Global Food Systems: An Outlook to 2050

IARAN

Summary

The global food system is central to ending world hunger, yet there is no common vision on the direction it should evolve. This report explores possible routes to a global food system that is capable of feeding the world's population in 2050. Exploring different visions for how this could be achieved allows us to more clearly examine the pros and cons of each potential avenue. Doing so is intended as a first step towards creating a vision for the kind of change that organizations fighting hunger want to see in the global food system.

This report is distinct from others on the subject in its use of normative scenarios that describe preferred futures, rather than possible futures. Each scenario is based on a different school of thought among leading actors who shape the global food system. Some actors assume development should continue along its current course, with food production boosted by expanding industrial agriculture. Others are calling for a shift towards pro-poor, climate-smart solutions. Still, others argue that the problems with the global food system are demand driven. Some are counting on new technologies to save the day. The scenarios based on these different visions are not intended to predict how the future will look. The future will likely include some elements of each.

The normative approach of this report is potentially contentious. Those who support one vision may object to the others. However, it is important to be aware of the different perspectives that are currently shaping the issue, along with the opportunities and threats that each may pose.

The scenarios are set in the year 2050 and describe what the global food system looks like under the vision in question, and what changes have occurred to reach this situation. Each scenario also discusses the implications, for better and worse, that have resulted from these changes. The scenarios are intended to assist organizations in defining their visions for the future of the global food system. From there, they can develop strategies on how their actions can help make their vision a reality. It is important to note that this report is not advocating for any one scenario and does not reflect the position of Action Against Hunger.

Scenario 1: The Production-based Vision. Increased agricultural production by expanding industrial agricultural systems in low-income countries.

- Opportunities: increased agricultural productivity in low-income countries, economic diversification and breaking rural poverty traps.
- Threats: increased economic inequality, loss of agricultural livelihoods, worsening obesity epidemic and micronutrient deficiencies and perpetuating the cycle of environmental degradation and climate change.

Scenario 2: The Consumption-based Vision. Reduced consumption by changing consumer behavior in high- and middle-income countries, including reducing food waste and the consumption of resource intensive foods (such as animal products).

- Opportunities: greater slack in the agriculture market, improved health conditions and consumer savings.
- Threats: fails to address economic inequality, loss of livelihoods for those producing livestock and resource intensive foods.

Scenario 3: The Regenerative-based Vision. Transformation of the global food system to one that is not just sustainable but also regenerative, including the creation of a circular economy and adoption of agroecology.

- Opportunities: addresses economic drivers of hunger, improved health and environmental outcomes.
- Threats: risk of increased food prices, some regions may still struggle, resistance from existing power structure.

Scenario 4: The Innovation-based Vision. A new agriculture revolution through biotechnology where farming is superseded by microbial synthesis.

- Opportunities: abundant food eliminates poverty as a driver of hunger, halts environmental degradation and climate change, economic diversification in low-income countries.
- Threats: Loss of agricultural livelihoods for over a quarter of the world's population, unprecedented rural-to-urban migrations, risk of deepening economic inequality and obesity epidemic.

Introduction

This report was commissioned by Action Against Hunger UK, to explore possible routes to an inclusive food system that can feed the world's population in 2050. Exploring the different visions of how this could be achieved allows decision-makers to examine the pros and cons of each potential avenue. This report is intended as a first step towards creating a vision for the kind of change that humanitarian organizations want to see in the global food system, and to contribute to the development of positions and messaging on the issue.

The global food system is central to ending world hunger, yet there is no common vision on the direction it should go. There are a range of solutions being proposed. Many assume development should continue along its current course with food production boosted by expanding industrial agriculture. However, a growing chorus of voices (including many in UN agencies and NGOs) are calling for a shift towards sustainable, pro-poor, climate-smart solutions. Others argue that the problems with the global food system are demand, rather than supply, driven. Still others are counting on new technological revolutions to save the day. Some of these visions of how the global food system should evolve reinforce each other, while others are mutually exclusive. None is a panacea. Each will have winners and losers. For organizations seeking to end hunger, they must decide on how they can help shape the global food system to achieve this goal. **This report is intended to assist organizations in defining their visions for the future of the global food system. From there, they can develop strategies on how their actions can help make their vision a reality and set clearly defined objectives to guide their progress.**

Several other scenario analyses currently exist on the future of the global food system.[1] They are based on **exploratory scenarios** that describe possible futures extrapolated from current trends. This report is distinct in that it describes four **normative scenarios**. Each is based on a future that is desirable to some of the leading actors who shape the global food system. This report examines what changes would need to occur to get from the present, to these different visions of the future. Each of the scenarios is based on a school of thought on how to end world hunger. They are set in the year 2050 and describe what the global food system looks like and what implications, for better and worse, have resulted from these changes. This normative approach, although potentially contentious, is useful to assist policy makers in determining how they want to approach the fight against hunger, from selecting goals to developing long-term strategies to obtain them. In making this decision, it is important to understand the different perspectives that exist and what potential benefits and consequences each would hold. This report does not advocate for any particular scenario and does not reflect the position of Action Against Hunger.

1. See: World Economic Forum. 2017. Shaping the Future of Global Food Systems: A Scenarios Analysis; Paillard, S., Treyer, S. and Dorin, B. eds., 2014. Agrimonde–scenarios and challenges for feeding the world in 2050. Springer Science & Business Media. Carpenter, S.R., Pingali, P.L., Bennett, E.M. and Zurek, M.B., 2005. Ecosystems and human well-being: Scenarios, Volume 2.

Food Systems

A food system is a holistic concept that describes all the elements, activities, and institutions that are required to feed people, and their related consequences.[2] At the center is the supply chain that food passes through: agricultural production, handling and storage, processing and packaging, distribution and market, and consumption. [3] The food system also encompasses how this supply chain impacts, and is impacted by, people and the environment.

so will require concerted effort and new challenges like climate change, which will have to be overcome. In addition, several trends are helping to slow the increase in the rate of demand. Population growth, the leading driver, is beginning to slow, and there is expected to be slowly declining per capita consumption rates in high and low-income countries in coming years.[8]

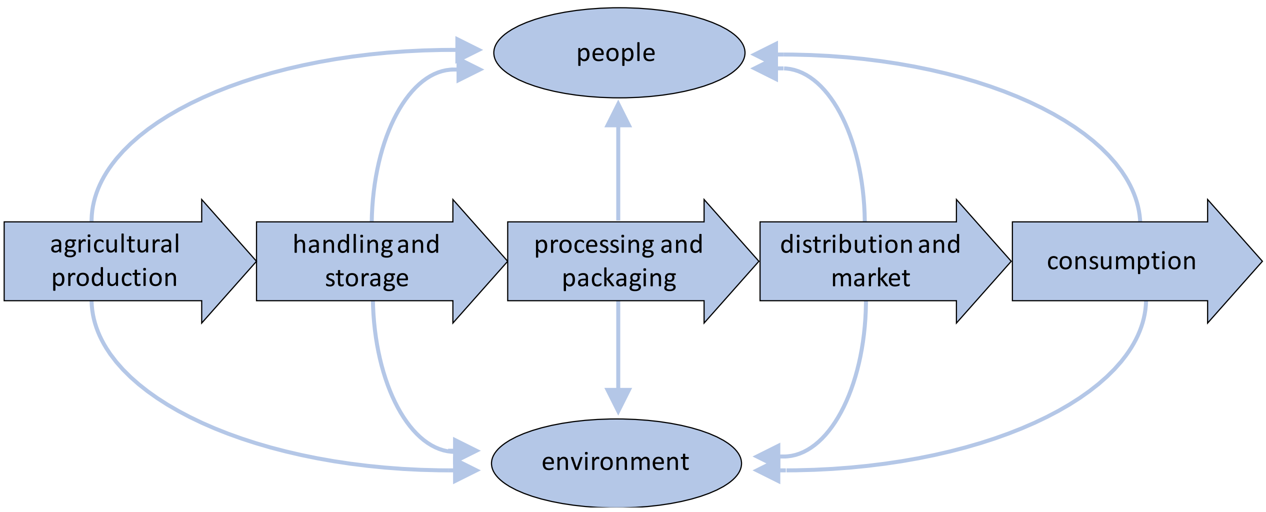


Figure 1. Conceptual representation of a food system.

The global food system is not actually one single food system, but all of the food systems around the world put together. Many food systems are interconnected as markets have grown increasingly integrated and global, while others are independent or have only a limited number of connections to others. For instance, while most of the UK relies on international food systems with half of its food imported from 160 countries, subsistence farmers in sub-Saharan Africa produce and consume most of their food locally. So, when speaking of the global food system, we must do so in generalization of the main trends with the understanding that there with will be a degree of contextual variation.

