers insights into the opportunities for poultry – chickens, geese, ducks, turkeys, guinea fowl, pigeons and quail – as well as for swine, small ruminants, guinea pigs and rabbits (IFAD, 2020). Building on case studies from Afghanistan, Lesotho, Nepal, Senegal and Venezuela, it concludes that small livestock contribute to:

Technical approaches have been dominant in research and development, and successful improvement has to start from smallholder livelihood realities.

- Mitigating negative impacts of the COVID-19 pandemic and improving food security, nutrition and livelihoods.
- Maintaining household food and nutrition security.
- Maintaining household economic security.
- Supporting opportunities for women's employment, especially related to livestock processing and rearing.

- Enabling climate change adaptation.

Establishing and sustaining effective livestock breeding programmes remains challenging in many countries, particularly in the low-input production systems of the developing world. But such programmes can sometimes give remarkable results that are relevant to livelihoods. Consider the relationship between tilapia breeding in Egypt and the food preferences of low-income consumers. Models predicted that younger women consumers with children in Lower Egypt were more likely to consume smaller tilapia sizes and prefer larger tilapia head traits. In this way, breeding programmes can be pro-poor and gender-responsive (Murphy et al., 2020).

Animal welfare receives less attention in lower-middle-income countries than in high-income countries, where animal rights are increasingly incorporated into legislation. Since prehistoric times, animals have been viewed as an integral part of human life – a source not only of livelihood but also of companionship. But in recent decades the debate on the use of animals in human society has been contentious, with the main focus on the benefits derived from them. McCrindle (1998) provided an overview of African perspectives on animal well-being set largely in a context of human poverty and malnutrition, where concern for animals exists but differs from the concerns of urban consumers in high-income countries.

Sustainability and resilience are at stake where food-feed competition and high GHG emissions predominate

The animal production sector uses most of the world's grasslands and more than a third of the world's arable land for feed production, while also driving heavy use of rainwater and irrigation water (World Bank, 2019; Oosting et al., 2021). Livestock use these resources mainly for feed production, with four broad impacts:

- **Conversion of forests and other natural vegetation to feed-crop land and pasture.** This results in loss of biodiversity, depletion of aquifers and GHG emissions, but also creates room for food and cash crops.
- **Competition with food crops for land and water.** Of the world's 2 billion hectares of grassland, one third could potentially be used as cropland. Feed production uses about a third of agricultural water. Livestock production is generally less efficient than crop production in terms of human food obtained per unit of arable land.
- **Land degradation.** Overgrazing affects vegetation cover and potentially results in productivity losses, soil erosion, carbon losses and adverse impacts on biodiversity and water cycles.
- **Pollution of water and land resources.** Pesticides, chemicals and other unwanted substances such as metals and organic residues end up in the ecosystem, affecting flora, fauna, fisheries, drinking water and tourism.

While animal production systems and ASF may cause major GHG emissions, their effects vary substantially by animal or food group, region and production system. Emissions from ASF production have been estimated to contribute 14.5 per cent of global anthropogenic GHG emissions (Duku et al., 2021). The largest contributor is methane (about 44 per cent in CO_2 equivalent), followed by nitrous oxide (29 per cent) and carbon dioxide (27 per cent). Emissions from ASF production account for 44 per cent of global anthropogenic methane, 53 per cent of global anthropogenic nitrous oxide and 5 per cent of global carbon dioxide emissions.

On both GHG emissions and land use per 100 grams of protein, beef, lamb and mutton rank convincingly at the top and fish, poultry, meat and eggs rank considerably lower (**TABLE 2.2**). Still, protein-rich food crops have smaller GHG emissions per 100 grams of protein (Poore and Nemecek, 2018). Contributing substantial GHG emissions, enteric fermentation from livestock production consists of methane gas produced in the digestive systems of ruminants and to a lesser extent non-ruminants (Duku et al., 2021).

