

White Paper

# Meat: the Future series

## Options for the Livestock Sector in Developing and Emerging Economies to 2030 and Beyond

January 2019



World Economic Forum  
91-93 route de la Capite  
CH-1223 Cologny/Geneva  
Switzerland  
Tel.: +41 (0)22 869 1212  
Fax: +41 (0)22 786 2744  
Email: [contact@weforum.org](mailto:contact@weforum.org)  
[www.weforum.org](http://www.weforum.org)

© 2019 World Economic Forum. All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, including photocopying and recording, or by any information storage and retrieval system.

**Prepared by the International Livestock Research Institute for the World Economic Forum's Meat: the Future dialogue series**

This White Paper has been published by the World Economic Forum as a contribution to a project, insight area or interaction. The findings, interpretations and conclusions expressed herein are a result of a collaborative process facilitated and endorsed by the World Economic Forum, but whose results do not necessarily represent the views of the World Economic Forum, nor the entirety of its Members, Partners or other stakeholders.

# Contents

Foreword	4
Introduction	5
1. Trends and projections in the demand for meat, milk and eggs	6
2. The numerous roles of livestock	8
3. Pathways to the future	13
4. Enablers for transformation	19
5. Conclusion: All shapes, sizes and systems	22
Endnotes	23

# Foreword



**Shirley Tarawali,**  
Assistant  
Director-General,  
International  
Livestock Research  
Institute, Nairobi,  
Kenya

How to meet the world's growing protein needs is a pressing challenge. Food-producing farm animals – and the meat, milk and eggs they provide – are not the only solution, but they undoubtedly are one of the major contributors and will continue to be for decades to come. Public concerns in the developed world about livestock risks to animal welfare, human health and the environment are valid. These concerns also run the risk of marginalizing the perspectives of – and the opportunities for – people around the world, and especially those in developing countries, for whom livestock represent not simply commodities to be consumed but “living assets”, the fundamental sources of food, nutrition, livelihoods, jobs, incomes, savings and much more. Over half a billion people in emerging and developing economies<sup>1</sup> continue to depend entirely or partially on farm animals. While the demand for meat, milk and eggs is levelling off in most high-income countries, it will continue to rise in emerging and developing economies. The good news is that the livestock sector presents many opportunities both to do greater good and to mitigate potential harm to human well-being.

This paper focuses on emerging and developing nations. It argues that making use of the great diversity of livestock systems along with “enablers for transformation” creates opportunities to translate today's rapid growth in demand for livestock-derived foods into rapid progress in sustainable and equitable development. We recognize that while most stakeholders in livestock development have the same end in mind – the evolution of a sustainable, responsible and efficient livestock sector – the great diversity of livestock species and production systems will necessitate very different starting points and trajectories. This diversity should be approached not as a problem to be solved but as a requirement for meeting societies' protein and other needs.

The work of many scientists over many years and from many organizations and initiatives is presented in this paper, in addition to the work of the International Livestock Research Institute (ILRI). In particular, we want to acknowledge the livestock specialists at the Food and Agriculture Organization of the United Nations, the International Fund for Agricultural Development, the World Bank Group, the World Organisation for Animal Health and the Global Agenda for Sustainable Livestock, along with our sister CGIAR centres, in particular the International Food Policy Research Institute, numerous academic institutions, such as Wageningen University and Research (WUR) in the Netherlands and the Commonwealth Scientific and Industrial Research Organisation in Australia, and many others. The committed work and studies generated by these and other expert groups have laid the foundation for our assessment of the role of livestock in developing and emerging economies, including for this paper which, while any errors are ILRI's own, represents a collective achievement.

I particularly thank fellow ILRI authors David Aronson, Isabelle Baltenweck, Paula Dominguez-Salas, Dolapo Enahoro, Polly Ericksen, Delia Grace-Randolph, Susan MacMillan, Thomas Fitz Randolph, Keith Sones, Steve Staal and Iain Wright.

# Introduction

The World Economic Forum White Paper “Meat: the Future” of January 2018 argued that it is “time for a protein portfolio to meet tomorrow’s demand”.<sup>2</sup> Providing for the world’s 21st-century protein needs safely and in environmentally sustainable and broadly affordable ways will be a challenge, particularly with a changing, more erratic climate and diminishing natural resources. Already, about 821 million people are undernourished<sup>3</sup> and 151 million children under the age of five are stunted in size.<sup>4</sup> The vast majority of undernourished people lack sufficient quantities of the proteins and micronutrients readily available in nutrient-dense animal-sourced foods – meat, milk/dairy, fish and eggs – to lead healthy and productive lives.

Globally, transforming food systems to meet demand in inclusive, sustainable, healthy, nutritious and efficient ways is recognized as one of the world’s biggest challenges. Opportunities to apply the latest physical, scientific and digital innovations to tackle this challenge are being explored. Strikingly, something as fundamental to human existence as food has yet to fully exploit and benefit from the latest digital, physical and scientific technologies of the Fourth Industrial Revolution.<sup>5</sup> The January 2018 “Meat: the Future” paper laid out a portfolio of solutions to meet these challenges, including alternative proteins, advances in current production systems and changes in consumer behaviour. This January 2019 paper explores production systems further, recognizing the many challenges and opportunities from the perspective of the livestock sector in developing and emerging economies, where the need and the potential to transform this aspect of the food system are vast.

The livestock sector can play instrumental roles in achieving the 2030 Agenda for Sustainable Development, given the many multiplier effects of livestock production systems in low- and middle-income countries. In these nations, livestock remain the mainstay of household economies, food and livelihoods, especially in rural areas. Livestock contribute to all 17 of the Sustainable Development Goals (SDGs)<sup>6</sup> and make significant and direct contributions to eight SDGs, in particular the first three. This paper makes the case for seizing big opportunities to get this job done through the developing world’s small- and medium-scale livestock sector – namely, to help feed the world sustainably, safely and equitably.

The livestock sector accommodates huge diversity, and all livestock production systems in all regions need to become safer and more sustainable, responsible and efficient. While the rapid growth in livestock production occurring now in emerging and developing nations is unlikely to end in the short term, it can be harnessed to greatly enhance rather than harm human and environmental well-being.

Consider the diversity of livestock keepers: they include smallholder mixed farmer, medium-sized cooperative member, pastoral herder, female head of household, traditional villager and urban entrepreneur, as well as millions of people engaged in trading and processing livestock foods

or providing inputs and services to the sector. Or consider the variety of animal husbandry practices: from massive dairies in China to medium-sized enterprises raising a few hundred pigs in the emerging economies of Asia, to family farms raising one or two cows and a handful of goats and chickens in Africa. With such huge diversity, many different roads to sustainable livestock production will be needed, each with its opportunities and challenges, starting at different points and taking different trajectories. No one solution will lead to the better livestock systems required and desired.

Focused on developing and emerging economies, this paper reviews the different ways of meeting the growing future protein needs and the consequences and opportunities of different future trajectories. The starting point and primary focus for this assessment is the livestock sector, given the prevalence and multiplier effects already mentioned.

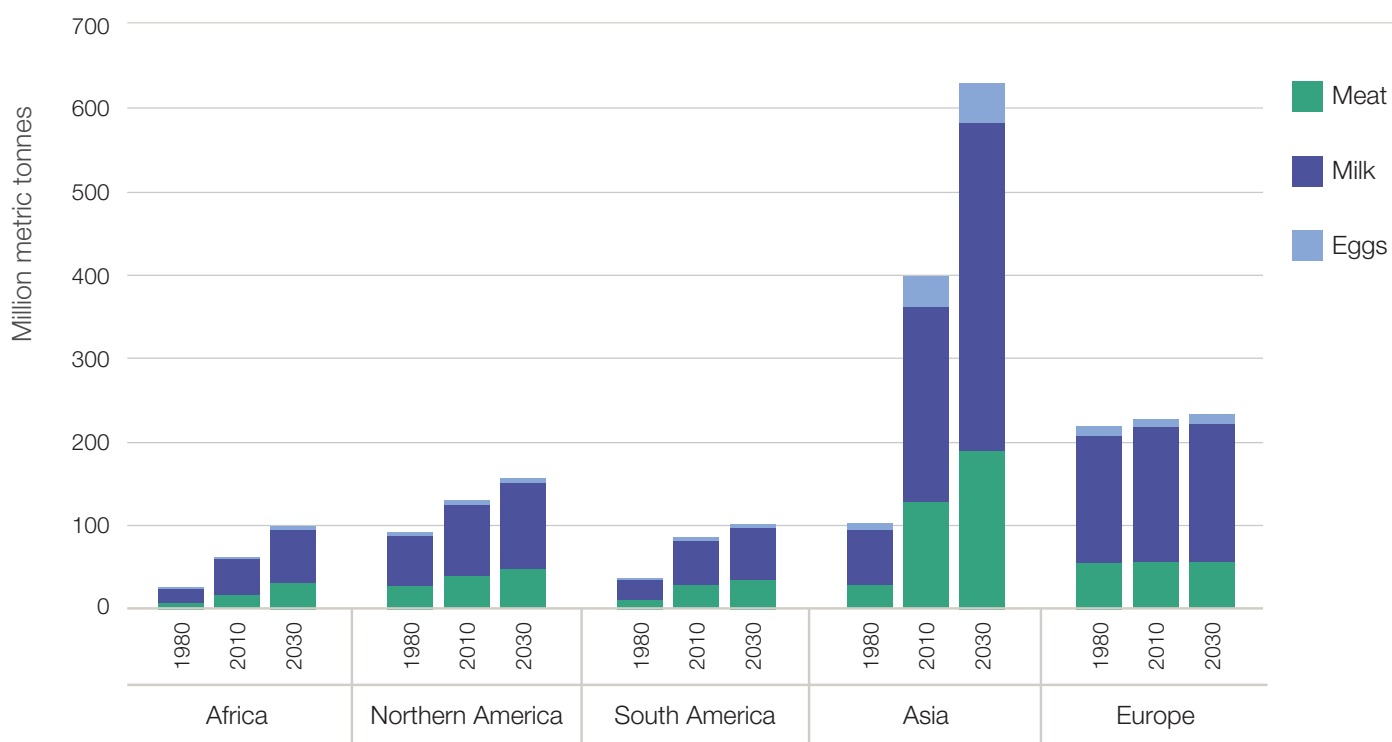
# 1. Trends and projections in the demand for meat, milk and eggs

While demand for livestock-derived foods is growing only modestly in high-income countries, it is growing rapidly in Africa due mostly to rising populations and in Asia due to rising incomes as well as populations.

Africa's demand for livestock-derived foods is projected to increase by a remarkable 80% in just two decades (from 2010 to 2030) due mostly to its increasing population. In 2030, that population is expected to consume 125% more beef, 60% more poultry, 46% more milk and 77% more eggs than in 2010 (Figure 1). Most Africans, however, will not be eating better; per-capita income is growing slowly in many countries on the continent, and some models actually forecast a slight decline in per-capita consumption

of livestock-derived foods over this period.<sup>7</sup> Moreover, the overall increases in demand and consumption are not driven by overconsumption: recent statistics from the Organisation for Economic Co-operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO) indicate that annual per-capita consumption in Africa of beef, veal, pork and poultry combined is about one-sixth that of OECD countries.<sup>8</sup> Rather, the increases are driven by population growth, which will be most dramatic in Africa in the coming decades. While the continent's population was only 18% of Asia's in 1950, it is projected to become nearly as big as Asia's (94%) by the end of the century, growing from 810 million in 2000 to 4.5 billion by 2100.<sup>9</sup>

**Figure 1: Total household demand by continent/region for selected products (2030 projected)**



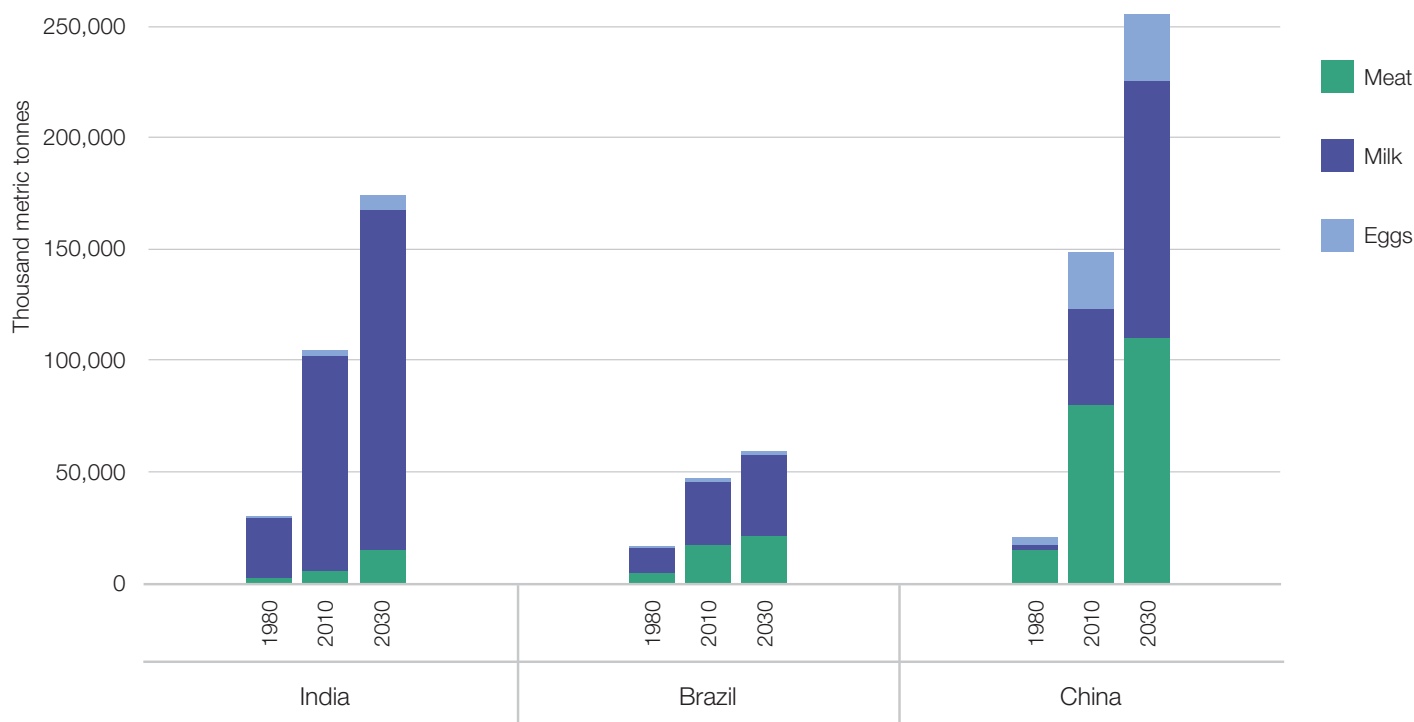
Note: "Northern America" includes the United States, Canada, Greenland, Bermuda, and Saint Pierre and Miquelon.

