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UNIVERSITY OF CAMBRIDGE
INSTITUTE FOR SUSTAINABILITY LEADERSHIP

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# FOOD SECURITY

## *Closing the food gap: opportunities for investment?*

GROUPE BPCE

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With our best regards and thanks.

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EXECUTIVE SUMMARY

## A multidimensional issue

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organisation (WHO) define food security ***as a situation where 'all people, at all times, have physical social and economic access to sufficient, safe, and nutritious food to maintain a healthy and active life.'*** For Mirova, any interpretation of this concept in light of investing involves the additional dimension of sustainability: ensuring that the conditions necessary to produce foodstuffs do not deteriorate and jeopardise the food security of future generations.

**The three main pillars of food security** are commonly considered to be:

- **Availability** (domestic production and imports);
- **Access** (determined by income, purchasing power, and transport/market infrastructure);
- **Use** (food safety, supply chain processes, dietary habits).

However, while food security is conceptually fairly easy to grasp, it is extremely complex in practice, and the issues involved each have multiple dimensions: public/private, supply/demand, upstream/downstream, developed and developing countries.

Where are we today? Currently, the world's agricultural production of 8 billion tonnes in 2012 (FAO, 2012) would hypothetically suffice to feed the population of the planet. Yet undernutrition remains a serious problem in certain parts of the world, even as obesity rates skyrocket in both developed and developing countries.

Where will we be tomorrow? Independently of distribution issues, our research, based on OECD-FAO figures, suggests **that 1.5 billion tonnes of additional food will be needed over the next 10 years1 (equivalent to 2% CAGR for 2012-2022)** to ensure adequate supply for the expected population. This difference between current production and future need is known as the 'food gap'. Meeting this increased need will have to take place in the face of growing constraints as well.

Supply-side challenges ahead include:

- **Limited access to arable land** due to urbanisation and conflict over land resources;
- **Limitations on yields** caused by:
  - Climate change (fresh water scarcity, temperature variations, $CO_2$ levels),
  - Depletion of resources (erosion, soil depletion, biodiversity losses),
  - Biotic factors (pests such as fungi, insects, rodents, weeds).

In terms of demand, concerns revolve around the following issues.

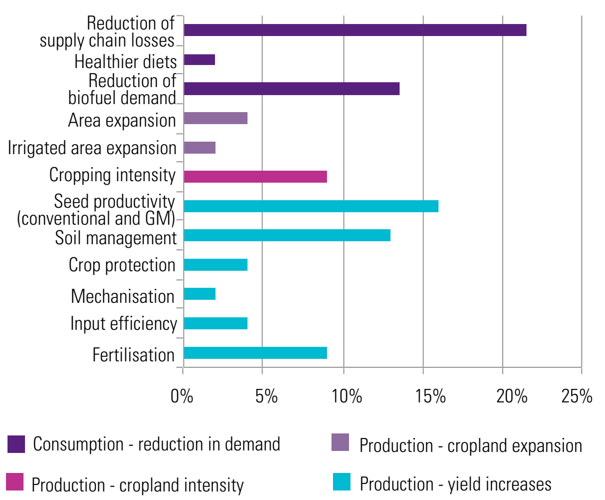
- **Population growth:** while demographic trends are expected to flatten, a population increase of approximately 1 billion is expected by 2025;
- **Shift in consumer diets:** a vast expansion of the middle class is already underway. This is accompanied by increased consumption of calories, especially resource-intensive animal proteins;
- **Increasing demand for crops** destined for non-food uses.

## Closing the food gap: defining an approach and estimating needs

For the purpose of this study, we have limited our understanding of food security to the first two pillars of the definition, i.e. providing enough food to meet future requirements with constrained resources, leaving quality aspects aside.

Solutions for closing the food gap are likely to come from both production innovations and changes in consumption trends: on the one hand, it is essential that we increase the supply of food, while on the other, there is real potential for a reduction in demand for certain commodities. Based on an extensive review of key sources (Alexandratos & Bruinsma, 2012; FAO, 2013; Fuglie & Nin-Pratt, 2012; OECD-FAO, 2013; WRI, 2013), we have estimated a broad range of sources liable to provide additional growth in the next ten years. These have been aggregated in Figure i, details on pp. 15-16).