In the coming years, there will be an increased demand for food, as the global population will continue to expand and because individual consumption rates are anticipated to rise, on average, as more people are lifted out of poverty. Global per capita food consumption is expected to rise by 210 calories per day, from 2,860 in 2015 to 3,070 in 2050[4]. Additionally, the global population was 7.4 billion in 2015 and is projected to be over 9.7 billion in 2050.[5] The UN Food and Agriculture Organization (FAO) estimates that agricultural production will need to increase by about 50% by 2050 to keep pace with rising demand.[6] Such projections appear alarming. However, for decades we have met even higher food production growth requirements. The world continues to produce enough food to feed everyone and is expected to continue to do so through 2050,[7] although doing

So, if we produce enough food to feed everyone, why do people go hungry? Poverty and conflict are widely regarded as the two leading causes of hunger. Poverty results in people not having access to food even if it is otherwise available. Conflict impacts the availability of food as it disrupts food systems by preventing people from farming, distributing, and retailing food. In extreme cases, governments or non-state armed groups use hunger as a weapon of war by deliberately making food unavailable. Conflict also impacts access to food when displaced people and conflict-affected communities lose their livelihoods and sink into poverty. In addition to poverty and conflict, other issues that contribute to hunger include: lack of agriculture investment, price volatility, food loss and waste, and increasingly the effects of environmental change.[9] Such drivers of hunger can often form vicious cycles, compounding each other as conditions deteriorate. The following report is not an analysis of the causes of hunger,[10] instead it explores visions of future where the global food system, including production and other factors, is capable of feeding everyone.

A food system is a holistic concept that describes all the elements, activities, and institutions that are required to feed people, and their related consequences.

2 . FAO. 2014. Food losses and waste in the context of sustainable food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security.
3. Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. and Searchinger, T., 2013. Installment 2 of "creating a sustainable food future" reducing food loss and waste. World Resources Institute, United Nations Environment Programme: Washington, DC.
4. Alexandratos, N. and Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision (Vol. 12, No. 3). ESA Working paper.
5. UN Population Division. 2018. World population prospects 2017.

6. FAO. 2017. The future of food and agriculture: trends and challenges.
7. Wise, T.A., 2013. Can we feed the world in 2050: A scoping paper to assess the evidence. Global Development and Environment Institute Working Paper, 13-04.
8. OECD/FAO. 2016. OECD-FAO agricultural outlook 2016-2025.
9. WFP. 2013. Stories: what causes hunger?
10. For a more detailed discussion on the drivers of hunger see: IARAN. 2017. An outlook on hunger: a scenario analysis on the drivers of hunger through 2030.

Figure 2. Per capita food consumption (kcal/person/day) [11]

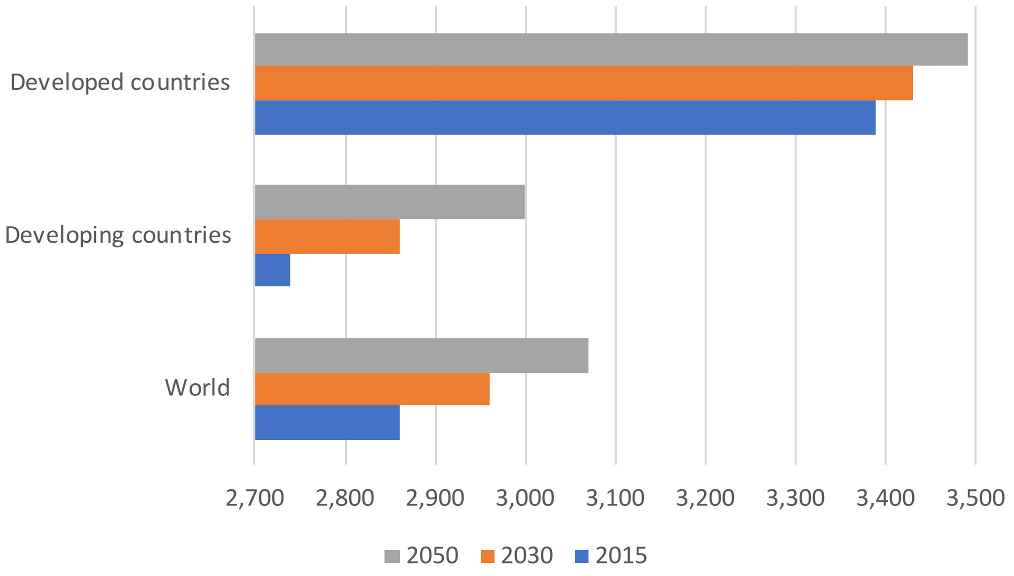


Table 1. Population growth estimates by region, 2015-2050 (medium variant). [12]

	Populations (millions)				% change from 2015			Net increase from 2015 (millions)		
	2015	2030	2040	2050	2030	2040	2050	2030	2040	2050
World	7383	8551	9210	9772	16%	25%	32%	1168	1827	2389
Africa	1194	1704	2100	2528	43%	76%	112%	509	906	1333
Asia	4420	4947	5154	5257	12%	17%	19%	527	735	837
Europe	741	739	729	716	0%	-2%	-3%	-1	-12	-25
Latin America	632	718	757	780	14%	20%	23%	86	125	147
Northern America	356	395	417	435	11%	17%	22%	39	61	79
Oceania	40	48	53	57	21%	33%	44%	8	13	18

11. Alexandratos, N. and Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision (Vol. 12, No. 3). ESA Working paper.
12. UN Population Division. 2018. World Population Prospects 2017.

Methodology

The scenarios presented in this report were developed using IARAN's scenario analysis toolkit. The analysis was specific to the global food system with an outlook from 2019, through 2050. The following are the analytical steps used in the report. For a more detailed description, see the annex.

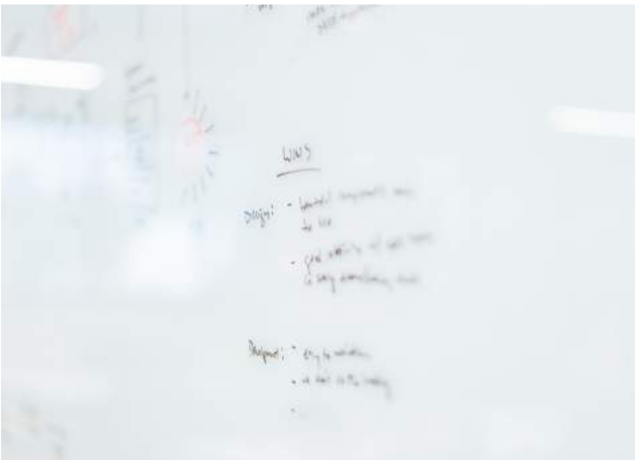
1. **System Architecture** – A schematic representation of the factors central to the issue. Used to compile the factors to include in the analysis while mitigating cognitive bias.

2. **Factor-Factor Matrix** – A network analysis of the direct influence of the factors on one another. Used to classify factors by their level of influence and dependence and identify those most central to the system.

3. **Hypotheses Matrix** – A tool for developing scenarios based on combinations of potential outcomes of the most influential factors in the system.

4. **Scenarios** – Narrative descriptions of probable futures based on the results from the analytical process. Used as the basis for developing strategic options.

The analysis identified five key drivers of change that will shape the future of the global food system: existing technologies, new technologies, loss and waste, production systems and dietary patterns. A back casting exercise was used to determine what would have to happen to each of these drivers to get from the present to the normative futures addressed in the different scenarios.



Scenario 1 – The Production-based Vision

The first scenario envisions reducing hunger by increasing agricultural production through the expansion of industrial agricultural systems in low-income countries.

Today, in the year 2050, there are over 9.7 billion people in the world, with net population growth over the past half century in Asia and Africa.[13] Populations are highly urban now, with these two regions also seeing the most urbanization in recent decades. There are also far fewer people living in extreme poverty. With the increased food accessibility that comes with less poverty, per person kilocalorie consumption has grown by 3% in high-income countries, and 9.5% in low-income countries since 2015.[14] As a consequence, total demand for food has grown with today's larger and wealthier populace.

Agricultural production has been able to keep pace with increasing demand by growing at a steady rate of around 2% per year,[15] which has kept food prices low for decades. In order to achieve this, the use of industrial agriculture has expanded and become more efficient. Industrial farming systems continue to supplant traditional systems, particularly throughout Eastern Europe, Latin America, South Asia, and sub-Saharan Africa. The industrial production system is based on increasing production through capital inputs, such as mechanization, irrigation, high-yield seed varieties, and artificial fertilizers and pesticides. The amount of agricultural land has expanded to a small extent through land-use conversion,[16] with most of this occurring in high latitudes as the boreal zone thaws from climate change. Most production increases have instead been attained by closing yield gaps (the difference in potential and actual yields), with the most noticeable improvements being in sub-Saharan Africa. Additionally, improvements in technology and practices have also increased total factor productivity (TFP), meaning that farmers are able to produce more, with the same amount of inputs.