TABLE 2.2 GREENHOUSE GAS EMISSIONS AND PRESSURE ON LAND ASSOCIATED WITH THE PRODUCTION OF PROTEIN-RICH FOODS

PROTEIN-RICH FOODS	GHG EMISSIONS (KG CO_2 EMITTED PER 100 G PROTEIN)		LAND USE (M^2/YEAR/100 G PROTEIN)	
	AVERAGE	10^{TH} PERCENTILE	AVERAGE	10^{TH} PERCENTILE
ANIMAL-SOURCED				
Beef	50.0	20.0	164.0	42.0
Lamb and mutton	20.0	12.0	185.0	30.0
Cheese	11.0	5.1	41.0	4.4
Pig meat	7.6	4.6	11.0	4.8
Fish (farmed)	6.0	2.5	3.7	0.4
Poultry meat	5.7	2.4	7.1	3.8
Eggs	4.2	2.6	5.7	4.0
PLANT-SOURCED				
Tofu	2.0	1.0	2.2	1.1
Groundnuts	1.2	0.6	3.5	1.8
Peas	0.4	0.3	3.4	1.2
Nuts	0.3	-2.2	7.9	2.7
Grains	2.7	1.0	4.6	1.7

Source: Poore and Nemecek, 2018.

Manure is another major source of GHG emissions. Of all food production processes, manure contributes the second highest GHG emission levels in all regions, with more than half from manure deposited on pastures (Gerber et al., 2013; Tubiello et al., 2013;). Forage can be combined with shelters and rotational grazing to restore pasture and reduce GHG emissions (**BOX 2.5**).

Major shifts to fish-based and vegetarian and vegan diets would be needed to eradicate animal-related GHGs, following the EAT-Lancet approach, which emphasizes the need for much greater consumption of plant-based foods and lower consumption of ASFs, particularly red meat (Poore and Nemecek, 2018). Some oppose the EAT-Lancet approach, claiming it is focused solely on the threat ASF consumption poses for sustainability and human health, ignoring variability in the environmental impact of livestock production and failing to adequately include the experience of marginalized women and children in low- and middle-income countries whose diets regularly lack the necessary nutrients (Adesogan et al., 2020).

How do animal production systems and ASF fit into a circular food system?

Moving from linear to circular systems has been advocated as part of a food system transformation that is healthy, inclusive, and environmentally sustainable and resilient (CHAPTER 7). For animal production systems and ASF, the contribution of specific farmed animal groups to circular food systems can be assessed against four criteria:

BOX 2.5 LIVESTOCK AND PASTURE DEVELOPMENT IN TAJIKISTAN

Khatlon is the poorest region of Tajikistan, with 78 per cent of the population below the national poverty line and livestock one of the main sources of income. Decades of overgrazing to meet rising demand for animal feeding has deteriorated pastoral land. Fodder, veterinary services and other livestock support services can, therefore, contribute to increasing meat and milk production.

An IFAD project that ran from 2011 to 2017 addressed nutritional deficiencies in Khatlon and contributed to livestock production and productivity increases while addressing climate change adaptation and mitigation needs. It did this through pasture-user unions, farm equipment and seed upgrades, and the construction of water points and sheds for livestock, combined with guidance on breeding techniques and veterinary services.

Livestock production increased dramatically, benefiting more than 23,000 households. The number of livestock owned increased by 60 per cent, sheep and cattle weight increased by 17 per cent and 27 per cent, respectively, and livestock income per year increased by 42 per cent. Reducing the cost of water and increasing access to water was crucial in implementing the project.

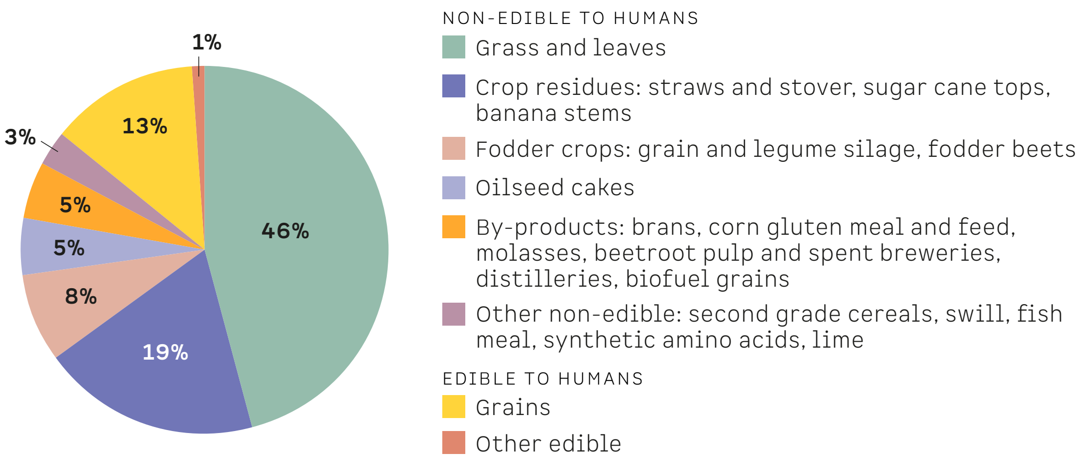
Source: IFAD, Livestock and Pasture Development Project, Tajikistan impact assessment technical report and project completion report.