**Figure i.** Main sources of increased food availability for the next ten years identified by Mirova (percentages represent the relative contribution of each solution the estimated growth)




Source: Mirova, 2014.

1. While we acknowledge that food security will probably not be achieved within 10 years, we assume that the solutions proposed are also suitable for a longer horizon, and that 10 years is a reasonable time perspective for a long term investor.

According to our estimates, approximately 38% of the additional food needed to close the food gap will come from the consumption end, predominately from **avoidance of supply chain losses**, both close to the farm (postharvest, transport, and storage losses) and close to the fork (processing retail, shelf life). We also believe that reducing demand for biofuels that compete with food by **developing 2nd and 3rd generation biofuels** would, if implemented, contribute to closing the food gap. The balance of the food supply increase, or 62%, will have to come from the production side. A portion of this will be shouldered by **expansion of irrigation** designed to permit the cultivation of crops in areas previously not considered arable, and **expansion to areas not previously cultivated.** While the former solution involves water management infrastructure, the latter often entails deforestation and may require major infrastructure. According to our estimations, **yield increases will account for providing around 44% of the increases to available food needed to feed the world's population over the next 10 years.**

In terms of solutions that produce increased yields, **mechanisation** was the primary driver of the first 'Green Revolution,' however, we do not anticipate it to be highly important in further advances, except in developing countries that were previously passed over. **Soil fertility management,** however, is necessary both for improving yields in terms of weight and nutritional value, and for ensuring sustainability. While much has been made of biotechnology, we do not expect **genetically modified, or GM breeding** to make large contributions compared to **conventional seed productivity** improvements, but taken together, the improvement of plant traits is a significant factor. The broader deployment of crop protection methods, both **chemical pesticides and bioprotection**, is also expected to boost yields somewhat. Lastly, increasing the efficiency of inputs, including **rainwater harvesting,** better irrigation and **precision agriculture**, will likely go a small way toward meeting the agricultural production increases needed.

As a responsible investor, **investing in these sources of growth means honing in on potential private sector contributions to closing the 'food gap' while increasing agricultural sustainability and ensuring access.**

Our analysis therefore focuses on the solutions linked to these sources of growth, and provides a synopsis of the effectiveness, sustainability, and cost of implementing each one.

## Private sector potential

Obviously, not every solution lends itself to private investment. Certain aspects of food security, for instance, are not treated here at all, notably issues linked to changing dietary habits at the consumption end or increasing crop rotation on the production side.

In this study, we highlight investment opportunities in the developing world, as this is currently where we see the highest value added from private investment, both in terms of closing the food gap, and realizing social and environmental benefits. According to the UNCTAD (United Nations Conference on Trade and Development), the annual investment gap for the 2015-2030 period is estimated at US$ 260 billion in the developing world.

The developed world has an important role to play, especially as concerns consumer efforts, but these are, in many instances, behavioural changes that are primarily the purview of the public sector.

Another upside of investing in developing countries is that they often promote investment in infrastructure that is beneficial for the population as a whole, as well as enabling significant knowledge transfers. But it is also important to weigh the sustainability of outcomes in making agricultural investments, and one of the most significant risks for local populations is environmental degradation, followed by dispossession of traditional land rights following large-scale land deals. As a first step towards evaluating private investment's impacts, the global community has established a framework for guiding investment in agriculture in the form of the **Principles for Responsible Agricultural Investment (PRAI)**, which will be taken into account in our assessment of companies. These guidelines cover 10 areas : contribute to Food Security and Nutrition, contribute to sustainable and inclusive economic development and the eradication of poverty, foster gender equality and women's empowerment, engage and empower youth, respect tenure of land, fisheries, and forests, and access to wate, conserve and sustainably manage natural resources, increase resilience and reduce disaster risks, respect cultural heritage and traditional knowledge, and support diversity and innovation, promote safe and healthy agriculture and food systems, incorporate inclusive and transparent governance structures, processes and grievance mechanisms, assess and address impacts and promote accountability

Amongst the many innovations developed by the corporate sector that have been identified, which are likely to be the most cost-effective and sustainable in closing the food gap? **Our approach has been to monetise environmental and social benefits, and subtract these amounts from the estimated cost of implementing the solution itself.** Conversely, the estimated cost of environmental and social harm is added to the cost of implementation.