Keeping the world fed comes with costs. The environmental consequences are great. Industrial agriculture relies on the heavy use of external inputs, like chemical fertilizers and pesticides, which can pollute the land and water and decrease biodiversity. This production system can also lead to soil degradation through tilling and the use of external inputs, which lead to erosion, damage to soil structure, and the killing off of beneficial microbes. There are some improvements being made to help reduce the impact, such as the growth in precision agriculture, which makes use of remote sensing and GPS to more efficiently use inputs and reduce pollution. Yet, the environmental costs are taking a toll on the world. Land degradation and climate change are threatening future gains in net agricultural production, while already some of the increased production must go to covering the losses from these environmental changes. It is becoming a vicious cycle ,where production leads to environmental costs that cut into production, so production is further increased along with the environmental costs, and so on until the system risks collapsing.

There are also social costs to the reliance on industrialized agriculture. Earlier in the century, large-scale farms were concentrated in high- and upper-middle-income countries, with most agricultural land represented in farms of dozens to hundreds of hectares. In low-income countries, most farmland was only a few hectares.[17] Today, large-scale operations are continuing to move into low-income countries, replacing smallholder production. In some instances, smallholders are willing to sell their land and move to the city. In other instances, the government has pushed out the local population to allow for this agricultural transition. Foreign companies are often the ones buying up the land, which only increases public opposition and distrust. Such instances have led to a number of political, and sometimes violent, crises.

This agricultural transformation has contributed to an overall structural transformation in many countries, where the shift from subsistence to commercial agriculture is mirrored by an overall shift from producing primary products to manufacturing and service industries.[18] The proportion of urban populations in low-income countries is now at 65%, a 35 percentage point increase since 2015 and surpassing earlier expectations.[19] Urban growth is the result of reduced labor inputs required in the agricultural sector, while rural workers are lured to cities by better paying jobs in the manufacturing and service industries. The rapid rural-to-urban migration in low-income countries is straining already fragile urban infrastructure systems. Expanded slums surround most major cities. Despite these challenges, there are also positive outcomes. Low-income countries are seeing far more economic innovation and diversification. As less of the population is required to produce food, their labor is employed in alternative industries. The manufacturing and information technology sectors are showing strong growth.

The changes in agricultural production and urbanization also affects how food is distributed. The supply chain is increasingly centralized in low-income countries. Each stage is dominated by large-scale agribusinesses, from production, to processing, to distribution, to retail. The transition has come with growth in infrastructure, from roads to electrification, that has many other additional benefits to local economies and quality of life. The operations provide new employment opportunities that did not exist before. However, many small operations have been put out of business.

Today, in the year 2050, there are over 9.7 billion people in the world, with net population growth over the past half century in Asia and Africa.[13]

13. UN DESA. 2017. World population prospects: the 2017 revision, key findings and advance tables.
14. Alexandratos, N. and Bruinsma, J., 2012. World agriculture towards 2030/2050: the 2012 revision (Vol. 12, No. 3). ESA Working paper.
15. Foresight. 2011. Foresight: the future of food and farming, final project report. The Government Office for Science, London.

16. Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A., Heimlich, R., Boval, M., Chemineau, P. and Dumas, P., 2014. Creating a sustainable food future. a menu of solutions to sustainably feed more than 9 billion people by 2050. World resources report 2013-14: interim findings.
17. Lowder, S.K., Skoet, J. and Raney, T., 2016. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. World Development, 87, pp.16-29. Figure 5.
18. FAO, IFAD, IMO, and WFP. 2018. The Linkages between Migration, Agriculture, Food Security and Rural Development.

Most of the world's poor, now living in cities, have access to a much wider variety of foods than in decades past. Cold chain infrastructure increases the diversity of available produce, meat and dairy products, while also reducing health risks. However, the most accessible and often preferred foods are also the least healthy. The global dietary convergence sees people in low-income countries starting to consume more processed foods (e.g. sugar, oil and animal products). Consequently, obesity and related non-communicable diseases (NCDs) like diabetes and heart disease are on the rise. Often these health issues coexist with undernutrition in the same population, household or even individual, in what is known as the double burden of malnutrition. Many of the countries that are known for high rates of malnutrition are now showing high rates of these NCDs.[20]

While consumers are seeing greater diversity, and greater obesity, agricultural diversity around the world has declined. More farms are taking the form of large-scale monocultures producing only a few varieties of crops, replacing small farms that had greater crop variety and used local varietals. As a result, the global food system is becoming less resilient, especially to agricultural disease.

There have been no significant net changes in global food loss and waste, as decreases in food loss have been offset by increases in food waste. In high- and middle-income countries, food loss and waste rates have remained consistent on a per capita basis, with around one third of agricultural production not being consumed. However, with more people now living in high- and middle-income countries, there is an increase net impact. Retail and marketing pressure continue to promote food waste in the retail and consumer areas of the food system, through overabundance (such as serving sizes being more than people can consume in a sitting) or by overstocking markets so that the goods expire on the shelves. The use of "sell by" dates also continues to promote food being disposed of before it is actually unsafe to consume. Consumer attitudes are also still a problem, from not buying "ugly" food to, buying more than can be consumed before it expires.[21]

In low-income countries, food loss rates have fallen from around 20% to 10% in the past half century. Food waste rates remain low as economic constraints continue to encourage more prudent management of household resources. Food loss rates have declined considerably as the food system has modernized. Food is kept or made edible by increases in: market access, processing capacity and access, transportation and cold chain infrastructure, and safety standards[22] Additionally, the transition from smallholder to industrial agriculture has reduced loss from premature harvesting by smallholders when confronted with the immediate need for food or money.[23]

Agricultural production is increasing enough to meet the growth in demand and keep prices low. The interconnectivity of the global food system also helps to mitigate local shocks. Yet the foundations of the global food system appear to be unsustainable. More of the world's population is suffering the effects of obesity. Environmental change is threating global production levels. The global food system is still able to meet the world's needs, but unless some of these structural issues are addressed, it is unclear for how much longer.

Opportunities in this scenario:

- Economic disruption could break rural poverty trap.
- Low-income countries increase agricultural productivity and economic diversification.

Threats in this scenario:

- Economic inequality.
- Small-scale producers lose livelihoods and/or are displaced.
- Global populations increasingly suffer from obesity and related health issues.
- Micronutrient deficiencies persists from production of nutrient poor foods.
- Environmental degradation and increase in climate change.

Indicators of this trend becoming reality:

- Little or no change in business-as-usual.
- Examples of agribusiness moving into low-income countries, foreign land grabs.

Barriers in this scenario becoming reality:

- Public opposition industrial agricultural practices and products.
- Protectionist trade policies.
- Spike in fuel prices.

Resilience of this global food system:

- Decreased: more centralized, lower crop diversity, and worsening effects of environmental change.

Role of NGOs in this in this scenario:

- Crisis response to system shocks.
- Support for the poor, particularly in newly expanded slums.
- Nutritional education and advocacy.
- Support for accountable governance and land rights.

19. FAO. 2017. The future of food and agriculture – trends and challenges.
20. Ford, N.D., Patel, S.A. and Narayan, K.V., 2017. Obesity in low-and middle-income countries: burden, drivers, and emerging challenges. Annual review of public health, 38, pp.145-164.
21. FAO. 2011. Global food losses and food waste: extent, causes and prevention.
22. Ibid.
23. Ibid.

Scenario 2 – The Consumption-based Vision

The second scenario envisions reducing hunger by reducing consumption through changes in consumer behavior in high- and middle-income countries.

As a result of responsible consumer behavior, the global food system is feeding the world without a large increase in production. For decades, there has been a global food surplus, but in the past that surplus was squandered by the wealthy on waste, over consumption, and producing resource intensive foods. The first change that led towards the current situation entailed cutting consumer waste. In the 2010s, North American consumers were wasting 12.6% of their edible food: nearly ten times that of the 1.3% waste in sub-Saharan Africa.[24] In North America, this equated to 150kg per person per year compared to 7kg in sub-Saharan Africa, over sixteen times greater because the former was also consuming more per person. Such large amounts of preventable waste, alongside health considerations related to overconsumption and dietary choices, galvanized policies and initiatives to support change. Recent years have seen considerable changes in consumer habits in high-income countries.

With great effort, the world met the first part of Sustainable Development Goal target 12.3, cutting retail and consumer food waste in half. Unfortunately, efforts to meet the second part of the target, reducing food losses in production and supply chains, were far less successful due to a lack of investment and will on part of industry and government. In low-income countries, the target of halving food waste was much easier to meet because these figures were so low already. Few changes in consumer behavior were needed, and the improvements came more from structural changes such as access to electricity and refrigeration. Halving the food waste in middle- and high-income countries reduced total global food loss and waste by about 15% as compared to decades past.[25] While this may not seem like much, it is equal to nearly half of all the food produced in sub-Saharan Africa.[26]

The second major change was in reducing resource intensive food production, such as animal products. Greater awareness and civic mindfulness led consumers to re-evaluate how their eating habits affect the rest of the world, as well as their own health. Animal-based foods, such as meat, eggs and dairy, are important nutrient sources, and deficiencies in these nutrients can contribute to malnutrition (particularly among children).[27] However, animal-based foods are also far less efficient in terms of resource inputs than plant-based nutrient sources. In feedlot systems, it requires 7kg of grain to produce 1kg beef; for pork this ratio is 4:1, chicken 2:1, and farmed fish less than 2:1.[28,29] In previous decades, resources that could go to producing crops for human consumption were used instead to produce animal feed; the world thus lost a great deal of potential food that could have gone towards feeding the expanding population and those who remained hungry. However, livestock are also capable of eating things that people cannot, such as grasses. When they do so, they turn otherwise agriculturally unutilized resources into food. Livestock are therefore very important food sources in rangelands and other areas that are not suitable for crop cultivation. They are also a very useful part of integrated farming systems, such as those practiced by small-scale producers. The world has more food available today in part, because people transitioned away from resource intensive animal-based foods, while not giving up all animal-based foods.