Sources: 1980 and 2010 data from FAOSTAT; 2030 estimates from Enahoro, D., 2018 (unpublished), using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) baseline, <https://www.ifpri.org/program/impact-model>.

In much of Asia, on the other hand, population growth has begun to stabilize but incomes are growing, prompting a rising demand for more and higher-quality livestock-derived foods. Recent OECD-FAO figures reflect the differences between the two continents: while growth in per-capita consumption of meat and fish in Sub-Saharan Africa will decrease slightly (-3%) between 2018 and 2027, India (+12%) and China (+13%) will have the highest increases. In contrast, the greatest increase in total consumption of meat and fish will be in Sub-Saharan Africa (28%) compared to 25% and 16% for India and China, respectively, over the same period.<sup>10</sup>

Other models forecast demand for livestock-derived foods in Asia, which already consumes nearly twice as much of these foods as any other region, will continue to grow rapidly to more than 600 million metric tonnes per year by 2030 (Figure 1). Continental totals of course conceal great diversity. In China, for example, demand for livestock-derived foods is projected to grow rapidly and focus on meat. Projected growth in India will be slower and concentrate on milk. Brazil's demand, starting from a much higher base per capita and shown in Figure 2 for contrast, is expected to grow much more slowly than China's or India's (Figure 2).

**Figure 2: Total household demand by country for selected products (2030 projected)**



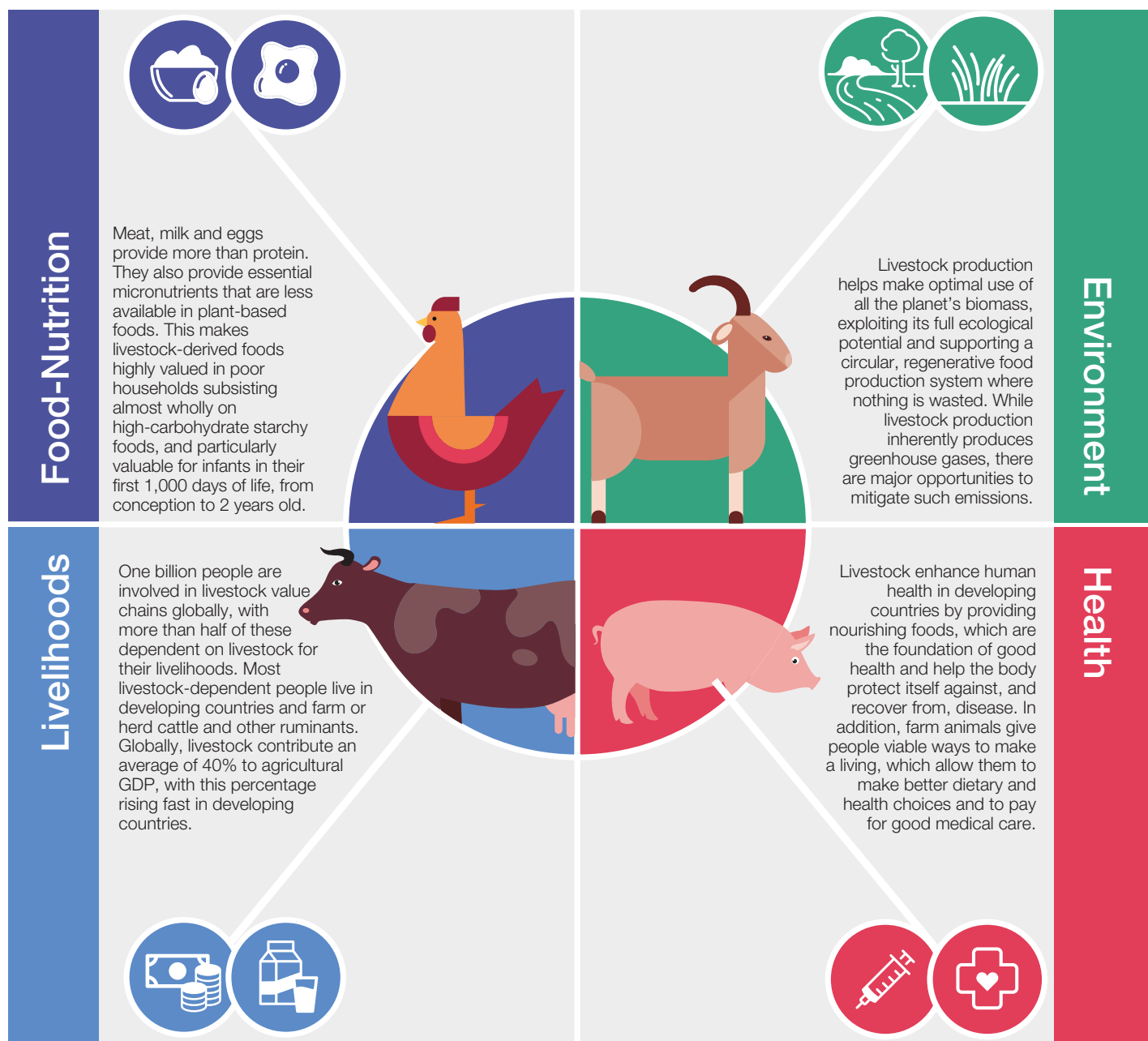
Sources: 1980 and 2010 data from FAOSTAT; 2030 estimates from Enahoro, D., 2018 (unpublished), using IMPACT model baseline, <https://www.ifpri.org/program/impact-model>.

## 2. The numerous roles of livestock

The diverse roles of livestock in developing and emerging countries create opportunities to meet nutrition, income, livelihood and ecosystem needs while mitigating livestock-related threats to human and environmental health. But these opportunities must be managed to add to the positive aspects livestock provide while mitigating the negatives.

The four livestock-enhanced development areas highlighted in this section and in Figure 3 have recently been prioritized by the FAO<sup>11</sup> as well as by an official communiqué<sup>12</sup> issued by 69 agricultural ministers attending the Global Food and Agriculture Forum in Berlin in January 2018.

Figure 3: Some of the livestock sector's numerous roles



Source: Authors



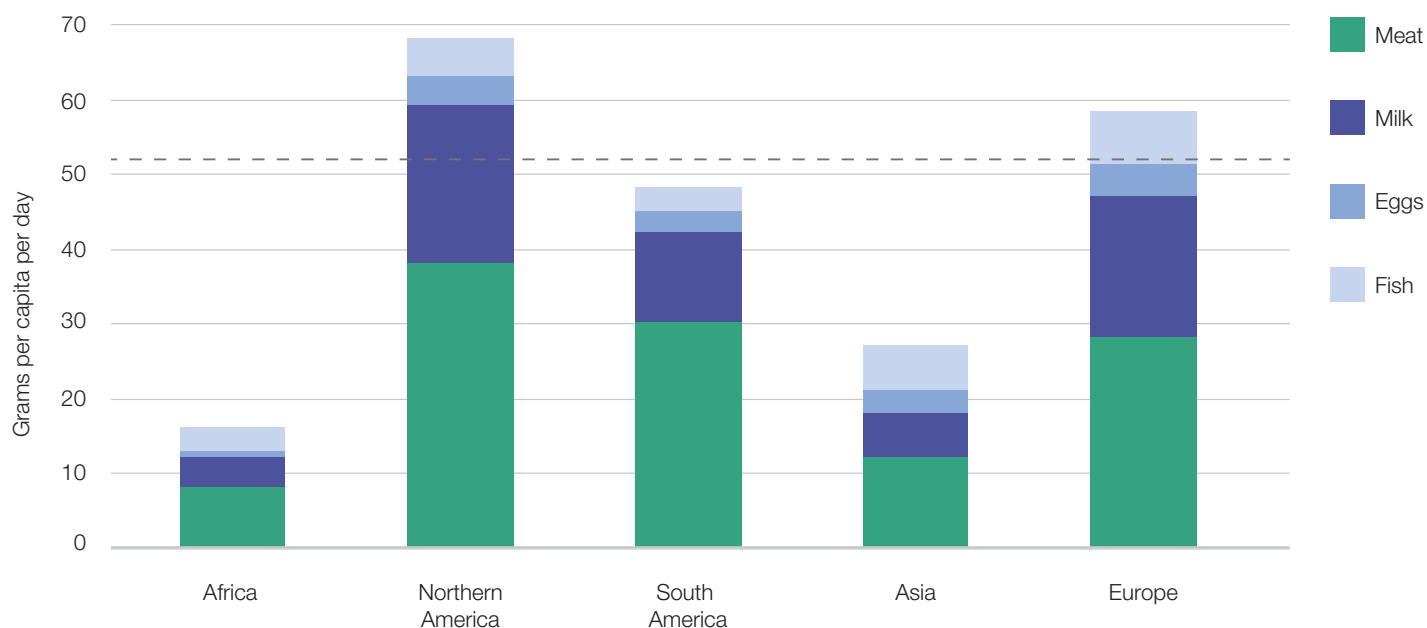
## 2.1 Livestock's role in food and nutritional security

Livestock are the most common and ubiquitous source of high-quality protein for most people.<sup>13</sup> Meat, dairy, eggs and fish provide 40% of the world's protein and 18% of its calories.<sup>14</sup> Livestock-derived foods, however, supply much more than protein; they provide essential micronutrients that are not found in plant-based foods or are present but in lower concentrations, or that are less bioavailable. Livestock-derived foods are particularly important for infants in their first 1,000 days of life and in poor households subsisting almost wholly on starchy foods high in carbohydrates, such as grains, cassava and potatoes. In sharp contrast, as incomes rise, overconsumption increases among better-off, usually urban households, thus leading to the "double burden" of malnutrition for many emerging economies.

Humans have evolved to eat both plants and animals.<sup>15</sup> Compared to plant-based sources of protein, animal-based sources possess denser and significantly more bioavailable forms of protein that more closely match human dietary needs.<sup>16</sup> To maintain balanced diets, vegetarians and vegans must have access to nutritious and diverse plant foods and often to additional supplements.<sup>17</sup>

The daily protein supply from animal products varies hugely between continents, from more than 60% in Northern America (or nearly 70 grams per person per day) to slightly over 20% (15 grams) in Africa (Figure 4).<sup>18</sup> The World Health Organization recommends sedentary adults consume approximately 50 grams of protein daily.<sup>19</sup>

**Figure 4:** Protein supply from animal-sourced foods by region/continent in 2013



Notes: The recommended protein intake (shown on the above chart as ----) will depend on an individual's age, sex, body weight, health status and activity level. The World Health Organization and the Food and Nutrition Board of the US National Academy of Sciences recommend a dietary reference intake (DRI) of 0.8 grams (g) of protein per kilogram of body weight. This number is used to calculate an average recommended protein intake of 52 g per person per day, that is based on the average DRI values (46 g for females, 56 g for males) for adult individuals of average weight and activity levels. DRI values are based on food intake, which normally would be observed from household-level data. Estimates of per-capita food supply are instead averages derived from national aggregates. Data used here from the Food and Agriculture Organization of the United Nations do not factor in possible losses at the retail or household levels, meaning values cannot be directly compared to those based on intake amounts. Distribution of supply according to demography or rural/urban areas is also not included.