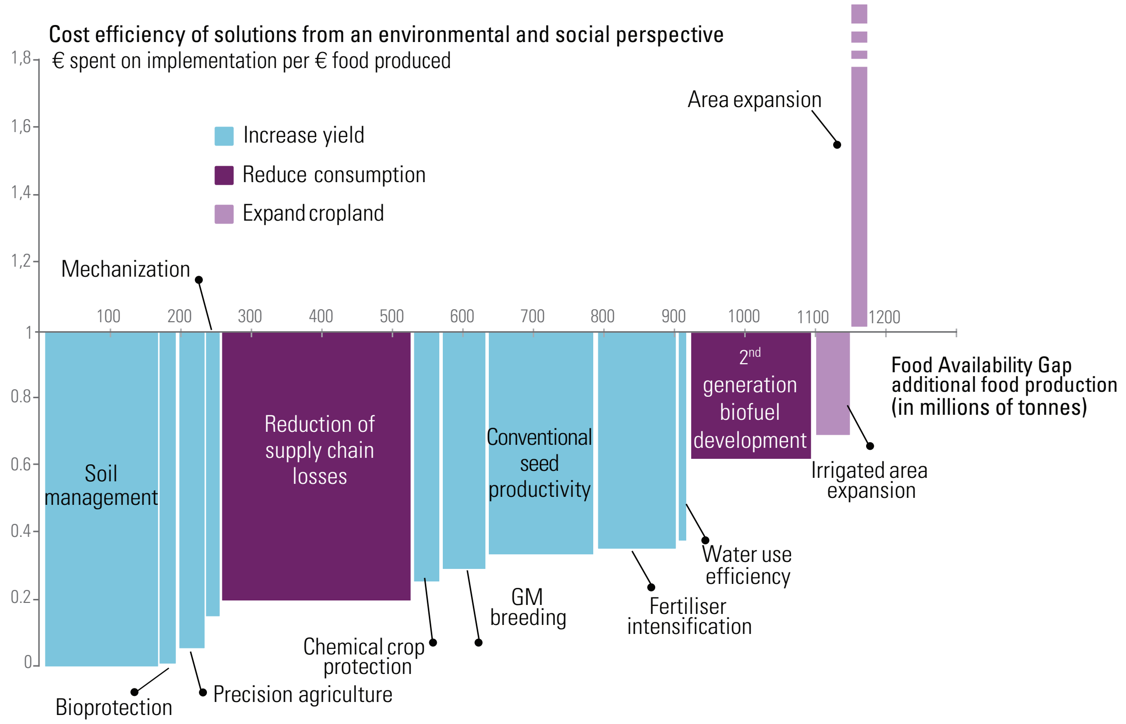
In a first cost curve, we thus examined the payoff, in terms of euros of food produced (using World Bank pricing), for each euro of investment in a particular solution, against a baseline of €1 to €1 parity. The conclusion was that a majority of the solutions identified are 'cost effective', and that yield increases provide the highest cost efficiency overall.

We then incorporated the monetised impact of social and environmental factors, based on the following proxys: price of $CO_2$ emissions, environmental costs for water use and value of pollination services provided by the ecosystem (see Figure ii).

In light of these calculations, certain solutions, such as soil fertility management and bioprotection, carry no cost at all, once the environmental benefits are calculated. Expanding the area under cultivation, on the other hand, tends to carry high costs once environmental externalities are taken into account, because of the destruction of $CO_2$ capture ecosystems and loss of biodiversity associated with deforestation.

With the exception of area expansion, the conclusion of our research is that all solutions have a role to play in closing the food gap by 2025. However, our attention will focus on solutions that best take into account environmental and social externalities including responsible soil management (biofertilisation, low/no till seeding, organic farming, etc), bioprotection, precision agriculture, reduction of supply chain losses.

**Figure ii.** Cost curve for proposed solutions adjusted for environmental and social impacts




Source: Mirova 2014.