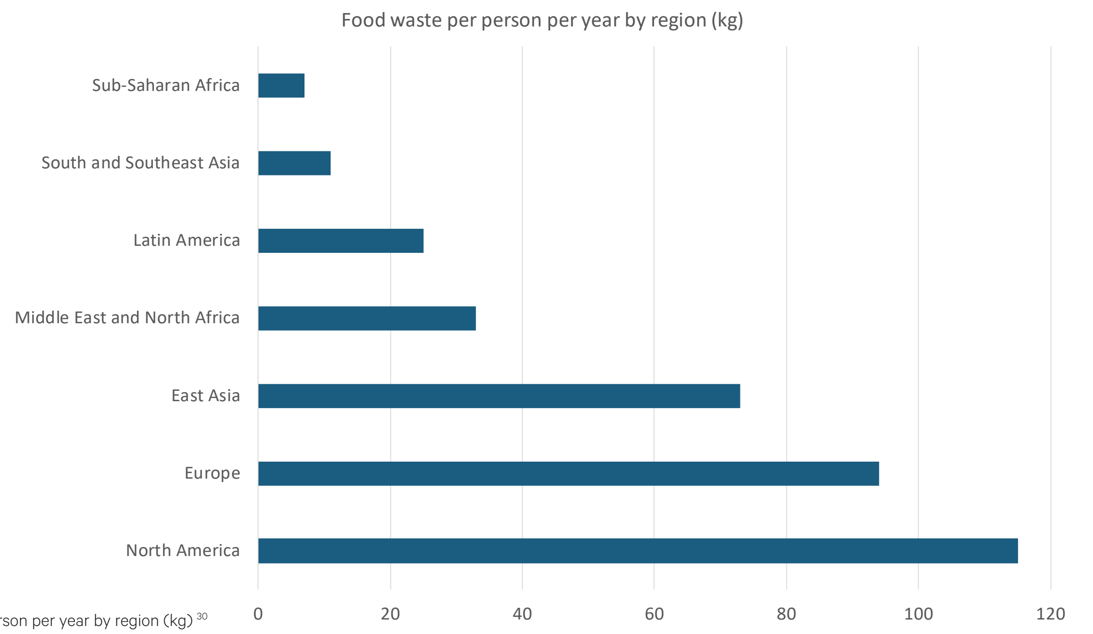


Figure 3. Food waste per person per year by region (kg) [30]

24. Timmermans, A.J.M., Ambuko, J., Belik, W. and Huang, J., 2014. Food losses and waste in the context of sustainable food systems (No. 8). CFS Committee on World Food Security HLPE.
25. Lipinski, B., Hanson, C., Lomax, J., Kitinoja, L., Waite, R. and Searchinger, T., 2013. Installment 2 of "Creating a sustainable food future" reducing food loss and waste. World Resources Institute, United Nations Environment Programme: Washington, DC. Page 8.
26. FAO. n.d. Key facts on food loss and waste you should know!
27. Headey, Derek D.; Hirvonen, Kalle; and Hoddinott, John F. 2017. Animal sourced foods and child stunting. IFPRI Discussion Paper, 1695.
28. Lester, B.R., 2006. Plan B 2.0: rescuing a planet under stress and a civilization in trouble. Earth Policy Institute.
29. There is some new research that challenges these widely cited figures, arguing that the portions of the grain weight are not edible to humans and so the conversion rates are 2.8:1 for ruminants and 3.2:1 for monogastric animals. See: Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C. and Gerber, P., 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. Global Food Security, 14, pp.1-8.
30. Timmermans, A.J.M., Ambuko, J., Belik, W. and Huang, J., 2014. Food losses and waste in the context of sustainable food systems (No. 8). CFS Committee on World Food Security HLPE.

Consumption patterns for animal-based foods have been changing for decades. In high-income countries, total meat consumption per person has been declining since the 2010s , as people have increasingly eaten more fruits, vegetables and legumes.[31] In addition, the meat people do eat is healthier and more resource efficient. For example, beef consumption has been declining since the 1970s, replaced mostly by chicken.[32] More recent years have also seen a rapid growth in fish, because it is more resource efficient and because improved aquaculture production has made it more affordable. Emerging economies saw rapid growth in animal-based food consumption beginning in the 1980s and 1990s.[33] These rates have long since stabilized and several have even declined more recently, for similar reasons as in high-income countries. Additionally, as the demand for meat expanded along with total food demands, prices for meat rose. In low-income countries, per capita consumption of animal-based foods remains low but is an important source of nutrients. Most of the animal-based foods consumed are resource efficient, because they are produced on rangelands as part of an integrated agricultural system. However, the rapid population growth in these countries has led to a larger net consumption rate. The reductions made by consumers in high-income countries have offset these gains and prevented malnutrition among many of the world's poor.[34]

The third major change was the reduction in overconsumption. Earlier in the century, people in many high-income countries were consuming on average 50% more calories than were needed to maintain a healthy life. At the same time, nearly a billion people did not have enough to eat. Such inequality harmed both sides, either from undernutrition or over-nutrition. The rapid shift towards a "Western" diet of processed foods high in sugar and saturated fat resulted in nearly two billion overweight adults, more than a quarter of whom were obese. At the time, this was commonly referred to as the "nutrition transition." Many believed that this was the inevitable end stage of increased wealth and consumer choice. However, the nutrition transition has proven to be a larger process of social development over time and space, similar to the interrelated concept of demographic transition. Fortunately, the nutrition transition does not end with humanity eating itself to death. The pattern characterized by this "Western" diet and obesity is the fourth of five patterns as described in the following table.

Table 2. Description of the nutrition transition..[35]

Pattern	Name	Society type	Examples (2018)	Diet	Nutrient deficiencies	Activity	Obesity
1	Food gathering	Hunter- gatherers	Isolated tribes	Diverse foods from plants and animals	↓	↑	↓
2	Famine	Early agricultural	Sub-Saharan Africa	Dependent on staple crops	↑	↑	↓
3	Reducing famine	Late agricultural	Latin America	Increase in fruit, vegetable and animal products	→	→	→
4	Degenerative diseases	Industrial	North America	Transition to foods high in fat, sugar and refined carbohydrates	↓	↓	↑
5	Behavioural change	Post industrial	Japan, Sweden	Transition to a healthy diet	↓	→	↓

31. Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A., Heimlich, R., Boval, M., Chemineau, P. and Dumas, P., 2014. Creating a sustainable food future. A menu of solutions to sustainably feed more than 9 billion people by 2050. World resources report 2013-14: interim findings.
32. Darbandi, E. and Saghaian, S., 2018. Beef consumption reduction and climate change mitigation. International Journal of Food and Agricultural Economics, 6(2), pp.49-61.
33. Data from FAOSTAT.
34. Searchinger, T., Hanson, C., Ranganathan, J., Lipinski, B., Waite, R., Winterbottom, R., Dinshaw, A., Heimlich, R., Boval, M., Chemineau, P. and Dumas, P., 2014. Creating a sustainable food future. A menu of solutions to sustainably feed more than 9 billion people by 2050. World resources report 2013-14: interim findings.
35. Popkin, B.M., 2006. Global nutrition dynamics: the world is shifting rapidly toward a diet linked with noncommunicable diseases–. The American journal of clinical nutrition, 84(2), pp.289-298.

So, while there was great concern over the ill-effects of populations moving from pattern three to four, it was often overlooked in previous decades that other populations had moved from pattern four to five. For example, it was feared that as Asian populations got wealthier, they would adopt the unhealthy diet and lifestyle of Westerners and suffer the same health consequences. Yet at the time, it was largely the poorer segment of the Western population (particularly American) that was still in pattern four, while the more affluent had begun to adopt the healthier pattern five. As researchers and policy makers learned more about the nutrition transition, efforts were made to assist the rest of the world from falling into the same trap of obesity that Western countries had fallen into. Through concerted nutritional campaigning alongside economic assistance, social safety nets and progressive food policies, other segments of the world's population have been able to reduce the time they spend in pattern four or skip it entirely, moving directly from pattern three to five. While a large share of the world still lives in stages two and three, development programs are better positioned today to assist them through this transition when it occurs. The result is that the world is consuming far less than had previously been projected and feared. With less being consumed by the wealthy, there is more available for the poor.