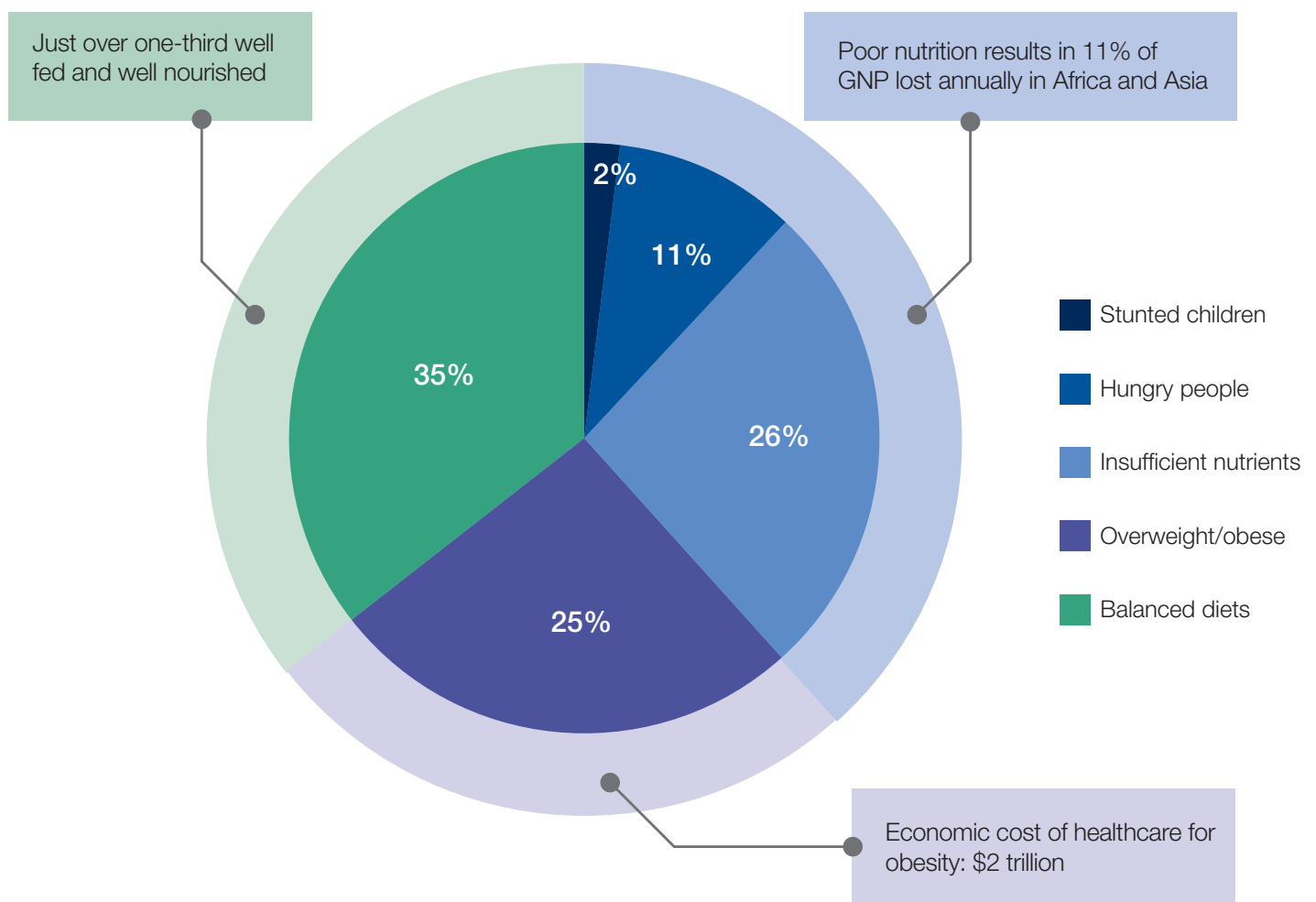
Sources: Food and Agriculture Organization of the United Nations, data extracted from "Food Balance Sheets", (n.d.), <http://www.fao.org/faostat/en/#data/FBS>; World Health Organization, Protein and Amino Acid Requirements In Human Nutrition: Report of a Joint WHO/FAO/UNU Expert Consultation, WHO Technical Report Series 935, 2007, [http://www.who.int/nutrition/publications/nutrientrequirements/WHO\\_TRS\\_935/en/](http://www.who.int/nutrition/publications/nutrientrequirements/WHO_TRS_935/en/); US National Academy of Sciences, Food and Nutrition Board, from National Institutes of Health, "Nutrient Recommendations: Dietary Reference Intakes (DRI)", (n.d.), [https://ods.od.nih.gov/Health\\_Information/Dietary\\_Reference\\_Intakes.aspx](https://ods.od.nih.gov/Health_Information/Dietary_Reference_Intakes.aspx).

Significant divides in nutrition and consumption persist among the world's 7.5 billion people. Astonishingly, just over one-third of them are well fed and well nourished (Figure 5).<sup>20</sup> Roughly another third is overweight or obese, which immensely burdens healthcare systems as well as individuals and families, most of whom are in developed economies. The other third either does not get enough to eat or does not get enough of the right nutrients, resulting in about 2 billion hungry or malnourished people, most of whom live in developing countries. For these people, livestock are critical for food and nutritional security, especially because they provide dense proteins, highly bioavailable micronutrients and combinations of amino acids needed for a healthy life. Incorporating animal-sourced foods in diets greatly helps people to meet basic nutritional needs. With insufficient supplies of the micronutrients found in livestock-derived foods, adults and children can suffer physical and cognitive impairments, develop deficiency diseases and become immune-compromised, with long-term consequences.<sup>21</sup>

Consumption of modest amounts of milk, eggs and meat is especially critical in the first 1,000 days of life (from conception through pregnancy, breastfeeding and up to two years of age) and continues to be very important for children's development during their first 3,000 days. Providing infants with as little as a single egg daily in addition to their usual diet for six months, for example, was found to cut stunting rates by nearly half (47%).<sup>22</sup>

Globally, convergence poses a critical question regarding the livestock-nutrition nexus – namely, can overconsumption of food, including meat, eggs and dairy products, be reduced while increasing the consumption of livestock-derived foods among the 2 billion or so for whom small amounts of such foods would improve their nutrition and health?<sup>23</sup> And of course, can the food for that be produced in a sustainable, efficient way? Both those overconsuming and those underconsuming face existential challenges deserving urgent attention. In addition, ensuring that the needs of people who make poor food choices do not override those of people with few or no food choices will be critical.

**Figure 5: Nutritional divides among the world's 7.5 billion people**



Sources: Data from FAO, IFAD, UNICEF, WFP and WHO, "The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition", 2018, <http://www.fao.org/3/I9553EN/i9553en.pdf>; Development Initiatives Poverty Research Ltd, Global Nutrition Report 2017: Nourishing the SDGs, 2017, [https://reliefweb.int/sites/reliefweb.int/files/resources/Report\\_2017.pdf](https://reliefweb.int/sites/reliefweb.int/files/resources/Report_2017.pdf).

## 2.2 Livestock's role in human health

*Livestock enhance human health not only by providing nourishing foods but also by supporting viable livelihoods, which allow people to make better dietary and health choices. On the other hand, like all perishable foods, those from livestock can be contaminated by pathogens, causing illness when consumed. In addition, many diseases are transmitted between livestock and people, and imprudent use of antimicrobial drugs in livestock production systems may exacerbate an ongoing rise in antimicrobial-resistant pathogens.*

The intersection of human and livestock health presents both threats and opportunities. Human health is intimately tied to the health of animals and ecosystems. Because of these links, human health may sometimes be improved more effectively and efficiently by targeting animals or ecosystems rather than humans directly. For example, human brucellosis is better controlled by vaccinating livestock than by treating sick people.

Like all foods, those derived from livestock can contain hazards that cause illnesses. They are perishable and can cause diseases if not stored or cooked well.<sup>24</sup> About 600 million people worldwide are sickened and 420,000 people, mostly children, die each year from food-borne diseases; the economic loss for low- and middle-income countries totals \$95 billion annually.<sup>25</sup> Many of these diseases are associated with animal-sourced foods and could be prevented by adopting relatively simple, practical programmes and techniques.<sup>26</sup>

More directly, livestock and humans share many diseases. Unhealthy livestock can transmit them to people; such “zoonotic” diseases are best controlled in livestock – every dollar invested in doing so is estimated to generate five dollars’ worth of benefits.<sup>27</sup> If appropriate capacity for monitoring and diagnosis is in place, livestock can also usefully serve as “canaries in the coal mine”, allowing detection of disease in animals before the disease reaches people.

Plagues and pandemics make up another, though fortunately rare, disease category of concern, with the potential to rapidly afflict large numbers of people and with serious to cataclysmic consequences.<sup>28</sup> The Black Death of Eurasia in the early Middle Ages, estimated to have killed 75 million-200 million people, and the global Spanish flu of the early 20th century that caused 50 million-100 million deaths, are prime examples. Many novel human plagues and pandemics can be traced to animals, with livestock (and wildlife) often involved.<sup>29</sup> Healthy livestock are less likely than sick livestock to originate or transmit new pandemics.

A current area of concern is antimicrobial resistance (AMR). Some experts forecast that by 2050, the rise of bacteria and other microbes resistant to antibiotic and other antimicrobial drugs could cause 10 million human deaths a year worldwide.<sup>30</sup> The extent to which AMR in humans results from overuse of antibiotics in livestock is heavily debated;

still, the precautionary principle suggests that use of antibiotics should be minimized to the extent possible. Industrialized nations are already pursuing this; producers are relying more on disease preventive regimes based on vaccines and better hygiene and other biosecurity measures.<sup>31</sup> In developing countries, beyond improving their understanding of the risks of AMR, the main precautions include improved husbandry so animals get sick less often; and, should they become ill, making appropriate animal health services more accessible and affordable.

Societies around the world increasingly recognize the obligation to treat animals humanely. Animal welfare fits naturally into health discussions: poor animal health causes great animal suffering, and reduction in animal disease also reduces disease in humans. In addition, animal welfare is related more broadly to livestock production. Providing adequate nutrition, husbandry and housing for livestock is critical for their welfare as well as for their productivity. Adequate livestock transport and competent slaughter processes reduce both animal suffering and losses from damaged carcasses. In developing and emerging economies, improvements in livestock welfare often simultaneously improve livestock productivity, presenting a win-win opportunity.

## 2.3 Livestock's role in livelihoods and economies

*More than 1 billion people are involved in livestock value chains globally, with more than half of these dependent on livestock for their livelihoods. Meat, milk and eggs make up five of the world's top 10 highest-value agricultural commodities, and the livestock sector contributes 40% to global agricultural gross domestic product. While this share varies from 15% to 80% across emerging and developing economies, it is rising fast in many countries and will need support from a range of technical, policy and institutional enablers.<sup>32</sup>*

The milk, meat and eggs produced by farm animals generate much-needed regular cash incomes in developing and emerging economies.<sup>33</sup> They also make crop agriculture possible. They transform grass, kitchen waste and other inedible biomass not only into nutrient-dense foods and reliable incomes, but also into manure, which enriches soils, nourishes crops and increases crop yields.<sup>34</sup> Livestock are especially important for poor rural populations in low- and middle- income countries and, in many countries, are richly integrated into religion and culture.

For many of these households, livestock are the family's prime asset, helping it to balance trade-offs and manage risks. Two-thirds of the world's poor livestock keepers are women, and as animals are often the only asset that women can own, they provide a vital source of income for household essentials, including payment of school fees and medical expenses. Beyond the farm, livestock enterprises provide jobs. In Kenya, for example, the livestock subsector employs 50% of agricultural labour and has the highest employment multiplier.<sup>35</sup> Farm animals also constitute “walking bank and savings accounts” – mobile assets that

households can sell for extra cash when needed, such as to smooth out cash flows or to make lump-sum payments for school or medical fees.<sup>36</sup> And they serve the many “unbanked” communities as insurance against disaster, such as a failed crop harvest or market failure.<sup>37</sup>

The relationship of livestock with the livelihood and resilience strategies for many millions of households is complex. Importantly, livestock are often crucial to enabling farm families to move up to more productive, market-linked production enterprises or to step out from agriculture altogether to take up more remunerative livelihoods.<sup>38</sup>

## 2.4 Livestock’s role in environmental health

*Livestock production systems can both enhance and harm environmental health, making it imperative to understand and balance these trade-offs. Livestock help to make optimal use of the planet’s biomass, exploiting the world’s full ecological potential, supporting a circular, regenerative food system and contributing to reducing greenhouse gas (GHG) emissions. However, industrial systems can pollute land and water and can contribute to GHG emissions. Smallholder mixed crop-livestock systems may be less efficient and thus have a larger GHG footprint per unit of product than industrial systems. Additionally, fragmented pastoral rangelands caused by development infrastructure and human population growth can restrict nomadic movement, leading to land degradation and biodiversity reduction by nomadic herds.*

Livestock are the primary productive assets of about 200 million pastoral and agropastoral people living in drylands, where herders periodically move their ruminant stock to find new water and fodder resources, allowing them to cope with a variable climate. Good grassland management to enhance forage production could sequester up to 150 megatons of carbon dioxide equivalent annually, with over half of this potential in developing countries.<sup>39</sup> Improving grassland forage production also restores soil health and increases livestock productivity. Pastoral livestock production can maintain native plant and animal species effectively, and moderate grazing has been shown to support more palatable plant species.<sup>40</sup> In addition, raising pastoral livestock is highly compatible with wildlife diversity.