- Does the ASF production system use arable land and water bodies primarily to produce food for direct human consumption?
- Does it avoid or minimize food losses and waste?
- Does it recycle inevitable food losses, waste streams and by-products (such as crop residues, processing co-products, manure and excreta)?
- Does it use animals for unlocking biomass – with low-opportunity cost to humans – into high-value food, manure and other ecosystem services?

Only about 14 per cent of feed dry matter ingested by livestock is edible for human beings – and the share is likely to be even lower in some developing countries, where ruminant livestock subsists mainly on pastures or crop residues (**FIGURE 2.3**). The land to produce that 14 per cent, however, includes land that could be used to grow food crops.

How much circularity is achievable and desirable, and how many animals should be part of it? "Optimal" animal populations would allow protein consumption from ASF to be maintained at up to 7-36 grams per capita per day – with the restrictive boundary condition that livestock and fish would consume only feed from waste streams and from land (and water bodies) unsuitable for human food crop production (Van Kernebeek et al., 2014; Van Zanten, Van Ittersum and De Boer, 2019; van Hal, 2020). This condition rules out using land for pastures and feed crops that could also be used for food crops.

FIGURE 2.3 GLOBAL LIVESTOCK FEED DRY-MATTER INTAKE FROM DIFFERENT SOURCES



Source: Adapted from Mottet et al. (2017).

Farmed animal production systems should be assessed for their degree of and potential for circularity

Smallholder farmers generally manage animal production systems that are already largely circular and non-detrimental, requiring few external inputs. The animals feed on crop residues and on land that is either not suitable for other purposes or where crops have already been grown and residues have been left in the field to feed animals. When animal production intensifies, with feed from outside the system, circularity needs to be managed better. For example, integrated farming systems depending on animal traction face challenges when herd sizes become too large.

In South-East Asia and sub-Saharan Africa, farmed animals play important roles in circularity. Because feed inputs and fertilizers are scarce, most farming systems use crop residues, agro-industrial by-products and manure as inputs. Three systems are relevant for their degree of circularity: pastoralist herding, fish farming and dairy farming.

Traditional pastoralist herding systems are found in regions where human food crop production is biophysically impossible. Such systems do not directly compete for land use with human food crop production. They also avoid food waste by exploiting dryland grazing areas and the biomass growing there. If not grazed, the biomass will turn dry and will not be used. Pastoralists can draw on extensive traditional ecological knowledge to align their land and water use with natural dynamics in these regions. Waste recycling occurs as herds manure the croplands while they graze crop residues in the dry season. Pastoralist systems use animals for what they are good at: turning low-opportunity cost biomass into valuable food. Yet present-day expansion of sedentary agriculture puts pressure on the sustainability of pastoralist systems (Rao et al., 2021).

Fish farming in ponds does not compete with human food crop production directly – but it can do so indirectly. In South-East Asia, inland and coastal ponds are the major fish-farming systems, contributing more than 75 per cent to global fish and shrimp production (FAO, 2020b). Many ponds are fertilized with leftovers, manure and kitchen waste. For example, the semi-intensified systems in Bangladesh (Belton and Azad, 2012) produce fish with a combination of organic fertilizer, kitchen waste, home-made feed from local agricultural by-products and commercial feed (Mamun-Ur-Rashid et al., 2013; Jahan et al., 2015; Henriksson et al., 2018). Commercial feed produced in Bangladesh accounts for 2 million metric tons (Mamun-Ur-Rashid et al., 2013), and 90 per cent of the ingredients are by-products from other agricultural activities (Mamun-Ur-Rashid et al., 2013; Kabir et al, 2017). Some of the production models from Asia have been piloted in several African countries. A pilot rice-aquaculture model in the inland valley swamps of Sierra Leone enhanced the circular use of agricultural waste and by-products: thanks to this approach, fish was produced as an additional source of animal protein, increasing profitability (Sankoh et al., 2018; **BOX 2.6**).