Changing consumer and business behavior was challenging. Doing so required a long campaign to educate the public and encourage the desired change. National governments and civil society proved successful in the end. In some instances, realizing change required incentive systems to discourage certain practices. Several nations sought to economically incentivize behavioral changes through taxation, in the form of full cost accounting. This is where food is taxed for the indirect costs its production and distribution have on the environment and society. Increasing the cost of less healthy and more resource intensive foods proved very successful in changing consumer behavior,[36] similar as had previously been achieved in reducing tobacco consumption. This approach was never intended to eliminate certain foods altogether, but to make them infrequent treats rather than daily staples. Food prices in most wealthier nations now include the indirect costs associated with their life cycle, such as their environmental, social and health impacts. Policies are designed to maintain an incentive system that discourages foods which contribute negatively to the global food system, and human wellbeing.

The world can feed everyone without having had to increase production.[37] While not easy to achieve, it was done by reducing waste, overconsumption and the consumption of particularly resource intensive foods. This has prevented a decrease in the availability of food and prevented overall increases in price. The world's population is now healthier than in decades past. However, without reforming other aspects of the food system many of its negative outcomes remain, such as poverty, inequality, inefficient production, environmental degradation and climate change.

36. Andreyeva, T., M. W. Long, and K. D. Brownell. 2010. "The Impact of Food Prices on Consumption: A Systematic Review of Research on the Price Elasticity of Demand for Food." American Journal of Public Health (100): 216–222.
37. Stuart, T., 2015. World food: how much does the world need? World Economic Forum.

Opportunities in this scenario:

- Reduced demand for food creates greater slack in the market.
- Improvement in health outcomes around the world.
- Cost savings to consumers in high- and middle-income countries.

Threats in this scenario:

- Does not address economic inequalities that cause hunger, particularly for small-scale producers in low-income countries.
- Loss of livelihoods for those employed in food systems based on animal-based and other resource intensive products.
- Loss of profits for agribusiness and food retailers.

Indicators of this trend becoming reality:

- Changing consumer behaviors in high-income countries towards more healthy and/or sustainable products.

Barriers in this scenario becoming reality:

- Difficulties in changing consumer behavior.

Resilience of this global food system:

- No change.

Role of NGOs in this in this scenario:

- Crisis response to system shocks.
- Support for the poor.
- Nutritional education and advocacy.

Scenario 3 – The Regenerative-based Vision

The third scenario envisions reducing hunger by transforming the nature of the global food system to one that is not just sustainable but also regenerative.

Conventional agricultural practices were degrading the environment. They over exploited natural resources, while polluting the land, sea and air. A billion people were left without enough to eat, while two billion suffered the health effects of eating too much. Inequality deepened both within and among nations. Climate change and environmental degradation were nearing a tipping point. Something had to change. And it did. After centuries of despoiling the world, humanity had to think beyond just sustaining what was left. People needed to create a system that could endure, while also regenerating the environment. An impact-neutral form of human development was not enough to repair the damage that had already been done. Instead, development needed to have a restorative impact. This marked the shift in vision from a sustainable to a regenerative future.

The circular economy still requires energy to sustain itself and to turn waste products into inputs. This energy is now based on renewable sources. The continued reliance on fossil fuels was another example of a linear system, where a limited resource was exploited unsustainably, while producing pollution that negatively impacted the climate, the environment and human health. Alternatively, the use of solar and wind energy promises to indefinitely provide humanity with its energy needs, without creating harmful byproducts. Reduced costs for green energy sources and improvements in energy storage systems have made this transition possible.

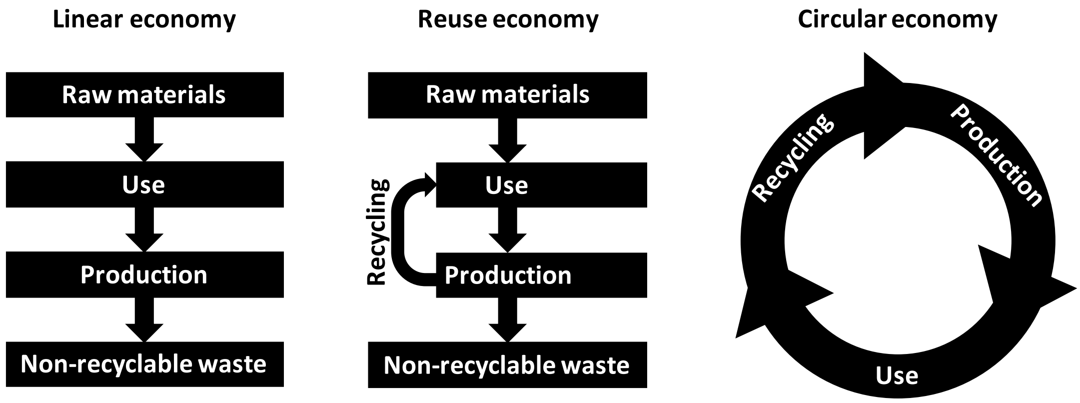


Figure 4. Diagram of linear and circular economies.[39]

One of the central pillars of today's regenerative system is a "circular economy."[38] Since the industrial revolution, product life cycles had followed a linear model. Raw materials were extracted, manufactured into goods, consumed and then discarded. Such an approach has been referred to as "cradle to grave." It converts natural resources into waste. Given the challenges humanity faced in the first half of the 21st century, a preferable option was to close this loop into a "cradle to cradle" approach, in which waste is used as the input for the product cycle in such a way that it becomes self-supporting. Recycling is a simple example of this: a can is melted down to provide the metal for another product, rather than burying it in a landfill and mining more metal. Another example is using food waste as compost to nurture the next generation of crops, rather than adding organic waste to the landfill and using chemical fertilizers to provide nutrients for crops. By closing this loop to create a circular economy, resources are not endlessly wasted. To make such a system truly regenerative though, these resource loops had to be designed in a way that improved their resource base in a virtuous cycle.

Industries around the world transitioned towards more regenerative systems, including those comprising the global food system. In the agricultural sector, this meant the adoption of agroecology. While simply understood as "the study of the relation of agricultural crops and environment,"[40] the term denotes far more.[41] It is a science that blends agriculture, ecology and ethnobotany; an agricultural practice based on the principals of sustainability and traditional ecological knowledge; and a social movement advocating for sustainability, smallholders and indigenous rights. The adoption of agroecology resulted in a movement away from the industrial agriculture of the previous century. Farmers now work with nature rather than against it.

38. Geissdoerfer, M., Savaget, P., Bocken, N.M. and Hultink, E.J., 2017. The Circular Economy–A new sustainability paradigm?. Journal of Cleaner Production, 143, pp.757-768.
39. The Government-wide programme for a Circular Economy. 2016. A Circular Economy in the Netherlands by 2050. The Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs.
40. OECD. n.d. Glossary of statistical terms.
41. FAO. n.d. Agroecology knowledge hub: agroecology definitions.

Key principals behind agroecology:[42]

- Make the farm a mini-ecosystem that maintains circular nutrient flows. Use compost and manure as fertilizers to restore nutrients to the soil (notably carbon, nitrogen, phosphorus, potassium and micronutrients).
- Regenerate the soil by ensuring it has enough organic matter and beneficial microorganisms.
- Keep the soil covered to protect it from the elements by using cover crops or mulch.
- Promote agro-biodiversity, and genetic diversity, on the farm and in the surrounding landscape. Diversity creates resilience and provides for more symbiotic opportunities. Practices that promote this include: rotating between different crops, growing different crops together or mixing crops with livestock and/or trees.
- Use beneficial natural relationships to maintain nutrient flows, enhance soil fertility, manage pests and increase productivity. For example, legumes fix soil nitrogen for other plants, bees pollinate crops and birds eat pests.

Practicing agroecology requires farmers to be more knowledgeable about their land and environment. To this end, the use of local and traditional knowledge is of great importance. Farms are now smaller in size, so they can be effectively understood and managed, as opposed to the hundreds or thousands of hectare farm sizes that were common with the industrial systems of decades past. Farming is also more labor intensive. Instead of relying on external inputs and heavy mechanization, knowledge and environmental management have become key.

In high-income countries, there is still an ongoing transition from industrial to agroecological systems of production. Some agribusinesses have chosen to adjust their practices and break up their large land holdings into smaller managed units. Even small changes like crop rotation and no till farming have enabled significant reductions in the amount of artificial fertilizers and pesticides they use. High-income countries have also seen growth in small family farming using agroecology principals, particularly to supply produce to urban centers. The shift has required increased labor, which has increased food costs for consumers, but for many the ethics and quality of food are worth it. The increase in local food production has also helped to shrink the supply chain between farmers and consumers. Cutting out middle men has increased profits for farmers and mitigated some of the extra costs for consumers, while also minimizing the food loss and waste that result from longer supply chains.