These cost curves, of course, represent a work in progress. The key to improving their accuracy and relevance lies in incorporating additional features (geographic distinctions, valuation of additional environmental externalities such as soil fertility, and social externalities such as life-expectancy and health issues).

## Options for investing in listed equities

Having determined the highest-potential areas for private investment in solutions to closing the food gap with positive social and environmental impacts, we then turned to identifying specific companies significantly exposed to such solutions in which to invest. Bearing in mind that our investment scope is limited to listed equities, de facto excluding a large spectrum of potential investment opportunities (private or small companies, public-private partnerships, etc.), we screened a large universe of listed companies to identify those involved in these solutions. Selected companies present at least one of the following features:

- offer an environmentally-friendly alternative to conventional agriculture;
- provide current solutions to the problem of increasing food availability and access with a strong exposure to developing countries.

All companies were required to fit within our investor constraints.

The conclusion of our screening was that the choice of 'pure players' combining innovation, impact and sustainability, and fitting our investor constraints remains restricted on this theme. Innovative sustainable solutions that contribute to resolving the food security challenge are either developed within small divisions of large corporations involved in very diverse activities, or else by small (and often unlisted) enterprises.

**Table i.** Examples of companies offering sustainable food security solutions (within our investor constraints)

| | Value Chain | Examples of companies offering sustainable solutions | Exposure |
|---|---|---|---|
| Improving food AVAILABILITY - Farming efficiency | **Farm inputs** | | |
| | Seeds | VILMORIN ET CIE | Medium |
| | Other inputs (fertilisers, crop protection, etc.) | NOVOZYMES AS | High |
| | **Farming equipment** | | |
| | Machinery | KUBOTA CORP. | High |
| | | DEERE & CO. | Medium |
| | | AGCO CORP. | Medium |
| | GPS and other technologies | TRIMBLE NAVIGATION LTD. | Medium |
| | | TOPCON | Medium |
| | Irrigation | JAIN IRRIGATION SYSTEMS LTD. | High |
| | | TORO | Medium |
| | | VALMONT INDUSTRIES | Medium |
| | | LINDSAY CORP. | Medium |
| Improving food ACCESS - Reducing food losses and waste | Packaging | MPACT LTD. | High |
| | | MONDI | Medium |

Source: Mirova 2014.

In light of this reality, it may be necessary to consider other feasible solutions if the food gap is to be closed. We therefore broadened our screening of companies to include more conventional solutions to closing the food gap, what we would consider business as usual solutions (BaU). Nevertheless, where solutions pose high environmental and/or social risks, a company's capacity and willingness to minimise and manage such risks must be meticulously analysed (see for example Mirova's previous study on palm oil).[2]

**Table ii.** Examples of companies offering BaU solutions contributing to food security (within our investor constraints)

| | Value chain | Examples of companies |
|---|---|---|
| Improving food AVAILABILITY - Farming efficiency | **Farm inputs** | |
| | Seeds | KWS Saat AG |
| | Other inputs (fertilisers, crop protection, etc.) | The Mosaic Co., K+S AG |
| | **Farming equipment** | |
| | Machinery and other agricultural technologies | Bucher Industries, CNH, Exel industries, Titan International |
| | **Production** | |
| | Farms/Farming | Select Harvests Ltd, NBPO Ltd, Fresh Del Monte Produce Inc., China Modern Dairy, Adecoagro, SLS Agricola |
| Improving food ACCESS - Reducing food losses and waste | Storage / Transportation / Refrigeration | Canadian National Railway Co., Ag Growth International |
| | Packaging | Brambles, Mayr-Melnhof Karton AG, Winpak Ltd, Rock-Tenn Co., Packaging Corp. of America |

Source: Mirova 2014.

## A closer look

In addition to providing a list of companies we feel actively contribute to sustainable food security, this study investigates three categories of food security solutions that were selected to address issues that are prominent in debates today. Our focus on postharvest losses illustrates the differing profiles of solutions in developed and developing countries. Biotechnology, especially the area of GM seeds, is an issue that inspires confusion and hot debate. Water management was selected because it is closely tied to climate change, and critical to human health.