Estimates of the global contribution of livestock to total greenhouse gas emissions vary between 7 and 18% of total global anthropogenic emissions<sup>41</sup> via several main pathways. Claims that the livestock sector produces more emissions than the world’s entire transport are not based on a like comparison using full life cycle costs,<sup>42,43</sup> meaning livestock contribute far less than transport. However, like the transport sector, improving efficiency is critical. For instance, with technical and financial support to adopt improved practices, producers could reduce their livestock emissions by up to 30%.<sup>44</sup> Improved management of manure, which in mixed crop-livestock systems provides 23% of nitrogen

globally,<sup>45</sup> can reduce nitrous oxide emissions while concurrently enhancing soil fertility and quality.<sup>46</sup> Similarly, assessments of livestock’s use of water vary considerably depending on the species, production method and metrics used.<sup>47</sup>

Many interventions that enhance livestock’s contributions to biodiversity, land and water management, and the mitigation of GHG emissions are co-benefits of better overall livestock husbandry. Improving productivity through better nutrition and health can lead to a smaller GHG footprint. Supporting livestock mobility through planned grazing and participatory rangeland management can also foster healthier rangelands and the biodiversity they support.

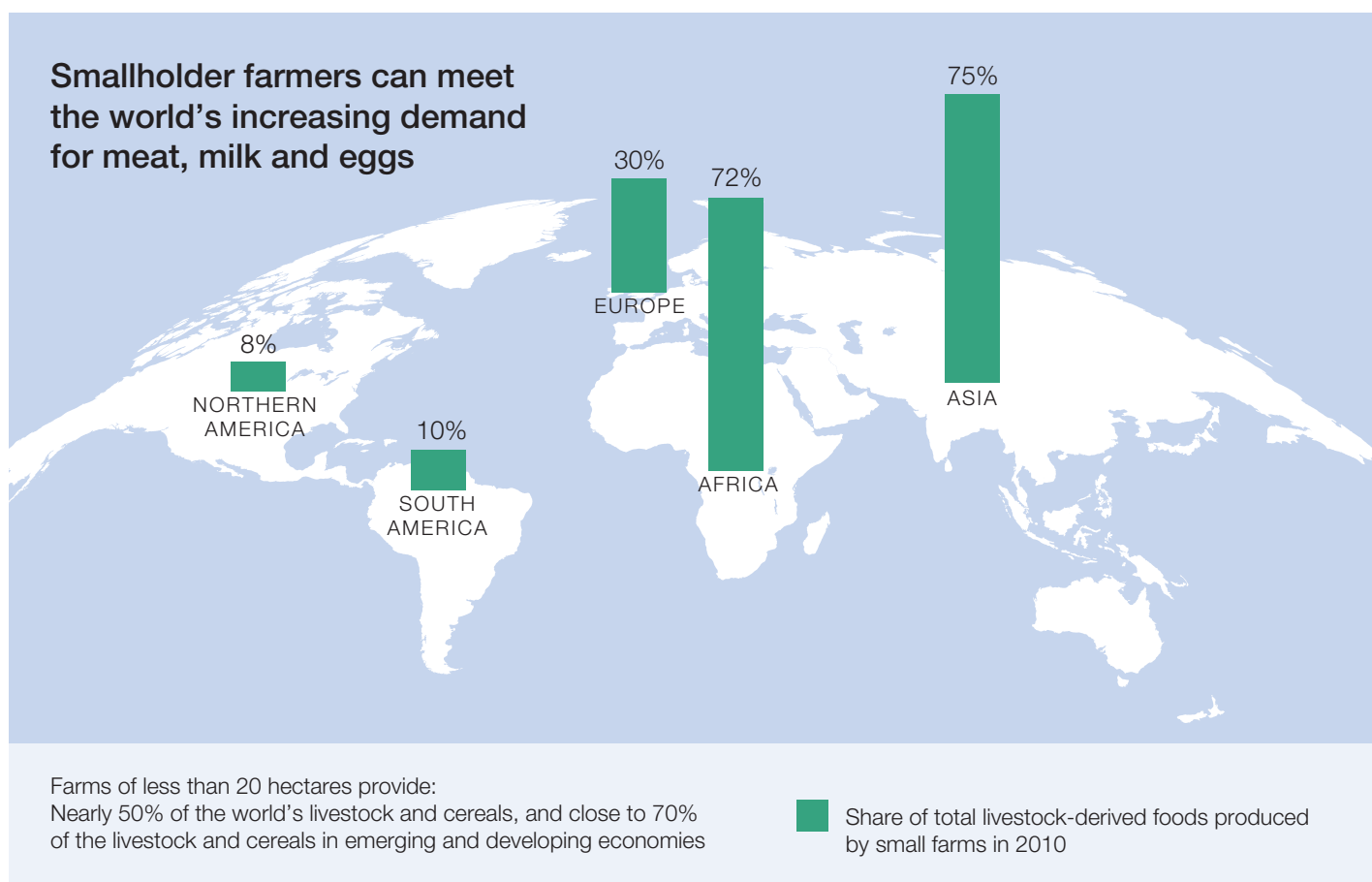
In terms of dry matter, 86% of the global livestock feed consists of materials that are inedible for humans.<sup>48</sup> Thus livestock, through their digestive capacity, play a role in food systems by optimally using available plant biomass. Ensuring a better match of food production with food consumption can also be achieved by adopting circular food production systems that use all biomass. This includes not only grass but also food surpluses, wastes and the residues (stalks and leaves) of crops after their grain has been harvested, and transforming this biomass into high-quality livestock and fish feed so nothing is wasted.<sup>49</sup>

### 3. Pathways to the future

Livestock continue to be raised in widely different ways around the world. By accounting for this diversity – in livestock systems and businesses and their various development trajectories – the rising demand for meat, milk and eggs can be met sustainably. This will require working with existing livestock systems, starting at different points and proceeding along different trajectories. For emerging and developing nations, where farms of less than 20 hectares supply most of the livestock-derived foods as well as cereals consumed in these countries, four main options exist for meeting the rising demand for such foods and are explored here. All these options are likely to coexist in the future, in complex mosaics of locally and globally interdependent pathways.

Consideration of the four options helps to understand how to accommodate the rising demand for livestock-derived foods. In addition, it identifies issues to address so that such trajectories not only contribute to meeting future protein needs, but also ensure a healthy and sustainable future. These hypothetical pathways are not mutually exclusive; they will likely coexist and be influenced by a wide range of economic, ecological and policy parameters. While recognizing that livestock will not be the only answer to the world's protein needs, the first of these pathways relates most directly to the systems that currently provide most of the world's livestock and cereal foods (Figure 6). Globally, nearly 50% of livestock-derived foods and cereals come from farms of less than 20 hectares. In emerging and developing economies, such smallholder farms produce close to 70% of both livestock and cereals and thus present opportunities for transforming to a “third way” (Box 1).<sup>50</sup>

Figure 6: Proportion of livestock-derived foods produced by small farms in 2010



Sources: Authors' estimations extrapolated from Herrero, M. et al., supplementary information and "Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems", *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 110, No. 52, 24 December 2013, pp. 20888-20893, <http://www.pnas.org/content/110/52/20888/tab-figures-data>.

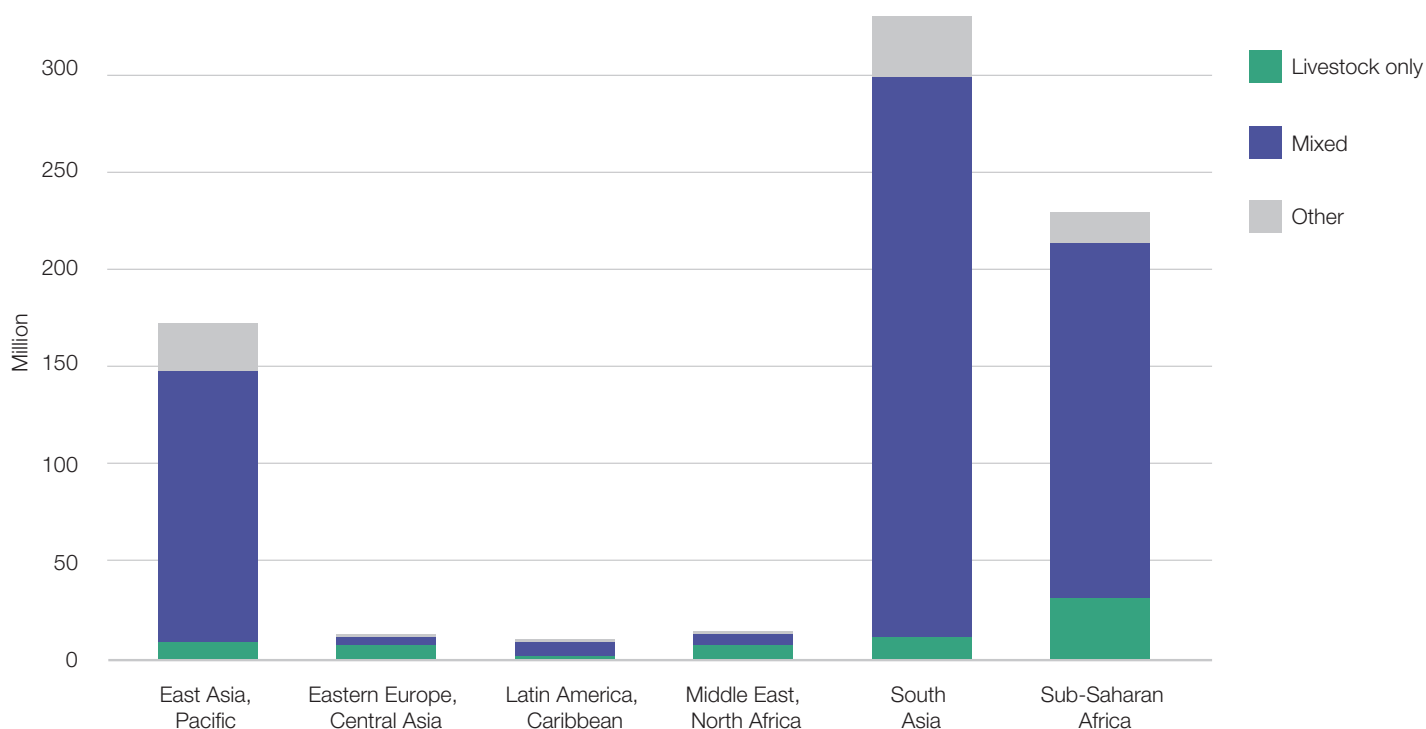
### 3.1 Transform small- and medium-scale mixed crop-livestock and livestock herding production systems into sustainable and profitable enterprises

This first option presents significant opportunities for emerging and developing countries by raising productivity while enhancing the livestock-dependent livelihoods of several hundred million people. Governments have opportunities to ensure their rapidly growing livestock sectors fulfil their potential to accelerate and sustain national economic growth. Grasping such opportunities will also require alternative livelihood options for those unsuccessful at transforming

their enterprises. In addition, as productivity responds to market demand, appropriate measures must help to avoid unintended health or environmental consequences.

Because of their large differences, these livestock systems are divided into two main types: (a) mixed, or settled farmers who integrate livestock raising with crop growing in arable regions; and (b) livestock-only, or nomadic/semi-nomadic pastoral herders living largely off their cattle, goats, sheep and other ruminant stock in drier regions. Over half a billion of the world's poorest rural people rely on livestock in these two systems (Figure 7).

Figure 7: Number of rural poor livestock keepers (living below \$2 income per day) in 2010



Notes: Livestock-only systems include livestock systems (mostly purely nomadic, pastoral) in arid, semi-arid and highland/temperate regions. Mixed crop-livestock systems include both rainfed and irrigated mixed crop-livestock systems in arid, semi-arid, humid, subhumid and highland/temperate regions (they also include some agropastoral, semi-nomadic systems). Other systems include root crop-based systems.  
Source: Robinson, T. et al., *Global livestock production systems*, FAO and ILRI, 2011, <http://www.fao.org/docrep/014/i2414e/i2414e.pdf>.

## a) Small- and medium-scale mixed crop-livestock systems

*Considerable, largely untapped opportunities exist to increase the food, nutritional and economic security of mixed crop-livestock farmers. Particular opportunities would be through jobs and improved livelihoods for women and youth, as well as in reducing the risks livestock can pose to the environment and public health.*

In such mixed agricultural production systems, animal rearing is closely integrated with crop production. These systems have supported good farming practices for millennia, for example with animal manure feeding soils that feed crops which in turn feed people.<sup>51</sup> Hundreds of millions of such mixed farms still exist in developing and emerging economies, and they are by far the most numerous type of farm in the world,<sup>52</sup> with many occupying just a hectare or two of land or less. Often these livestock producers remain surprisingly competitive with larger producers because they can draw on relatively cheap family labour and exploit the synergies between their different crop-growing and livestock-raising activities.<sup>53</sup> To respond to future demand, sustainable, efficient and inclusive transformation of such systems is needed.

Small family farms in the developing world are increasingly run by women as more and more men migrate to cities to find salaried work. Keeping animals enables many women to earn incomes, acquire skills and accumulate productive assets they would not have otherwise.<sup>54</sup>

Intensifying mixed crop-livestock farming – as opposed to industrializing it – represents a considerable potential through the adoption of technologies. These can enhance animal feeds (e.g. better quality and quantity of feed without switching to concentrates), breeds (e.g. better matching of genetics and environment) and health (e.g. vaccines, anti-parasitics, better housing), resulting in more efficient production and smaller environmental footprints per unit of meat, milk or eggs. Good potential also exists for livestock farmers to make much better use of the nutrient and water resources on their farms. Introduction of appropriate small-scale technologies for improving crop byproducts or making hay or silage can effectively smooth out seasonal feed shortages and avoid dry-season shortages of fodder and milk.