In low-income countries, the practice of agroecology is very extensive. Many smallholders had long embraced the principals through traditional farming practices, while others had to relearn lost indigenous knowledge. Modern science was also able to contribute to further improvements. Such work required a massive scale-up in extension efforts and farmer-to-farmer learning over many years, coordinated by international and national actors. This massive undertaking has paid off. There have been dramatic increases in production in areas with previously high yield gaps, such as much of sub-Saharan Africa, South Asia and Latin America. These regions have grown far more self-sufficient, reducing their dependence on imports and becoming more resilient to price spikes in global commodity markets. However, agroecology is not a magic solution and is still bound by ecological limits. Some areas, such as marginal lands, still struggle but the improvements they have seen have been most welcome.

The transition to agroecology has allowed smallholders to incorporate the principals of climate smart agriculture, which has further promoted their resilience to environmental risks and reduced the frequency and intensity of shocks. The change in agricultural practices has also had broad social impacts. Agroecology has required greater labor inputs per unit of land, which has provided many new job opportunities. This is turn has slowed, and in some cases reversed, economic migrations from rural areas to cities or abroad. Rural development has also improved with the growth in infrastructure, services and secondary businesses.

42. Third World Network and SOCLA. 2015. Agroecology: key concepts, principals, and practices.

The international political economy complicated the transition to regenerative systems for many low-income countries. Their governments sought to break from commodity dependence by implementing protectionist policies to encourage their agricultural transformations. For decades, cheap food imports had undercut domestic production and stymied growth in the sector. Smallholders simply could not compete with industrial agriculture's economies of scale, especially when subsidized by wealthy nations. By imposing tariffs on staple crops, governments were able to create enough competition in the market to allow this new form of agricultural development to take hold. Food prices were kept stable and there was minimal impact on the food security of their people by imposing tariffs gradually as domestic production increased from the adoption of agroecology and investment in agricultural development. Governments also implemented social safety nets, funded in part by protectionist policies. Some countries have since lifted their trade restrictions, after determining that their farmers were secure enough to compete on the global market. Despite the great improvements seen around the world, some regions still struggle because of environmental and demographic pressures. Many countries have populations beyond the carrying capacity of their natural resources. Most of these countries are able to meet their food needs through trade for other goods and services, but there remain some countries that are unable to do so and thus require international food assistance.

Opportunities in this scenario:

- Addresses many of the economic and environmental drivers of hunger.
- Improved livelihoods and resilience for smallholders and agricultural laborers.
- Improved environmental conditions around the world.
- Better consumer access to quality food and public health outcomes.

Threats in this scenario:

- Risk of increased food prices.
- Region-specific environmental and demographic pressures that impact hunger remain.
- Requires large agribusinesses and other powerful actors in the food system to adapt or be regulated.

Indicators of this trend becoming reality:

- Public pressure on governments and businesses to adopt more sustainable practices.
- The long-term economic incentives of a circular economy.

Barriers in this scenario becoming reality:

- The vested interests of the current power structure, including multinational corporations and governments of high-income countries.
- Investment practices that value short-term gains over long-term sustainability.
- Risk aversion by large- and small-scale producers.
- Disinterest in farming and agriculture among younger generations.
- Risk of spike in food prices undermining the transition.

Resilience of this global food system:

- Increased due to having a distributed system, improved resource base and climate-smart practices.

Role of NGOs in this in this scenario:

- Provide assistance to populations struggling with environmental and/or demographic pressures and those that suffer during the transition (e.g. due to higher food prices).
- Technical assistance to governments and industry.
- Supporting smallholders in the transition to agroecology.

Scenario 4 – The Innovation-based Vision

The fourth scenario envisions reducing hunger through a new agricultural revolution based on biotechnology.

The world has witnessed the dawn of a new agricultural revolution. Through breakthroughs in biotechnology, food is now being biosynthesized rather than farmed. Microorganisms are genetically engineered into bio-factories to produce given compounds. Once the technology itself was developed, it proved very scalable. In a short time, it had reshaped the global food system.

Humans have been using microorganisms for thousands of years to produce foods like bread, cheese and beer. The 20th century saw great advancements in the use of microorganisms to synthesize products, such as pharmaceuticals from antibiotics to insulin. The fear in the mid-20th century of a looming global food crisis led to research into the industrial production of food and livestock feed from yeast. Gene editing opened new possibilities for what microorganisms could produce. First came the ability to splice genes from one organism to another, and then came the ability to design new organisms from a gene library. This "synthetic biology" could be programmed to synthesize nearly any biological compound.[43] Synthetic biology can even be designed to add additional nutrients and remove problematic compounds, such as those that cause common food intolerances, or allergies. Once such designer organisms were created, their use to create new products required no more sophisticated technology than that used to brew beer, something that human civilization already excelled at. Creating these new forms of life had been the technological constraint, but by the 2010s this was not only possible, but even commercially affordable.

The first products reached the market in the 2010s. These were high value products like biotech-produced saffron and vanilla,[44] and the demand for the natural equivalents began to decline exponentially as this new technology scaled up. Within two decades, the initial costs for biotech production had fallen from thousands of dollars per pound, to mere cents per pound.[45] Biotechnology proved a far more resource- and cost-efficient model for producing the food, fuel, fiber and medicine that society depends on. As a result, it displaced large portions of "traditional" agricultural products around the world, with everything from milk, to fuel, being produced by synthetic biology. Reliance on crops and livestock decreased dramatically. New, superior products are also now available, such as products made from spider silk.[46] Once the realm of science fiction, biotechnology is now a reality and has reshaped the global food system.

Industrial biotechnology uses microorganisms to produce desired compounds through two means, photosynthesis and fermentation. For the photosynthesis route, phototropic algae or cyanobacteria are used together with energy[47] (from sunlight), carbon (from the CO2 in the air), water and nutrients.[48] As the water sources do not need to be clean fresh water, seawater and waste water are often used. Nutrients including nitrogen, potassium, phosphorus, iron and sulfur are obtained in part by recycling waste products and wastewater.[49] For the fermentation route, yeast, bacteria and heterotrophic algae are the platform organisms,[50] together with carbon, water and nutrients as the inputs. The carbon and nutrients often come from lignocellulosic biomass (dry plant matter) from agricultural waste and non-food crops that grow more efficiently than food crops. In some cases, woody material within this dry plant matter is pretreated with fungi or bacteria to break it down into fermentable sugars[51] which, like in brewing, the microorganisms then convert into the desired product. The outputs from these processes are biofuel, carbohydrates and proteins, which contribute to meeting the world's energy needs (particularly for transportation) as well as the food needs of humans and livestock.

The microorganisms grow far faster than typical crops and can be harvested in days. In addition, the cost of creating and running the production facilities is very low. It is also an incredibly efficient process and food loss has become a concern of the past. Nearly every country in the world has at least a few facilities producing the mostly widely consumed products. Secondary businesses are based nearby to process the raw carbohydrates and proteins into other food products, which are then distributed to the surrounding population. As a result, food production is now centered in urban environments and distributed outward, whereas previously rural areas supported the world's food needs. The food produced through industrial biotechnology costs only a fraction of the cost of producing it from crops and livestock. It is produced at a scale that easily meets global demand and at a price that is accessible to even the most economically disadvantaged.

43. Andrianantoandro, E., Basu, S., Karig, D.K. and Weiss, R., 2006. Synthetic biology: new engineering rules for an emerging discipline. Molecular systems biology, 2(1).
44. National Public Radio. 2014. GMOs are old hat. Synthetically modified food is the new frontier. October 3, 2014.
45. Bethencourt, R. 2016. Feeding the bottom billion with biotech. PLOS blogs.
46. Michalczechen-Lacerda, V.A., Tokareva, O., de Rezende Bastos, A., da Silva, M.S., Vianna, G.R., Murad, A.M., Kaplan, D.L. and Rech, E.L., 2014, October. Synthetic biology increases efficiency of Escherichia coli to produce Parawixia bistriata spider silk protein. In BMC proceedings, 8(4), pp. 231
47. Sonck, M. 2016. Synthetic biology in industrial biotechnology. Synenergene.
48. Bhatnagar, S.K., Saxena, A. and Kraan, S., 2011. Algae-Based Biofuels: a review of challenges and opportunities for developing countries. Algae biofuel, pp.1-40.
49. Hannon, M., Gimpel, J., Tran, M., Rasala, B. and Mayfield, S., 2010. Biofuels from algae: challenges and potential. Biofuels, 1(5), pp.763-784.
50. Sonck, M. 2016. Synthetic biology in industrial biotechnology. Synenergene.
51. Anwar, Z., Gulfraz, M. and Irshad, M., 2014. Agro-industrial lignocellulosic biomass a key to unlock the future bio-energy: a brief review. Journal of radiation research and applied sciences, 7(2), pp.163-173.