BOX 2.6 FISH FARMING IN SIERRA LEONE TO IMPROVE FOOD AND NUTRITION SECURITY

Communities in the district of Tonkolili in northern Sierra Leone face high levels of child stunting due to food insecurity and malnutrition. Income-generating activities in the district are limited, aggravated by the decline in mining activities in the area. Since 2015, the Feed the Future project, funded by the United States Agency for International Development, has implemented new aquaculture practices in Tonkolili to boost farmed fish production and increase food and nutrition security as well as livelihood opportunities. Farmers are constructing their own ponds for tilapia production, providing nutrition-rich food for home consumption and generating a steady source of income by marketing the fish in the area. As part of the project, youth were involved in training on the role of nutrition in healthy diets.

FISH FARMER IN TONKOLILI DISTRICT, NORTHERN SIERRA LEONE

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Source: Regional consultations.

Dairy farming takes place in a peri-urban context – mostly on small-scale dairy farms with limited land for fodder production and a high livestock density – and can contribute to circular systems in the right circumstances. In Indonesia, 98 per cent of all dairy cattle are concentrated on the island of Java (home to more than half of Indonesia's human population) in a circular food system, mainly using feed and fodder as inputs and manure as outputs (**BOX 2.7**).

BOX 2.7 DAIRY FARMING AND CIRCULAR FOOD SYSTEMS IN INDONESIA

In the Indonesian subdistrict of Lembang, circularity reduces food-feed competition in dairy farming. The major part of the feed ration of dairy cows consists of by-products (de Vries et al., 2019). About 55 per cent comes from agro-industrial by-products – mainly tofu waste, cassava pomace and ingredients of compound concentrate feed (such as imported wheat pollard, palm oil meal and corn gluten feed). Another 15 per cent or so comes from crop residues (mainly rice straw).

Not everything about Lembang's dairy farm sector is so circular, however. Most of Lembang's dairy farmers (84 per cent) dispose of at least part of their herds' manure in the environment. Only a limited amount is used for fertilizer, mainly because dairy farmers have too little land to fertilize – and because their land is often far away from the cow barn. And when manure is applied to nearby cow barns, the amounts are extremely high, resulting in high run-off and leaching (de Vries and Wouters, 2017).

Most farmers acknowledge that manure disposal is a problem. Practical and economic barriers to the utilization of manure include the lack of land and the costs and labour required for handling and transportation. In addition, cattle manure has a relatively low nutrient content compared with synthetic fertilizer, which is heavily subsidized for small-scale farmers in Indonesia, making organic manures less competitive in terms of macronutrients (Warr and Yusuf, 2014).

Source: Oosting et al., 2021.

Circular innovations in novel protein development

Novel protein sources such as insects and micro- and macroalgae can contribute to future foods (Parodi et al., 2019). Their production could be based on recycling waste streams, with limited land use, and low GHG emissions and nitrogen and phosphorus pollution. Consuming insects and algae as human food is a novelty in some parts of the world, but it is already common in diets in many parts of the world. To reduce feed-food competition resulting from intensified animal systems, novel protein sources could replace traditional protein sources such as soybean meal and fish meal in concentrate feeds. Food safety regulations in many countries do not authorize the consumption of insects as human food (in the European Union, for instance) but include a recommendation for accelerating policies and regulations.

Producing insect protein for feed holds promise for circular food systems. Insects can convert waste – from many sources – into food and feed. They require limited water, nutrients, space and energy, and the GHG emissions associated with their production are low (van Huis and Oonincx, 2017; Parodi et al., 2019 (**BOX 2.8**)).

The production of insects using waste streams as a feed protein source can substantially reduce the use of farmland to produce feed ingredients, mainly proteins (Mulia and Doi, 2019). In Kenya, if insects supplied the 160,000 tons of protein needed annually for concentrate, about 200,000 hectares of land could be shifted from soybean production for feed to human food production.