Farming can be an attractive livelihood for younger generations, thanks to improved business models that make it less risky and more profitable and to labour-saving and productivity-enhancing technologies. “Dairy hubs” that link producers with input and service providers can also improve efficiency, productivity and profitability.<sup>55</sup> Small- and medium-scale dairy farmers often do surprisingly well compared to larger dairy operations, while smallholder pig and poultry farmers can struggle to compete with confined, intensive operations. Labour and input costs, notably for feed, are key variables; large producers enjoy considerable economies of scale in purchasing feed, which accounts for 70% or more of total production costs in smaller enterprises.<sup>56</sup> Smaller-scale ruminant livestock producers can use family labour and their own farm-grown fodder, particularly for dairy

farms, to their advantage.<sup>57</sup> Besides often profiting from innovative food safety solutions, smallholders benefit from consumers’ preference for more traditional products, such as slow-grown traditional breeds of chicken and fresh rather than powdered milk.<sup>58</sup>

Growing evidence shows that more intensive agriculture can be less costly to the environment compared, for example, to organic farming.<sup>59</sup> Moreover, intensifying both beef and dairy production in the United States by combining better genetics, nutrition and health interventions reduced the carbon footprint per kilogram of meat and milk by 16% and 63%, respectively.<sup>60</sup> A similar approach of “transformation through sustainable intensification” could yield a useful “third way” of conducting animal husbandry, one that copies neither the industrial livestock systems of high-income countries nor the subsistence livestock systems of low-income nations (Box 1).

## b) Livestock-only (pastoral-based) systems

*Some 200 million people herd livestock in regions too dry for crop production. With the right support, many could improve their livelihoods by helping to meet the rising local demand for meat and milk. Other pastoral herders will need support in transitioning away from herding livelihoods altogether or in reducing their vulnerabilities to climate and other shocks. Concurrently, they can enhance their livelihoods through opportunities such as wildlife conservation and storage of carbon in rangeland soils.*

Pastoral systems are diverse, ranging from managed grasslands in parts of Africa to pastoral rangelands in Africa’s Sahel region, the Horn of Africa and parts of Asia. In total, the rangelands supporting such livestock production systems make up about a third of the global ice-free land area, most of which has poor fertility. Herders in these traditional pastoral societies depend on being able to move their herds and flocks to take advantage of seasonal grazing and water sources.

Despite being susceptible to significant climatic shocks, such drylands provide considerable amounts of livestock produce: in Kenya, 80% of the total meat consumed comes from cattle, sheep and goats, most of which are reared in pastoral systems. Grazing systems produce 22% of the beef in Latin America, 56% of the small-ruminant milk in Sub-Saharan Africa and 25% to 40% of the small-ruminant meat in most regions.<sup>61</sup>

With the right support, such as reducing losses through vaccination and increased market opportunities, many pastoralists could help meet the rising local demand for livestock-derived foods. Many rangelands and natural grasslands provide outstanding wildlife habitats as well as vital ecosystem services such as carbon storage. While these vast “biodiversity hotspots” are increasingly threatened, their traditional use by pastoralists at moderate grazing levels is now recognized as a rational and sustainable way to maintain biodiversity and ecosystem functioning as well as pastoral livelihoods.<sup>62</sup> To realize this opportunity, incentives are required for common property management and public investments that facilitate the use of science-based solutions.<sup>63</sup>

### Box 1: Transforming smallholder livestock systems: A “third way”

In past decades in developed countries, the intensification of livestock production, defined as an increase in productivity per acre or other unit of inputs such as labour, feed or time, was instrumental in meeting a rising demand for food. As intensification continued and began to reach “industrial” levels, however, the harm these mass production methods can cause the environment, human health and animal welfare came increasingly into focus.

In great contrast to the industrial livestock production model of industrialized countries are the ubiquitous small and medium-sized mixed crop-livestock farms of developing and emerging economies. By default, most of these farms fulfil many of the qualities considered increasingly desirable by consumers in northern regions. They are mostly organic, not by choice but because of the lack of access to affordable inputs. Their small flocks and herds of livestock are often free-ranging, and crops and animals occur in integrated systems that make the most efficient use of farm nutrients. However, production and profitability are generally low, and these small- and medium-scale enterprises will need to be transformed if they are to help meet future demand. Moreover, due to the low productivity of their animals, their GHG emissions per unit of product are relatively high – greater than those generated by the industrial livestock systems in developed countries.

Big opportunities are available to support small- and medium-scale farmers to intensify in a third or middle way. This approach avoids the environmental, public health and animal welfare problems typical of many industrial systems in developed economies and moves away from negative dimensions associated with low-productivity smallholder farming in much of the emerging and developing world. Successes in transforming smallholder poultry in Indonesia<sup>1</sup> and dairy in India<sup>2,3</sup> have been documented.

Such a transformation requires:

- Maintaining close integration of crops and livestock wherever possible and promoting efficient nutrient cycling between them
- Preventing and controlling livestock diseases through biosecurity measures and vaccination procedures rather than relying solely on antibiotic drug treatments
- Maintaining trees and other natural features in the farming environment to provide shade, windbreaks, habitats for pollinators and other ecoservices
- Avoiding the crowding of animal stock in extremely confined spaces and other practices that harm animal welfare
- Making use of the latest technologies to improve livestock production efficiencies
- Broadening smallholder participation in the livestock market
- Implementing new smallholder-friendly business models
- Engaging the private sector in livestock value chains
- Applying mobile-phone and related innovations in information technology (IT) for more efficient livestock services, inputs and marketing

Intensifying rather than industrializing smallholder farming systems through this “third way” can provide the nutritious livestock-derived foods that growing and increasingly better-off populations need and want. It can also support more attractive livelihoods for hundreds of millions of small- and medium-scale farm households and other value chain actors, all without destroying the environment. One of the greatest opportunities in the livestock sector is to help meet the rising demand for protein and better nutrition while concurrently accelerating sustainable development and mitigating climate change and other environmental harms.

<sup>1</sup> Forster, P., “The Political Economy of Avian Influenza in Indonesia”, *STEPS Centre Working Paper 17*, 2009.

<sup>2</sup> Terhal, P. and M. Doornbos, “Operation Flood: Development and commercialization”, *Food Policy*, Vol. 8, 1983, pp. 235-239.

<sup>3</sup> Achaya, K. and V. Huria, “Rural Poverty and Operation Flood”, *Economic and Political Weekly*, Vol. 21, No. 37, 13 September 1986, pp. 1651-1656, [https://www.jstor.org/stable/4376123?seq=1#metadata\\_info\\_tab\\_contents](https://www.jstor.org/stable/4376123?seq=1#metadata_info_tab_contents).



### 3.2 Develop industrial-scale livestock production enterprises

*Industrial-scale production systems for raising livestock, common in high-income countries, are increasing in emerging and developing economies. Such systems can produce livestock-derived foods with a lower environmental footprint per unit of product than other systems, can enhance farmers' access to inputs and services, and can make livestock-derived foods more readily available and accessible to all consumers. But adoption of such concentrated operations presents big challenges.*

The livestock production systems of high-income economies typically confine large numbers of animals in “concentrated animal feeding operations”.<sup>64</sup> Often referred to as “industrial” systems, they are sharply distinguished from the ubiquitous small-scale livestock systems of low- and middle-income economies. Animals raised on industrial farms are kept in large numbers and are fed high-quality cereal grains and plant-based proteins, especially soybeans, or fishmeal derived from capture fisheries.<sup>65</sup>

These farms are beginning to appear in emerging and developing economies.<sup>66</sup> In some countries and subsectors – for example, dairying in Vietnam – they are the most rapidly growing type of farm.<sup>67</sup> Technological breakthroughs, such as making cooling systems more affordable in hot tropical countries, are driving their growth, as are the spread of livestock expertise, equipment, genetics and vaccines. Established multinational companies, keen to expand into the world's growing economies, are behind much of this effort.

Industrial livestock farms produce fewer GHG emissions and require less land per unit of product than small-scale livestock farms. They create markets for inputs and services that can benefit neighbouring local smallholders and generate jobs at both the higher and lower ends of the labour market. In Mozambique, for example, the arrival of vast chicken farms provided small and medium-sized poultry enterprises with access to both day-old chicks and poultry vaccines.<sup>68</sup> Industrial farms provide both rural populations and the burgeoning middle class with relatively inexpensive and accessible meat, milk and eggs.

On the other hand, industrial farms can displace smaller enterprises, impoverishing them or driving them out of business entirely. Their concentrated animal populations, while tightly monitored for biohazards, can pose significant disease risks.<sup>69</sup> Keeping the animals cool in giant pens requires significant energy supplies, even with recent technological breakthroughs. The animals' waste products may create new hazards because they are rarely incorporated back into production the way smaller producers apply animal manure to fertilize their crop fields.

The animals in industrial systems may require feed from land previously dedicated to crops meant for human consumption, or they may eat the grains and other foods once grown for people.<sup>70</sup> In short, while industrial farms

may provide urban centres with relatively inexpensive livestock-derived foods, they may also undermine rural economies, making such foods less accessible to the poorer populations they displace.

### 3.3 Import more livestock-derived foods

*Developing and emerging nations may choose to increase their imports of livestock-derived foods produced by industrial systems in developed countries. While increased imports could improve access to the meat, dairy or eggs many consumers increasingly demand, they could also reduce local job opportunities and increase threats to the environment, public health and animal welfare.*

Imports of livestock-derived foods are usually in processed forms that increase their shelf life.<sup>71</sup> Some of these products, especially those needing refrigeration, are found in urban supermarkets, restaurants and fast-food outlets. Some are relatively expensive, serving niche demand among urban elites. Other imports are accessible to poorer consumers; these include powdered or condensed milk, tinned meat and low-value cuts of meat, such as turkey tails and chicken backs and feet, which are scarcely demanded in more developed economies.<sup>72</sup> Small packets of these lower-value livestock-derived foods may give some consumers their first regular access to them. Small sachets of milk powder, for example, are sold for the equivalent of a few cents each in West Africa, where fresh milk is in short supply and too expensive for poor populations.<sup>73</sup>

Both the volume and the proportion of imported livestock-derived foods have increased significantly in many developing and emerging economies. Africa currently imports \$22 billion worth of meat, \$5 billion of milk and more than \$200 million of eggs a year. The proportion of poultry meat that Sub-Saharan Africa imported in the two decades between 1993 and 2013 grew to 28% of total consumption, or nearly sixfold.<sup>74</sup> Exports of European Union milk powder to West Africa almost trebled between 2011 and 2016.<sup>75</sup>

The benefits and costs of using imports to respond to increasing demand will vary. While consumers could benefit from greater access to affordable imports, the livelihoods and incomes of local livestock producers could suffer. Some milk producers in West Africa, for example, are faced with lower-cost powdered milk imports and thus are ceasing or cutting back on production.<sup>76</sup> While production of livestock-derived foods in developed economies usually emits fewer GHGs per unit of output than production in developing economies, the environmental cost of transporting meat, milk and eggs can be high and food safety issues can arise.<sup>77</sup>

For some emerging and developing nations, livestock keeping may not be central to the national economy or to the livelihoods of the population for reasons spanning economics, ecology, culture and history. These countries have no comparative advantage in producing livestock-derived foods; thus, importing such foods can be essential to responding to consumer demand and nutritional needs.

But they must remain cognizant of multiple trade-offs. For those economies where livestock-derived foods could be produced locally (with associated local livelihood benefits), the option to import them needs to be balanced against the potential strain on government resources deployed to procure goods and services that are unavailable locally, as well as against environmental and livelihood dimensions.

### 3.4 Use alternative forms of protein

*Mostly high-income economies are exploring alternative forms of protein (alt-proteins). These innovations will undoubtedly generate spillover benefits for emerging, developing and developed economies, and are likely to contribute to solving the world's protein needs. Their potential to provide sustainable, economically viable solutions to help meet the nutritional challenges facing developing countries needs to be explored further if they are to become meaningful options. In particular, efforts should consider co-designing solutions that leverage technologies developed in high-income economies and jointly adapting those with high potential for emerging and developing nations.*

Alt-proteins can include plant- or algae-based rather than animal-derived foods, as well as insects and alternative foods that mimic the look, feel and taste of meat, milk and eggs.

#### *Plant-based foods*

Cereals, legumes, seeds, nuts and other plant sources of food account for 57% of the protein consumed globally.<sup>78</sup> In developing and emerging economies, plant-based foods provide an even greater proportion of total protein.<sup>79</sup>

Traditionally processed protein-rich plant-based foods have long been a feature of Asian cultures. Tofu and tempeh are the two best known, although many local variants exist. As noted, plant-based foods are less nutrient-dense than livestock-derived foods and may need to be supplemented through a diverse diet to ensure the full complement of nutrients is provided.