However, there were profound social and economic disruptions as a result of this agricultural revolution. For most of the world's population, synthesized foods are far more affordable and have the same taste and nutrients, but there is still a market for "real" food produced from crops and livestock. High-end consumers are willing to pay a premium for these products, and some of the farmers who remain cater to this market by focusing on high-quality production. Such farms can be found scattered around the world outside major urban centers, where that they can provide fresh products to their customers. Other remaining farmers grow lignocellulosic biomass for fermentation, such as fast-growing grasses and trees, although this does not require much labor input and is highly mechanized and automatized. Synthesizing food requires very little labor. The share of the world's population employed in agriculture had already been steadily declining for decades, from 41% in 1995 to 27% in 2015.[52] This steady decline became a crash as biotech began to scale up and more of the world adopted it. In 2050, only 4% of the population is employed in agriculture. This disruption led to one of the largest social transformations since the first agricultural revolution when humans transitioned from a nomad life as hunter-gathers to living agricultural settlements. Over 2.5 billion people lost their agricultural livelihoods over the course of a couple decades.

An unprecedented number of people had to find new livelihoods, particularly in low- and middle-income countries where the agricultural sector had employed around 25% and 65% of the population, respectively. Though disruptive, this transition did not lead to mass starvation or food riots. Synthesized foods (and fuels) became so cheap that it put farmers out of business, but the food was also so cheap that governments and international donors could easily afford to feed those who had lost their livelihoods. The major challenge of this transition was that hundreds of millions of people moved to cities to seek new livelihoods, in an unparalleled wave of rural-to-urban migration. Slums proliferated as cities could not absorb the rural poor fast enough, which led to an array of related challenges in proving basic services to urban residents. This was a difficult period and required extensive national and international support. Major infrastructure development projects were required to meet the needs of these new urban populations. Governments and donors employed the new influx of labor to construct new housing, roads, water and sewer lines, etc. Along with this new infrastructure came many other benefits to the food system, such as household electricity and cold storage chains, which had often been missing in many low-income countries. It was often cheaper to build out rather than up, and urban sprawl spread through former farmlands. Not long after, these new megacities began to experience great economic booms as a result of this development. .

The manufacturing and service industries were able to develop in countries where the economy and labor force was previously dominated by agriculture. Today, for instance, the economies of sub-Saharan Africa[53] are far more robust and diversified than they would have been had they remained dependent on agriculture.

The global food system today is far more decentralized than at the start of the century. Countries and regions are largely independent in their production, distribution and consumption of food, with most being able to meet their own demand, as opposed to before, when much of the world depended on imported food from a handful of net exporters. At the national level, food systems are formed around centralized nodes. Traditional production-to-consumption chains have mostly disappeared, replaced by large urban production centers that distribute to meet the needs of their surrounding region. This change has made food systems more resilient to global shocks. For example, a Western financial crisis or drought in China no longer causes food prices to spike in sub-Saharan Africa. However, food systems are now less resilient to localized shocks. If a tropical cyclone disrupts industrial production in Manila, far more people are affected then in the past because there are no longer enough small-scale producers in the surrounding region who can support. International trade and assistance can help meet these challenges, but in the years to come many hope to bolster resilience by having industrial biotechnology further decentralized to the community level (like the equivalent of having a microbrewery in every town). This could also help revitalize rural towns and relieve pressure on megacities.

In the late 20th and early 21st centuries, wealthier populations were struck with obesity epidemics as a result of over-nutrition and sedentary lifestyles. The obesity epidemic is now a global pandemic unmatched in human history. Where previously meat, dairy and processed foods were a rare luxury for the world's poor, they are now cheap and readily available. At the same time, many more people have also transitioned from physical labor, to more sedentary work. There was not enough time or effort spent to help transition people from their traditional diets to healthy versions of new diets. Governments and international organizations are now struggling to treat the effects of nutrition-related non-communicable diseases. There is much discussion among health experts on how to bring systemic change to this pressing issue, but there has been a lack of political will, especially in the face of powerful food companies and publics who do not want to be told what to eat. The wealthier populations around the world have slowly continued to transition towards healthier diets and lifestyles, but many fear that without effective interventions, billions of the world's poor will suffer ill-effects of over-nutrition for generations to come.

52. World Bank. 2018. Data: Employment in agriculture (% of total employment) (modeled ILO estimate).
53. Headey, D. and Fan, S., 2010. Reflections on the global food crisis: how did it happen? how has it hurt? and how can we prevent the next one? (Vol. 165). IFPRI.

While the health impacts have been dire, the biotech revolution has had a very positive impact on global environmental issues. Biofuels provide a source of cheap, clean and renewable energy which has replaced the former reliance on fossil fuels. Similarly, fossil fuel-based plastics, which were a major waste issue, have been replaced with biodegradable bioplastics. The facilities which produce these products also remove and use CO2 from the atmosphere. The conversion of agricultural land from food to biomass production has additionally resulted in a net CO2 absorption, along with a reduction in soil degradation and the use of toxic pesticides and fertilizers. The dramatic decline in livestock numbers has meant that there is also far less methane coming from ruminants. Finally, with less land total needed for agriculture more has been returned to conservation and reforestation.

Opportunities in this scenario:

- Cheap and abundant food eliminates poverty as a driver of hunger.
- Low-income countries diversify their economies and end dependence on food imports.
- Reduction in greenhouse gases, pollution and habitat loss.

Threats in this scenario:

- Over 2.5 billion people lose their livelihoods.
- Economic inequalities could worsen if economic diversification does not occur, increasing the poor population's dependence on food assistance.
- Massive rural-to-urban migration, expansion of slums and challenges for basic service provision.
- Global increase in obesity and related health issues.

Indicators of this trend becoming reality:

- Biotech food products exist and are already entering the market in limited quantities of high-value items.
- Biotechnology is rapidly advancing and costs are decreasing exponentially.

Barriers in this scenario becoming reality:

- Additional scientific innovations are required.
- The economics of scaling up facilities and inputs, reducing cost and transitioning production.
- Sociological challenges of shifting traditional food sources and systems, including likely opposition from consumers and producers.

Resilience of this global food system:

- Increased due to decentralized structure and agricultural production levels no longer being affected by adverse weather.

Role of aid in this in this scenario:

- Providing food and fuel to large segments of the world's population who are without livelihoods.
- Supporting rural populations to transition to new livelihoods.
- Supporting governments to manage rapid urbanization and basic services in slums.

Conclusion

This report provides four different normative scenarios for the global food system in 2050. Each scenario represents a prevailing school of thought on how to feed the world's population in the years to come: through expanded industrial agriculture, through reduced consumption, through agroecology and through biotechnology. These scenarios are not necessarily mutually exclusive; some approaches could be combined to support one another. With the exception of the first scenario (industrial agriculture), they require considerable structural change and would not be easy to realize by 2050. As such, it is important to emphasize that these are visions to aid in planning. They do not attempt to predict what the future holds. The intention is to illustrate tradeoffs that need to be carefully considered regardless of the path forward, and to identify weaknesses in the global food system that can be addressed to produce positive outcomes. Changes to the global food system can have very beneficial or harmful results for global hunger, as well as for the environment, poverty and other interrelated issues. There are limits to the role the global food system can play in ending hunger. Issues like poverty and conflict must be addressed at the same time. It is essential for policy makers to reflect on what visions they are aiming to realize, because the strategies put in place today will influence the lives of tomorrow.

Annex - Methodology

The scenarios presented in this report are based on IARAN's scenario analysis toolkit. The analysis was specific to the global food system with an outlook from 2019 through 2050.

1. Architecture

The architecture is a conceptual representation of the system being studied. It is used to identify the drivers of change to be included in the analysis. The drivers of change affecting the development of the global food system were identified through a literature review and interviews with external experts. These were classified by their scale (local, national or global) and by a PESTLE framework (political, economic, social, technological, legal and environmental) to mitigate cognitive bias. These drivers then served as the basic elements of the subsequent analysis.

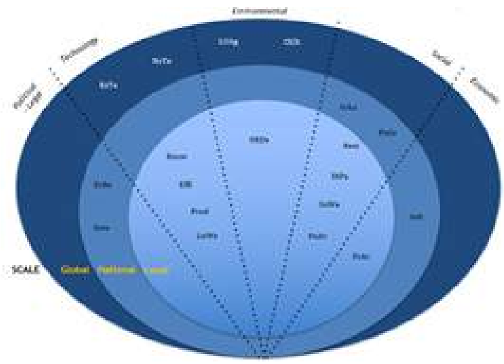


Figure 5. Represntation of the Architetcure showing classification by spatial scale and thematic area.

Table 3. Factors include in the Architecture classified by spatial scale.

System Scale	Factor	Code
Local	Production system	Prod
	Loss and Waste	LoWa
	Resilience	Resi
	Social Wellbeing	Resi
	Dietary Patterns	DiPa
	Nat Res Degredation	NRDe
	Knowledge	Know
	Efficiency	Effi
	Food Accessibility	FoAc
	Food Availability	FoAv
National	Economic Regulation	EcRe
	Investment	Inve
	Population Growth	PoGr
	Infrastructure	Infr
	Urbanization	Urba
Global	Climate Change	ClCh
	New Technologies	NeTe
	Existing Technologies	ExTe
	Land Use for Agriculture	LUAg

2. Factor-Factor Matrix

The Factor-Factor Matrix (also known as a MICMAC) is a network analysis technique, representing a directed graph of the network of interactions between factors. The factors were entered into an adjacency matrix where they were listed along both the x- and y-axes. The degree of influence each factor had on every other was then ranked (from 0-3). The resulting table of values was then used to classify each factor based on its net influence (the sum of its influence on all other factors) and dependence (the sum of all other factors' influence on it).