Substituting novel proteins can also reduce pressure on fish stocks in food systems that now use fishmeal in concentrate feeds. Aquaculture is the fastest-growing food sector, expected to contribute substantially to meeting the ASF protein requirements of a growing world population. To prevent competition for the same limited land and water, conventional protein ingredients can be replaced with microalgae, macroalgae (seaweed), yeast and bacterial biomass (microbial protein) (**BOX 2.9**).

BOX 2.8 INSECT PROTEINS PRODUCED FOR FEED AND FOOD IN EAST AFRICA

Human consumption of insects is common in Uganda. Edible insects are highly in demand in markets, and the prices are higher than those of beef, pork and poultry (Odongo et al., 2018). Insect marketing in Uganda is built on extensive supply chain networks of collectors and traders.

Insects have traditionally been eaten in northwest Tanzania, around Lake Victoria, where the local population appreciate the longhorn grasshopper *Ruspolia differens* as a delicacy (Mmari et al., 2017).

In western Kenya, people eat termites and other insects. Farming insects can be important for the livelihoods of smallholders, because it can increase household food supply, generate cash incomes and create employment opportunities for poor people (Kelemu et al., 2015; Ayieko, Ogola and Ayieko, 2016; Halloran et al., 2016).

BOX 2.9 ALTERNATIVE SOURCES OF PROTEINS AS FISHMEAL AND OTHER USES

Microalgae are microscopic algae found in the water column and sediments of freshwater and marine environments. They are at the base of the aquatic food chain, are responsible for half of the world's primary production and support the supply of 90 million metric tons of seafood per year through capture fisheries (Muller-Feuga, 2000; FAO, 2020b). If large-scale production of microalgae at an affordable cost becomes possible, microalgae could be a replacement for fishmeal and fish oil.

Macroalgae (seaweed) have a protein content of 5-50 per cent (Wan et al., 2019), can replace fishmeal in fish diets and are rich in highly unsaturated fatty acids. They are a popular human food in South-East Asia, and because no external nutrient inputs are needed, they could reduce GHG emissions by replacing terrestrial plant sources otherwise used in fish feeds.

Yeasts are co-products from the brewing industry. They contain 45-55 per cent crude protein and can replace fishmeal up to 75 per cent in fish diets without compromising growth (Pongpet, Ponchunchoovong and Payooha, 2015; Gamboa-Delgado et al., 2016).

Bacterial biomass is a popular alternative protein source not competing with human food. It can be grown using agricultural waste such as fruit pulp and corn stover effluents (Mahan et al., 2018), and even manure (Patthawaro and Saejung, 2019).

Simulation 2 in annex 1 illustrates how doubling the productivity of feed for livestock and aquaculture, against a business-as-usual baseline, increases the affordability of food but increases wages gaps for the lowest skilled.

Policy priorities for animal production and ASF

At the global level, concerns about increasing ASF intake and overconsumption – and about resulting negative impacts on health and sustainability – need to be communicated in a more precise way. The concerns are valid, but:

- ASF intake differs greatly across regions.
- Animals eat many products that are not edible for humans, including wastes that would otherwise be a nuisance.
- Animal food groups differ largely in their ability to move from linear to circular production systems.
- Animal proteins are important food intake in countries where there is underconsumption.

Game-changing yet realistic solutions are needed to drive the transition towards healthy and sustainable consumption patterns in a culturally appropriate manner. Support should be given to the promotion of sustainable smallholder livestock production systems in low- and middle-income countries.

- Protocols and simple input-output models should be developed that can easily map animal and ASF production systems in terms of their degree of circularity. Such models can inform accounts of pathways towards more circular food systems.
- Mechanisms should be put in place that create incentives for markets and corporations to provide ASF for healthy and sustainable diets. Such mechanisms can be based on national dietary guidelines.

Investments are needed in educating the younger generation on healthy diets, with unbiased information for consumers. Awareness-raising should focus on both the pros and the cons of consuming ASF in various quantities.

Novel protein development can be taken to scale through public-private investments. The potential is obvious, but it needs to gain momentum. Novel protein production can add greatly to traditional animal-derived proteins at a low environmental cost.

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