#### *Insects*

Insects, especially beetles, caterpillars, bees, wasps, ants, grasshoppers, locusts, termites and crickets, as well as other land-based invertebrates such as snails, earthworms and spiders, have been collected from the wild and eaten by communities throughout the world for thousands of years, especially in Africa, Asia and Latin America.<sup>80</sup>

Compared to traditional livestock, insects and other invertebrates are more efficient at converting feed to meat. Insects require little land, water and labour, generate few GHGs and raise few animal welfare issues. They are particularly good for converting waste to feed, thus supporting a circular bioeconomy as discussed in the section “Enablers for transformation”. Several initiatives are addressing the hurdles of scaling up production, including economic models, food safety, regulations and allergens. Additionally, further research may be needed to determine the optimal species, as the nutritional value of insects varies

given their huge diversity. For instance, studies have shown the protein content of insects ranges from 30% to 60%, and their levels of vitamin B12 and a range of other macro- and micronutrients are variable.<sup>81</sup> Opportunities to use insects as both food and feed are growing<sup>82</sup> and represent a critical area for further exploration.

#### *Alt-proteins*

Several kinds of alternatives to livestock-derived food products are in active development. They may contribute to global protein needs and reduce the environmental footprint per unit. These alternatives are explored thoroughly in the 2018 World Economic Forum report *Alternative Proteins*. Products include foods that mimic the look, feel and taste of meat, milk, eggs and fish to varying degrees and cover a spectrum of products – those made from lab-cultured livestock cells to others made from plants or microfungi.<sup>83</sup> Currently, these alternative foods (alt-meats, dairy-free milks and chickenless eggs) are aimed more at consumers in high-income countries. Livestock are mostly viewed there as commodities – meat, milk or eggs – whereas consumers in low-income countries or the poorer, often rural populations in middle-income countries consider livestock as “living assets”, namely animals that provide livelihoods as well as food.

In the short term, these products will support only a tiny fraction of the millions of jobs and livelihoods that conventional livestock-derived foods support today. For alternative products to provide available, accessible protein for consumers in developing and emerging regions, innovative interventions will be needed that simultaneously address two key aspects: having safe, affordable supply that responds to consumer preferences and balancing context-specific trade-offs such as environmental and livelihood dimensions for the millions who currently raise animals. Such products may allow consumers in emerging and developing countries to leapfrog some of the steps observed in developed nations.

## 4. Enablers for transformation

As with all dimensions of the food system, transformation of the livestock sector in emerging and developing countries must balance trade-offs and grasp opportunities to address some of the world's most pressing challenges.

The rapid increase in demand for livestock-derived foods in emerging and developing economies was coined the “livestock revolution” in 1999 in the first analysis that highlighted this impending global shift in consumer habits.<sup>84</sup> Yet, as this shift has since developed into an evolution (a process of steady, gradual change), transformations are urgently required that harness available livestock-based solutions and lessons along with new, available disruptive technologies.

In this final section, the enablers for such transformations are considered across the four pathways already noted. All enablers will need to operate simultaneously and interactively.

### 4.1 Decision-makers will need to assess priorities in relation to trade-offs in specific contexts.

Input from all stakeholders and use of the appropriate tools will help inform and support such efforts at prioritization. Critical to the process is to pose the question: what exactly is to be transformed? The answer and prioritized decisions are critical before embarking on any transformation. As the contexts will differ, the pathways will as well. All production systems, whether crops, livestock or integrated, or large-or small-scale, will present multiple trade-offs in all four dimensions. Such trade-offs are complicated for livestock. The most productive system is not necessarily the most profitable, and the most environmentally friendly system may be the least friendly regarding animal welfare. Moreover, some positives and negatives tend to go hand in hand: as livestock systems intensify and become more efficient, they may use more concentrated feeds and antimicrobial drugs. As with all sectors, trade-offs may exist in contributions to different SDGs.<sup>85</sup> Uncoupling these types of consequences is possible and requires intentional effort.

Decision-makers need to prioritize investments that respond to context-specific livestock demand while simultaneously pursuing local economic growth and sustainable development. Use of systems thinking is a fundamental requirement and must become part of everyday practice rather than serve as an add-on or an afterthought. For example, national “livestock master plans”, developed to help identify and prioritize opportunities and balance trade-offs, have been successfully undertaken in Ethiopia, resulting in significant new public- and private-sector investments.<sup>86</sup>

### 4.2 Governments will need to support livelihood transitions.

For many developing and emerging economies where millions of smallholders are involved in the livestock sector, governments should encourage opportunities for many smallholders to participate in the sector's transformation, while supporting others to step out to other livelihood options. The latter will require addressing a wide range of social and economic issues<sup>87</sup> that are beyond the scope of this paper.

Livelihood options might include new initiatives that pay for a system's services, such as stewarding livestock to enhance carbon sequestration, water and vegetation management, and animal and plant biodiversity. New business opportunities could include employment in many input enterprises and businesses providing services, in alt-protein production units, and in equipment, IT servicing and the provision of raw materials. Such employment, which could require increased technical capacity in areas ranging from biotechnology to IT and digital innovation, would likewise require investment in developing such skills. Even with new opportunities, many will need to find new livelihoods entirely outside the livestock sector.

### 4.3 Innovative modes of stakeholder engagement must be promoted at all levels.

Encouraging such engagement needs to occur at global, regional, national and local levels, and encompass the public and private sectors, development organizations, farmer organizations, civil society, consumer groups and research agencies. Improving interactions among all stakeholders in livestock development has enhanced sustainable progress across value chains, from production to processing and marketing – for example, the dairy sector in Tanzania<sup>88</sup> and the pork sector in Uganda.<sup>89</sup> New opportunities to transform these nascent value chains can be furthered by bringing the power of new information and communication technologies to bear – whether by enhancing communication among stakeholders themselves or delivering services, supporting financial transactions and providing technical, managerial, input and market information. Such innovations also open opportunities for the benefits generated by one value chain operating at an industrial scale to spill over to smaller enterprises.

Connecting all levels of private entrepreneurs and providing them with a viable business environment is a must, including specific financial approaches and other ways of enhancing opportunities for young people and women. From large multinationals to small and medium-sized enterprises, new business models and modalities are needed that build on what is available and rapidly harness new technologies. The Global Agenda for Sustainable Livestock,<sup>90</sup> which supports many productive multistakeholder partnerships, is an example of fostering institutional environments to help transform the livestock sector.

#### 4.4 The power of technology must be harnessed to address production, information and bioeconomic challenges.

The evolutionary progress made to date in transitioning livestock systems in emerging and developing economies comes with an important lesson: a simple “technology transfer” model for implementing a technical solution that worked well in developed nations does not work in developing nations. For example, many attempts to import improved breeds of animals for dairying in developing countries failed due to a range of pressures, including tropical diseases, harsh environments, scarce or low-quality feed and lack of healthcare. Ensuring that the most advanced livestock technologies will benefit developing-country livestock keepers requires, among other things, stakeholder participation, adaptation, a combination of different solutions, institutional and policy support, IT and a vibrant private sector.

Increased livestock **production efficiencies** are key to ensuring the availability of more livestock-derived foods, especially for the populations of emerging and developing economies. They are also important to reducing livestock’s environmental footprint. Achieving such efficiencies requires developing and applying the latest science-based solutions to improve animal nutrition, health and genetics. The growing number of advanced laboratories and trained laboratory staff in emerging and developing countries, as well as increasing private-sector investment in their agricultural sectors is reflected in increasing applications of the latest genomic and biotechnology tools in these nations. The tools help to assess and develop animal breeds better matched to developing-country environments and to improve veterinary care through new vaccines and diagnostics.

Developing and applying technical solutions can support a **circular bioeconomy** that mitigates waste and pollution issues and maximizes nutrient recycling. While integrated crop-livestock production is nothing new to the world’s smallholder farmers, new technologies are becoming available to recycle waste from livestock production for energy (biogas) or for fertilizer, ensuring optimal use of the earth’s resources.

**Innovative feed solutions** are critical not only to improving production efficiency, but also to reducing environmental footprints and enhancing the circular bioeconomy. Much of the feed used by industrial farms could be consumed, directly or indirectly, by people, which is in direct contrast to the grass and other biomass that are inedible for humans but consumed by animals in small and medium-sized enterprises. Feed production from cropland can also have a big adverse environmental impact, such as from water use and loss of biodiversity from the expansion of agricultural land, and particularly when it results in deforestation. New technologies can mitigate this food-vs-feed competition through the development of feeds from sources that cannot feed people and that do not compete with food crops for land. These are likely to include animal feeds based on insects, crop byproducts and microbes,<sup>91</sup> among others.

Developments in entoculture (raising insects to provide food or other products) are moving fast, and includes utilizing food waste as their feed.<sup>92</sup> The first commercial applications have been launched in Europe, the United States and Asia. Another example of a potential feed solution is the processing of cassava peel, an environmentally hazardous waste product, into a high-quality feed ingredient for ruminants, chickens and aquaculture. When cassava is processed for food, the peel is usually discarded, causing a serious environmental hazard; in Africa, 50 million metric tonnes of peels are generated annually. Of this total, 15 million tonnes come from Nigeria, where a recent study concluded that the peels could generate 5 million tonnes of high-quality feed.<sup>93</sup>

For most smallholder farmers, low-quality cereal residues provide the bulk of livestock feed. An innovative application of technology initially developed for second-generation biofuel production (ammonia fibre expansion), however, could upgrade these low-quality feeds into concentrate-level quality without competing with human food or using extra land.<sup>94</sup>

Using **digital information** in new ways is also speeding change in livestock systems. Tools range from tapping into mobile services for big-data gathering and application, such as a development under way in East Africa to identify the best dairy animals,<sup>95</sup> to using blockchain or the internet of things to improve livestock supplies and value chain traceability. Both of these can improve food safety and reduce waste.

#### 4.5 Enabling policies must be implemented and incentives provided to support equitable, affordable, safe and sustainable livestock-sector transformation.

Governments face a plethora of trade-offs that need to be assessed in implementing policies that support a vibrant transformation of the livestock sector. These include:

- Balancing and continually evaluating the multiple roles livestock play in people’s livelihoods, health, environment and economic development.
- Navigating the potentially conflicting interests of consumers, who want access to affordable, safe and high-quality livestock-derived foods, and private businesses, producers, input suppliers, processors and marketers, who have historically been motivated by production efficiency at the expense of planetary or other externalities. Policy instruments such as tariffs, quotas, standards and subsidies may play a role in addressing these competing interests. They also may need to be tailored to the context, as 70% of the livestock-derived foods in emerging and developing economies are still sold in informal markets.
- Providing enabling business environments as well as access to land and financing modalities that support all scales and sizes of private investors in the livestock sector.
- Implementing policies that shape the food system to support benefits for health, nutrition and gender equity, among others (for example, by backing small-scale milk traders to provide affordable milk to the poor rather than supporting supermarkets, or by encouraging the empowerment of women).

- Providing incentives, including those tailored for the informal sector, that reward practices that enhance the environment, ecosystem services, biodiversity, good food hygiene and animal welfare. Innovative digital and scientific technologies, such as the internet of things (to improve traceability) and new food sensing techniques, including near-infrared spectrometers and hyperspectral imaging, can help with implementing and monitoring such incentives.

#### **4.6 Informing and supporting consumer choices about livestock-derived foods is necessary.**

Some degree of convergence in consumption levels is required to ensure planetary boundaries, which include processes such as freshwater use, land-system change and biosphere integrity that regulate the earth's stability and resilience, are respected while ensuring that all the world's people are nourished. Certain populations will need to reduce the amount of meat, milk and eggs they consume while others must increase their consumption of these foods. Balanced global messages about the need for healthy, nutritious and sustainable diets for all people should be communicated instead of calls for one-size-fits-all solutions that could block access to livestock-derived foods for those who need them most. As few solutions to the world's protein challenge are value-neutral, global messaging must consider the voices of many hundreds of millions of people who depend on livestock in developing and emerging countries, and who would benefit from greater, not lesser, access to livestock-derived foods. As the access to and availability of milk, meat and eggs increases for poorer populations, policy-makers will need to promote sensible, balanced consumption as well as messaging that incorporates dietary, environmental, public health and animal welfare dimensions.

#### **4.7 Alt-proteins must be co-created and new innovations and investment furthered.**

Co-designing solutions for alt-proteins that take local contexts, values and behaviours into consideration will be imperative. In addition, business models, supply chains, infrastructure and regulatory environments conducive to new private-sector investment will need to be supported and developed, regardless of whether alt-proteins are produced in-country or imported. New innovations in food safety and the use of genetically modified organisms will be required – areas where the latest disruptive technologies of the Fourth Industrial Revolution would feature strongly, as would food safety and nutritional information for consumers.

#### **4.8 Greater investment is required to transform smallholder production.**

Regardless of the pathway, commodity or region, two actions will be crucial to transforming the livestock sector so that it addresses protein provision, livelihoods, environmental sustainability, healthy diets, equity and economic development. The first is greater and more intentional investment in opportunities to transform smallholder production, especially through a “third way”. The second is investment in new consultations that will bring existing and new players to the table to identify how to facilitate the rapid application of new innovations that can address this immense opportunity.

## 5. Conclusion : All shapes, sizes and systems

This paper has considered ways in which the livestock sector and developing and emerging economies can change not only in their response to protein demand but also in how they address a plethora of other development opportunities and challenges. Many of the options described here will undoubtedly be required to help nourish the world sustainably and equitably.

Over the coming decades, livestock will certainly remain a central part of the future of protein. Food-producing animals not only provide high-quality and bioavailable protein as well as many other nutrients, but also play important roles in cultivating food crops and serving as living assets and income sources, particularly for the world's poorer populations and for rural dwellers in higher-income countries. As entrepreneurs and policy-makers debate the future of protein delivery systems, no option should go unexplored, and no one must be left behind.