In the exampleto the far right, A influences B to a value of 3, B to C for a value of 3, and C to B for a value of 1. The directed graph can then be written as an adjacency matrix where the factors in the first column influence the factors in the top row. The sum of influence each factor has on the others would then be determined by summing the rows, where A=3, B=3 and C=1. The dependence is the sum of the influence every other factor has on each, calculated as the sum of the columns, where A=0, B=4 and C=3.

The influence and dependence scores of the factors were then graphed to create a "map" of the system. The location of the factors on this graph can be indicative of the stability of the system. If they are concentrated in the upper left, lower left and lower right quadrants, the system is likely to be stable. If they are distributed along the axis from the lower left to upper right, then the system is more likely unstable. This is because of the characteristics of the factors that fall into these different quadrants.

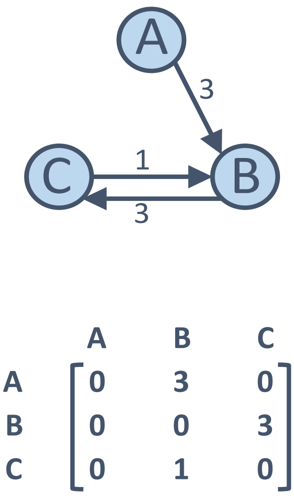


Figure 6a (top). Example of a directed graph. Figure 6b (bottom). Example of an adjacency matrix.

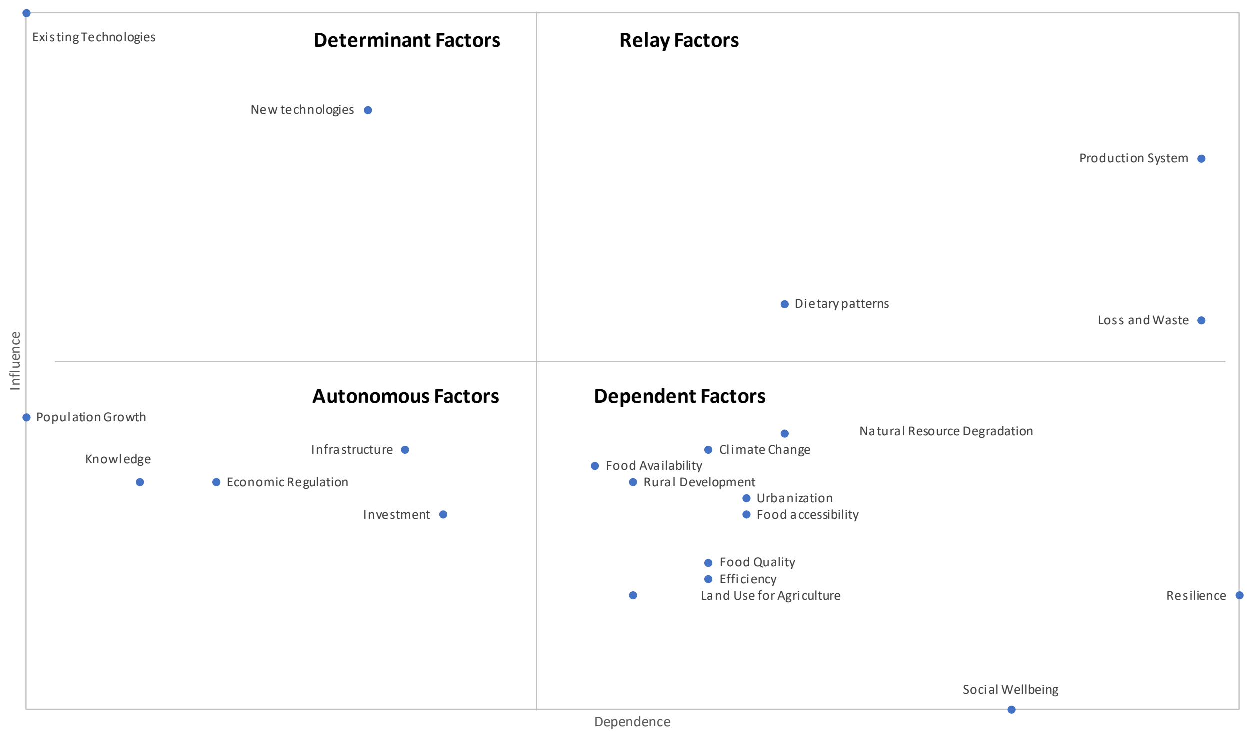


Figure 7. Factor–Factor Matrix.

The current system of factors shaping the global food system is relatively stable. The dynamics can change but will face some inertias in doing so. The most influential factors involve technology, agricultural production systems, dietary patterns and levels of food loss and waste. Changes to these factors will have a cascading effect that alters the rest of the system and its outcomes. Technological changes are shown to be largely outside the influence of other factors in the system. The latter three factors are good targets for intervention as they are influenceable and represent leverage points from which to affect systemic change.

System dynamics: Relative stability

Determinant Factors, located in the upper-left quadrant. These have a high level of influence over and a low level of dependence on the other factors. They are often entry points to the system and their direction will shape the rest of the system. As such they are crucial elements in determining the system's structure. Often, they can take the form of environmental variables that shape the system but are not in turn influenced by it. They have a strong impact on the other factors but are not influenced much in return. Similarly, these factors are important to watch, as they will have a considerable direct and indirect impact on the issue. However, these are also harder to change and less suitable targets for programming.

- New technologies
- Existing Technologies

Relay Factors, located in the upper-right quadrant. These have a high degree of influence and dependence on the other factors. As a result, actions on them are transmitted throughout the system. They therefore represent leverage points to influence the system as a whole. These are recommended as targets for intervention because they are susceptible to change and doing so will in turn have a cascading effect through the system.

- Production System
- Loss and Waste
- Dietary patterns

Dependent Factors, located in the lower-right. These are outputs of the system as they have a high level of dependence and low level of influence and as such, are sensitive to changes in the system. As a result, these often represent operational issues for actors. However, addressing them is unlikely to bring about systemic change which is better achieved by targeting factors with higher levels of influence.

- Rural Development
- Food Quality
- Resilience
- Efficiency
- Food accessibility
- Social Wellbeing
- Urbanization
- Climate Change
- Land Use for Agriculture
- Food Availability
- Natural Resource Degradation

Autonomous Factors, located in the lower-left. These are largely outside the system as they have a low influence and dependence on other factors. Acting on them will have little influence on the rest of the factors and the system as a whole. Important issues can still be located here, but ones that need to be addressed independently rather than through systemic changes.

- Economic Regulation
- Investment
- Population Growth
- Infrastructure
- Knowledge

3. Hypotheses Matrix (Morphological Analysis)

The hypotheses matrix is a means of developing the outline of the scenarios. For each of the most influential factors identified in the previous step (determinant and relay), a hypothesis is developed for how it could unfold in the future. For the purpose of the normative scenarios in this paper, the hypotheses were developed in light of the four different schools of thought being addressed. The hypotheses are written out in a matrix with the factors in the first column and their hypotheses in the following ones. For each scenario, the combination of the hypotheses serves as the basis.

Table 4. Morphological analysis table.

	Scenario			
Key Factors	**1. Production**	**2. Consumption**	**3. Regenerative**	**4. innovation**
Existing Technologies	**Capital intensive**	**No change**	**Labor intensive**	**Supplanted**
New Technologies	**No change**	**No change**	**No change**	**Biotechnology**
Production System	**Industrial agriculture**	**No change**	**Agroecology**	**Microbial synthesis**
Loss and Waste	**No change**	**Waste decrease**	**Loss decrease**	**Loss decrease**
Dietary patterns	**Global dietary convergence**	**Less resource intensive**	**Less resource intensive**	**Global dietary convergence**

4. Scenarios

The scenarios are intended to provide insight into the potential futures of the global food system and to assist decision-makers in identifying and planning for their preferred vision. The scenarios are based on the set of hypotheses related to the most influential factors that emerged from the analysis. The other factors, corresponding to the outcomes of the system, were added into the scenarios in logically consistent ways, where relevant based on the conditions set by the hypotheses. The scenarios are written in a narrative style from the perspective of the year 2050. They are specifically not predictions of the future and probabilities are intentionally not assigned to them. This is because doing so would encourage decision makers to focus on planning only for the "most likely" outcome, while not planning for other contingencies. A strategic plan that accounts for a range of likely outcomes is more robust against future uncertainty. It should also be noted that the scenarios do not account for all possible futures, as this would dilute planning efforts.