To nourish as well as feed all the world's growing population with protein and much else, livestock systems of all shapes and sizes will need to be transformed. Solutions for efficient, sustainable and equitable transformation will vary greatly depending on the species being raised, the regions concerned and the resources required. Such diversity is not a problem to be solved but is essential to the solution. It harbours options for finding a "third way" to raise and use livestock – a way that mimics neither the industrial livestock production systems of high-income countries nor the subsistence livestock production systems of developing and emerging countries. New and innovative partnerships involving large- and small-scale private enterprises, diverse business opportunities and close engagement with the public sector will all be required alongside the discovery and delivery of new science-based solutions.

In this diverse, innovative and transforming sector lies the means to meet a rising need and demand for protein, while at the same time protecting individuals' health and the environment and helping hundreds of millions of people to escape absolute poverty. And while the pathways and starting points for sustainable livestock systems will be different, they can and should all lead to the same end goal: more nourishing, accessible, affordable, safe and sustainable food systems for all the world's people.

# Endnotes

1. Commonly used terms to distinguish the economic status of nations, such as “rich”, “poor”, “developed” or “underdeveloped”, are disputed. The phrase “developing and emerging economies” is used in a good-faith effort to distinguish the lower- and middle-income countries from the high-income industrialized nations of North America, Western Europe and parts of Australasia.
2. World Economic Forum, “Meat: the Future – Time for a Protein Portfolio to Meet Tomorrow’s Demand”, January 2018, <https://www.weforum.org/whitepapers/meat-the-future-time-for-a-protein-portfolio-to-meet-tomorrow-s-demand>.
3. Food and Agriculture Organization of the United Nations (FAO), International Fund for Agricultural Development (IFAD), United Nations Children’s Fund (UNICEF), World Food Programme (WFP) and World Health Organization (WHO), *The State of Food Security and Nutrition in the World 2018: Building Climate Resilience for Food Security and Nutrition*, 2018, <http://www.fao.org/3/I9553EN/i9553en.pdf>.
4. Ibid.
5. World Economic Forum, *Innovation with a Purpose: The role of technology innovation in accelerating food systems transformation*, 2018, <https://www.weforum.org/reports/innovation-with-a-purpose-the-role-of-technology-innovation-in-accelerating-food-systems-transformation>.
6. Food and Agriculture Organization of the United Nations, “The livestock sector accepts the challenge of the UN Agenda 2030”, 23 June 2016, <http://www.livestockdialogue.org/events/events/multi-stakeholder-meetings/panama-20-23-june-2016/en/>; Food and Agriculture Organization of the United Nations, *World Livestock: Transforming the livestock sector through the Sustainable Development Goals*, 2018, <http://www.fao.org/3/CA1201EN/ca1201en.pdf>.
7. Enahoro, D. and authors, 2018, unpublished calculations using FAOSTAT data; Herrero, M. et al., “Farming and the geography of nutrient production for human use: a transdisciplinary analysis”, *The Lancet Planetary Health*, Vol. 1, No. 1, 2017, pp. e33-e42.
8. Organisation for Economic Co-operation and Development and the Food and Agriculture Organization of the United Nations, data extracted from *OECD-FAO Agricultural Outlook 2018-2027* [Dataset], [https://stats.oecd.org/viewhtml.aspx?datasetcode=HIGH\\_AGLINK\\_2018&lang=en](https://stats.oecd.org/viewhtml.aspx?datasetcode=HIGH_AGLINK_2018&lang=en).
9. United Nations Department of Economic and Social Affairs, “World population projected to reach 9.8 billion in 2050, and 11.2 billion in 2100”, 21 June 2017, <https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html>.
10. Organisation for Economic Co-operation and Development, *OECD Agriculture Statistics* [Datasets], <http://dx.doi.org/10.1787/agr-outl-data-en>; OECD/Food and Agriculture Organization of the United Nations, *OECD-FAO Agricultural Outlook 2018-2027*, 2018, with link for data on meat consumption at <http://dx.doi.org/10.1787/888933741998>.
11. Food and Agriculture Organization of the United Nations, “Shaping the Future of Livestock Sustainably, Responsibly and Efficiently”, 2018, <http://www.fao.org/publications/card/en/c/18384EN/>.
12. Federal Ministry of Food and Agriculture of Germany, “Global Forum for Food and Agriculture Communiqué 2018”, 20 January 2018, <http://www.gffa-berlin.de/en/gffa-kommunique-2018/>.
13. Elmadfa, I. and A.I. Meyer, “Animal proteins as important contributors to a healthy human diet”, *Annual Review of Animal Biosciences*, Vol. 5, February 2017, pp. 111-131.
14. Food and Agriculture Organization of the United Nations, data extracted from “Food Balance Sheets”, (n.d.), <http://www.fao.org/faostat/en/#data/FBS>.
15. Newman, T., “Is vegetarianism the natural option?”, *Medical News Today*, 15 November 2017, <https://www.medicalnewstoday.com/articles/320047.php>.
16. Ibid.
17. This paper does not focus on fish, apart from briefly considering its place in the overall supply of protein. While worldwide demand for fish continues to increase rapidly and is an important part of total animal-sourced foods, the issues surrounding fish, fisheries and the world’s water environments are sufficiently distinct to require separate treatment.
18. Food and Agriculture Organization of the United Nations, data extracted from “Food Balance Sheets”, (n.d.), <http://www.fao.org/faostat/en/#data/FBS>.

19. World Health Organization, "Protein and Amino Acid Requirements In Human Nutrition", World Health Organization, Food and Agriculture Organization of the United Nations, and United Nations University, 2007, [http://www.who.int/nutrition/publications/nutrientrequirements/WHO\\_TRS\\_935/en/](http://www.who.int/nutrition/publications/nutrientrequirements/WHO_TRS_935/en/); Gunnars, K., "Protein Intake – How Much Protein Should You Eat Per Day?", *Healthline*, 5 July 2018, <https://www.healthline.com/nutrition/how-much-protein-per-day>.
20. FAO, IFAD, UNICEF, WFP and WHO, 2018, op. cit.; Hawkes, C. and J. Fanzo, "Nourishing the SDGs: Global Nutrition Report 2017", *Development Initiatives*, 2017, [https://reliefweb.int/sites/reliefweb.int/files/resources/Report\\_2017.pdf](https://reliefweb.int/sites/reliefweb.int/files/resources/Report_2017.pdf).
21. Bailey, R.L., K.P. West Jr and R.E. Black, "The Epidemiology of Global Micronutrient Deficiencies", *Annals of Nutrition and Metabolism*, Vol. 66, Suppl. 2, 2015, pp. 22-33.
22. Iannotti, L.L. et al., "Eggs in Early Complementary Feeding and Child Growth: A Randomized Controlled Trial", *Pediatrics*, Vol. 140, No. 1, 2017.
23. Springmann, M. et al., "Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail", *The Lancet Planetary Health*, Vol. 2, No. 10, 2018, pp. e451-e461.
24. Grace, D., "Food Safety in Low and Middle Income Countries", *International Journal of Environmental Research and Public Health*, Vol. 12, No. 9, 2015, pp.10490-10507.
25. Jaffee, S. et al., *The Safe Food Imperative: Accelerating Progress in Low- and Middle-Income Countries*, World Bank Group, 2019.
26. Grace, D., op. cit.
27. McDermott, J., D. Grace and J. Zinsstag, "Economics of brucellosis impact and control in low-income countries", *Revue scientifique et technique* (International Office of Epizootics), Vol. 32, No. 1, 2013, pp. 249-261.
28. Rowe, T. and S. Beard, "Probabilities, methodologies and the evidence base in existential risk assessments", Working Paper, Centre for the Study of Existential Risk, July 2018, [http://eprints.lse.ac.uk/89506/1/Beard\\_Existential-Risk-Assessments\\_Accepted.pdf](http://eprints.lse.ac.uk/89506/1/Beard_Existential-Risk-Assessments_Accepted.pdf).
29. Grace, D., "The business case for One Health", *Onderstepoort Journal of Veterinary Research*, Vol. 81, No. 2, 2014, pp. 1-6.
30. O'Neil, J., "Antimicrobial Resistance: Tackling a Crisis for the Health and Wealth of Nations", *Review on Antimicrobial Resistance*, December 2014, [https://amr-review.org/sites/default/files/AMR%20Review%20Paper%20-%20Tackling%20a%20crisis%20for%20the%20health%20and%20wealth%20of%20nations\\_1.pdf](https://amr-review.org/sites/default/files/AMR%20Review%20Paper%20-%20Tackling%20a%20crisis%20for%20the%20health%20and%20wealth%20of%20nations_1.pdf).
31. Speksnijder, D.C., D.J. Mevius, C.J. Brusckke and J.A. Wagenaar, "Reduction of veterinary antimicrobial use in the Netherlands. The Dutch success model.", *Zoonoses Public Health*, Vol. 62, 2015, pp. 79-87.
32. Authors' own calculations; Livestock Data for Decisions (LD4D), "Livestock and Economy: Does the livestock sector make up 40% of total agricultural GDP globally?", LD4D Livestock Fact Check Series, Fact Check 2, June 2018, <https://www.era.lib.ed.ac.uk/bitstream/handle/1842/30115/Livestock%20Economy%20Fact%20Sheet.pdf?sequence=5&isAllowed=y>.
33. Food and Agriculture Organization of the United Nations, "Livestock, food security and poverty reduction", in *The State Of Food And Agriculture: Livestock in the balance*, 2009, pp. 32-52, <http://www.fao.org/docrep/012/i0680e/i0680e03.pdf>.
34. Food and Agriculture Organization of the United Nations, "World Livestock 2011: Livestock in food security", 2011, <http://www.fao.org/docrep/014/i2373e/i2373e.pdf>.
35. Gelan, A., E. Engida, A.S. Caria and J. Karugia, *Integrating livestock in the CAADP framework: Policy analysis using a dynamic computable general equilibrium model for Ethiopia*, Ethiopia Strategy Support Program II Working Paper 34, International Food Policy Research Institute, 2012.
36. Wade, C., "Strengthening Food Security in Africa: A Case for Supporting Pastoralism in East Africa," Institute for the Study of International Development, 2013, [https://www.mcgill.ca/isid/files/isid/pb\\_2013\\_16\\_wade.pdf](https://www.mcgill.ca/isid/files/isid/pb_2013_16_wade.pdf).
37. Moll, H.A.J., "Costs and benefits of livestock systems and the role of market and nonmarket relationships", *Agricultural Economics*, Vol. 32, No. 2, 2005, pp. 181-193.
38. Dorward, A. et al., "Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor", *Development in Practice*, Vol. 19, No. 2, 2009, pp. 240-247.
39. Herrero, M. et al., "Greenhouse gas mitigation potentials in the livestock sector", *Nature Climate Change*, Vol. 6, No. 5, 21 March 2016, pp. 452-461.



40. Maitima, J.M. et al., "The linkages between land use change, land degradation and biodiversity across East Africa", *African Journal of Environmental Science and Technology*, Vol. 3, No. 10, 2009, pp. 310-325.
41. Hristov, A.N. et al., "Mitigation of greenhouse gas emissions in livestock production – A review of technical options for non-CO<sub>2</sub> emissions". Gerber, P.J., B. Henderson and H.P.S. Makkar (eds), FAO Animal Production and Health Paper No. 177, FAO, 2013.
42. Mottet, A. and H. Steinfeld, "Cars or livestock: which contribute more to climate change?", *Thomson Reuters Foundation News*, 18 September 2018, <http://news.trust.org/item/20180918083629-d2wf0>.
43. Mitloehner, F.M., "Yes, eating meat affects the environment, but cows are not killing the climate", *The Conversation*, 25 October 2018, <https://theconversation.com/yes-eating-meat-affects-the-environment-but-cows-are-not-killing-the-climate-94968>.
44. Gerber, P.J. et al., *Tackling Climate Change Through Livestock: A Global Assessment of Emissions and Mitigation Opportunities*, Food and Agriculture Organization of the United Nations, 2013.
45. Liu, E. et al., "Long-Term Effect of Manure and Fertilizer on Soil Organic Carbon Pools in Dryland Farming in Northwest China", *Plos one*, Vol. 8, No. 2, 2013.
46. Pelster, D. et al., "Methane and Nitrous Oxide Emissions from Cattle Excreta on an East African Grassland", *Journal of Environmental Quality*, Vol. 45, No. 5, 2016.
47. Gates, B., "Is There Enough Meat for Everyone?", *gatesnotes*, 21 April 2015, <https://www.gatesnotes.com/Books/Should-We-Eat-Meat>.
48. Mottet, A. et al., "Livestock: On our plates or eating at our table? A new analysis of the feed/food debate", *Global Food Security*, Vol. 14, September 2017, <http://dx.doi.org/10.1016/j.gfs.2017.01.001>.
49. Fresco, L., "Can Livestock Production Meet the Growing Demand for Meat in Developing Countries?", *The Borlaug Blog*, 23 October 2017, [https://www.worldfoodprize.org/index.cfm/88533/18099/can\\_livestock\\_production\\_meet\\_the\\_growing\\_demand\\_for\\_meat\\_in\\_developing\\_countries](https://www.worldfoodprize.org/index.cfm/88533/18099/can_livestock_production_meet_the_growing_demand_for_meat_in_developing_countries).
50. Enahoro, D., 2018, and authors, Unpublished calculations using data from FAO statistics; Herrero, M. et al., "Farming and the geography of nutrient production for human use: a transdisciplinary analysis", *The Lancet Planetary Health*, Vol. 1, No. 1, 2017, pp. e33-e42.
51. Parikh, S.J. and B.R. James, "Soil: The Foundation of Agriculture", *Nature Education Knowledge*, Vol. 3, No. 10, 2012, p. 2.
52. Herrero, M. et al., "Farming and the geography of nutrient production for human use: A transdisciplinary analysis", *The Lancet Planetary Health*, Vol. 1, No. 1, 2017, pp. e33-e42.
53. Delgado, C.L. et al., *Determinants and Implications of the Growing Scale of Livestock Farms in Four Fast-Growing Developing Countries*, Research Report 157, International Food Policy Research Institute, 2008.
54. Kristjanson, P. et al., "Livestock and Women's Livelihoods: A Review of the Recent Evidence", Discussion Paper No. 20, International Livestock Research Institute, 2010, <https://cgspace.cgiar.org/handle/10568/3017>.
55. Aronson, D., "In Tanzania, a better cow is the way to a better future", *ILRI News*, 8 August 2018, <https://news.ilri.org/2018/08/08/in-tanzania-a-more-productive-and-resilient-cow-is-the-way-to-a-better-future/>.
56. Food and Agriculture Organization of the United Nations, Regional Office for Latin America and the Caribbean, "Livestock production in Latin America and the Caribbean", (n.d.), [www.fao.org/americas/prioridades/produccion-pecuaria/en/](http://www.fao.org/americas/prioridades/produccion-pecuaria/en/).
57. Wijethilaka, D. et al., "Factors affecting sustainable dairy production: A case study from Uva Province of Sri Lanka", IOP Conference Series: *Earth and Environmental Science*, Vol. 157, 2018; Staal, S.J., "The competitiveness of smallholder dairy production: Evidence from sub-Saharan Africa, Asia and Latin America", in "Smallholder Dairy Production and Marketing-Opportunities and Constraints, Proceedings of a South-South Workshop", *ILRI Proceedings*, 2002, pp. 250-264.
58. Padhi, M.K., "Importance of Indigenous Breeds of Chicken for Rural Economy and Their Improvements for Higher Production Performance", *Scientifica*, Vol. 2016, Article ID 2604685, 2016; O'Connell, J., "Micro-dairies: small farmers fight back", *The Guardian*, 20 August 2014, [www.theguardian.com/lifeandstyle/2014/aug/20/micro-dairies-small-farmers-fight-back](http://www.theguardian.com/lifeandstyle/2014/aug/20/micro-dairies-small-farmers-fight-back); Mtimet, N., D. Baker, U. Pica-Ciamarra and J. Jagwe, "Consumer Preferences for Animal Source Foods in Uganda: Quality, Retail Forms and Retail Outlets", *International Journal on Food System Dynamics*, Vol. 4, No. 2, 2013, pp. 106-116; Jabbar, M.A., D. Baker and M.L. Fadiga (eds), *Demand for livestock products in developing countries with a focus on quality and safety attributes: Evidence from Asia and Africa*, International Livestock Research Institute, Research Report 24, 2010.

59. Thomassen, M.A. et al., "Life Cycle Assessment of Conventional and Organic Milk Production in the Netherlands", *Agricultural Systems*, Vol. 96, No. 1-3, 2008, pp. 95-107.
60. Capper, J.L., "Replacing rose-tinted spectacles with a high-powered microscope: The historical versus modern carbon footprint of animal agriculture", *Animal Frontiers*, Vol. 1, No. 1, July 2011, pp. 26-32.
61. Herrero, M. et al., "Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems", *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 110, No. 52, 24 December 2013, pp. 20888-20893.
62. McGahey, D., J. Davies and E. Barrow, "Pastoralism As Conservation in the Horn of Africa: Effective Policies for Conservation Outcomes in the Drylands of Eastern Africa", *Annals of Arid Zones*, Vol. 46, No. 3 & 4, 2007, pp. 353-377; Notenbaert, A. et al., "Policies in support of pastoralism and biodiversity in the heterogeneous drylands of East Africa", *Pastoralism: Research, Policy and Practice*, Vol. 2, No. 14, 2012; Norton-Griffiths, M. and M.Y. Said, "The Future for Wildlife on Kenya's Rangelands: An Economic Perspective", in du Toit, J., R. Kock and J.C. Deutsch (eds), *Wild Rangelands: Conserving Wildlife While Maintaining Livestock in Semi-Arid Ecosystems*, 2009, pp. 367-392.
63. Kasyoka, S., "Joint village land use planning secures over 95,000 hectares of grazing lands for livestock keepers in Tanzania's Kiteto District", International Livestock Research Institute, *Sustainable livestock systems* [blog], 2 November 2018, <https://livestocksystems.ilri.org/2018/11/02/joint-village-land-use-planning-secures-over-95000-hectares-of-grazing-lands-for-livestock-keepers-in-tanzanias-kiteto-district/>.
64. United States Department of Agriculture, Natural Resources Conservation Service, "Animal Feeding Operations: Animal Feeding Operations (AFO) and Concentrated Animal Feeding Operations (CAFO)", (n.d.), <https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/plantsanimals/livestock/afo/>.
65. Wilde, F.D., L.J. Britton, C.V. Miller and D.W. Kolpin, "Effects of Animal Feeding Operations on Water Resources and the Environment", *Proceedings of the technical meeting*, Fort Collins, Colorado, August 30-September 1, 1999, U.S. Geological Survey Open-File Report 00-204, 2000.
66. Faunalytics, "Factory Farming In Developing Countries: A Review", *Faunalytics*, 30 March 2017, [www.faunalytics.org/factory-farming-developing-countries-review](http://www.faunalytics.org/factory-farming-developing-countries-review).
67. Ngo, H., "Potential Dairy Industry in Vietnam – Case Study: Vinamilk LTD", Thesis, Centria University of Applied Sciences, 2018.
68. BBC News, "The challenges of chicken farming in Mozambique" [video report], 3 June 2016, <https://www.bbc.com/news/av/business-36444326/the-challenges-of-chicken-farming-in-mozambique>.
69. Clarey, B.R., "Concentrated Animal Feeding Operations: Hazards, Environmental and Health Risks as the Latent Products of Late Modernity", University of New Orleans Theses and Dissertations, 2012.
70. Cassidy, E.S., P.C. West, J.S. Gerber and J.A. Foley, "Redefining agricultural yields: from tonnes to people nourished per hectare", *Environmental Research Letters*, Vol. 8, No. 3, 1 August 2013.
71. Nigatu, G. and R. Seeley, "Growth in Meat Consumption for Developing and Emerging Economies Surpasses That for the Developed World", *Amber Waves*, United States Department of Agriculture, Economic Research Service, 6 July 2015, <https://www.ers.usda.gov/amber-waves/2015/july/growth-in-meat-consumption-for-developing-and-emerging-economies-surpasses-that-for-the-developed-world/>.
72. Vorley, B. and F. Lançon, "Food consumption, urbanisation and rural transformation: The trade dimensions", International Institute for Environment and Development, Working Paper, May 2016, <http://agritrop.cirad.fr/583130/1/10767IIED.pdf>.
73. Adewumi, O.O., O.A. Lawal-Adebowale and D.A. Adegbemile, "Rural farm families' probable acceptability of small ruminant's milk for consumption in Ogun State", *International Journal of Livestock Production*, Vol. 6, No. 7, July 2015, pp. 78-86.
74. Food and Agriculture Organization of the United Nations, data extracted from "Food Balance Sheets", (n.d.), <http://www.fao.org/faostat/en/#data/FBS>.
75. Livingstone, E., "How EU milk is sinking Africa's farmers", *Politico*, 18 April 2018, <https://www.politico.eu/article/eus-milk-scramble-for-africa/>.
76. Diakonisches Werk der EKD e.V. for "Brot für die Welt" and Evangelischer Entwicklungsdienst (EED), "Milk Dumping in Cameroon: Milk powder from the EU is affecting sales and endangering the livelihoods of dairy farmers in Cameroon", October 2009, [https://www.brot-fuer-die-welt.de/fileadmin/mediapool/2\\_Downloads/Fachinformationen/Aktuell/Aktuell\\_02\\_englisch.pdf](https://www.brot-fuer-die-welt.de/fileadmin/mediapool/2_Downloads/Fachinformationen/Aktuell/Aktuell_02_englisch.pdf).
77. Caro, D., S.J. Davis, S. Bastianoni and K. Caldeira, "Global and Regional Trends in Greenhouse Gas Emissions from Livestock", *Climatic Change*, Vol. 126, July 2014, pp. 203-216.

78. Food and Agriculture Organization of the United Nations and World Food Programme, *The State of Food Insecurity in the World: Addressing food insecurity in protracted crises*, 2010, <http://www.fao.org/3/a-i1683e.pdf>.
79. Schönfeldt, H.C. and N. Gibson Hall, "Dietary protein quality and malnutrition in Africa", *British Journal of Nutrition*, Vol. 108, Supplement 2, August 2012, pp. S69-S76.
80. Raheem, D. et al., "Traditional consumption of and rearing edible insects in Africa, Asia and Europe", *Critical Reviews in Food Science and Nutrition*, 15 March 2018, <https://www.tandfonline.com/doi/full/10.1080/10408398.2018.1440191>.
81. van Huis, A. et al., *Edible insects: Future prospects for food and feed security*, Food and Agriculture Organization of the United Nations Forestry Paper No. 171, FAO, 2013.
82. Dobermann, D., J.A. Swift and L.M. Field, "Opportunities and hurdles of edible insects for food and feed", *Nutrition Bulletin*, Vol. 42, No. 4, December 2017, pp. 293-308.
83. Haspel, T., "Lab-grown meat and the fight over what it can be called, explained", *Vox.com*, 31 August 2018, <https://www.vox.com/2018/8/30/17799874/lab-grown-meat-memphis-just-animal-cell>.
84. Delgado, C. et al., "Livestock to 2020: The Next Food Revolution", Food, Agriculture, and the Environment Discussion Paper 28, *Outlook on Agriculture*, Vol. 30, No. 1, 2001, pp. 27-29.
85. Nilsson, M., D. Griggs and M. Visbeck, "Map the interactions between Sustainable Development Goals", *Nature*, Vol. 534, 16 June 2016, pp. 320-322.
86. Shapiro, B., "Ethiopia Livestock Plan Offers Route to Middle-Income", *Financial Times*, 2017, <https://www.ft.com/content/796e4fe4-6554-11e7-9a66-93fb352ba1fe>.
87. Mellor, J.W., *Agricultural Development and Economic Transformation: Promoting Growth with Poverty Reduction*, 2017.
88. Kawuma, B., "Maziwa Zaidi policy forum promotes inclusive investment in Tanzania's dairy sector", *CGIAR Research Program on Livestock* [blog], 1 June 2017, <https://livestock.cgiar.org/2017/06/01/maziwa-zaidi-policy-forum/>.
89. Kawuma, B. and E.A. Ouma, "Multi-stakeholder platforms for smallholder pig value chain development in Uganda", Research Brief, International Livestock Research Institute, June 2016, [https://www.researchgate.net/publication/318596691\\_Multi-stakeholder\\_platforms\\_for\\_smallholder\\_pig\\_value\\_chain\\_development\\_in\\_Uganda](https://www.researchgate.net/publication/318596691_Multi-stakeholder_platforms_for_smallholder_pig_value_chain_development_in_Uganda).
90. For more information, see the Global Agenda for Sustainable Livestock, <http://www.livestockdialogue.org/>.
91. Pikaar, I. et al., "Decoupling livestock from land use through industrial feed production pathways", *Environmental Science & Technology*, Vol. 52, No. 13, 2018, pp. 7351-7359.
92. Walsh, B.J. et al., "New feed sources key to ambitious climate targets", *Carbon Balance and Management*, Vol. 10, No. 26, 2015.
93. Le Borgne, E., "New factories in Nigeria transform cassava peels into livestock feed, creating jobs and incomes for women", *ILRI news* [blog], 23 August 2017, <https://news.ilri.org/2017/08/23/ifad-cassava-processing-site-visit/>.
94. Blümmel, M. et al., "Ammonia Fiber Expansion (AFEX) as spin off technology from 2nd generation biofuel for upgrading cereal straws and stovers for livestock feed", *Animal Feed Science and Technology*, Vol. 236, 2018, pp. 178-186.
95. Okeyo, A.M. et al., "Herd recording and farmer education using digital platforms are feasible and can be transformative in Africa", presented at the Mid-Term Livestock Genetics Flagship Meeting, ILRI, Nairobi, 5-6 September 2017, <https://cgspace.cgiar.org/handle/10568/89115>.



---

**COMMITTED TO  
IMPROVING THE STATE  
OF THE WORLD**

---

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

---

World Economic Forum  
91–93 route de la Capite  
CH-1223 Cologny/Geneva  
Switzerland

Tel.: +41 (0) 22 869 1212  
Fax: +41 (0) 22 786 2744

[contact@weforum.org](mailto:contact@weforum.org)  
[www.weforum.org](http://www.weforum.org)