### Postharvest losses

According to the UN, 1.3 billion tonnes, or nearly a third of food production, is wasted or lost each year. Food waste involves food that is fit for consumption but discarded at the retail or consumer level: this is largely a problem in the developed world. Food losses, on the other hand, refer to food that spills, spoils, is attacked by pests or incurs an abnormal reduction in quality such as bruising and wilting. This type of damage takes place primarily between the harvest and processing phases, and affects the developing world most deeply. Estimates suggest that 170kg/yr per capita could be saved by eliminating Postharvest losses (PHL) in Sub-Saharan Africa and Asia.

Solutions to focus on are then different for developing and developed countries.

From our review of the available options, **mechanisation, cooling and packaging** are the key solutions for tackling food losses in developing countries. Several technologies and practices have been identified as combating PHL in **developing countries**, including machinery (combined harvesters and threshers), Integrated Pest Management (IPM), humidity and temperature monitoring and control devices. Storage improvements entail extending the application of basic technologies such as containers that are pest-proof (plastic crates, hermetic polythene bags or metal silos). There is an especial need for companies offering transport containers designed to protect specific types of crops in transit, and for providing infrastructure (roads etc.); improvements in this area are particularly important for enabling development of the cold chain.

In developed countries, perishable food items are often transported considerable distances, while conventional standards require that fruits and vegetables show no signs of bruising or wilting. Several new technologies have emerged to reduce such damage and/or prolong shelf life. Modified atmosphere, which reduces cellular respiration, currently garners the most votes for potential effectiveness.

Technologies for maintaining a cold chain and packaging solutions (from hermetic seals in developing countries to more innovative modified atmosphere packaging or smart packaging in developed countries) have thus the potential to reduce Food Losses and Waste (FLW) at many stages of the food chain.

### Biotechnologies

The topic of GM technology is not an easy one. The technology itself is fairly complicated and the environment surrounding it (regulation, public opinion) even more so. Nevertheless with seed companies spending a significant amount of their R&D into the area, it has become an issue for responsible investors.

In terms of food security, there is no question but that GM has a role to play. GM technologies present a wide variety of opportunities: increased food availability, more efficient use of natural resources, improved soil fertility management, increases in farmers' income. At the same time, GM solutions also present a broad array of potential risks. There remains considerable ignorance as to the long-term impact, both environmental and in terms of human health, of applying such technology on a large scale. Risks are largely similar to the problems associated with all monocultures, and include pest resistance, threats to biodiversity, and risk of reliance on very few varieties. Confusion and fear on the part of the public further make for a regulatory climate that augments risks associated with investment in biotechnologies, as there is little assurance that products will be permitted to market. Nearly all countries impose some kind of restriction on GM foodstuffs.

*2. All the selected companies undergo further environmental, social and governance (ESG) risk reviews as well as an in-depth analysis of their economic and financial potential before entering our portfolios.*

As a responsible investor, Mirova endeavours to integrate all these elements in its assessment of seed companies. While acknowledging the significant public mistrust surrounding GMOs and more broadly vegetal biotechnologies, it appears that these technologies have a role to play in providing for food security and nutrition which should not be overlooked. Given its capacity to permit more efficient plant breeding and offering possibilities which cannot be achieved by conventional breeding techniques, reliance on biotechnology should not be considered in and of itself a reason for exclusion. Biotechnology embraces a large number of techniques, some of which have been applied for decades. Some emerging technologies may raise concern, and scientific evidence of their innocuity must be produced. However, despite significant environmental and social issues linked to the current GM crops (mainly reliant on transgenesis), a direct link between the technique used and observed externalities over the last 15 years (resistance to pests, pollination issues, etc.) has not been clearly demonstrated by scientific research. In the absence of sufficient scientific conclusions regarding techniques, we seek to assess companies on the sustainability of the outcome where GM crops are concerned.

Essentially, GM is one solution that, properly employed, can find a place within sustainable food security, particularly when used to tailor seeds to local conditions, but is not a panacea. The focus needs to be on outcomes, including the full horizon of risks, particularly social risks associated with dependence on industrially controlled seed material.

As each GM crop is unique, a case-by-case analysis is needed. The following factors are to be considered when analysing and engaging with companies:

- Traits of the GM crop: bio-fortified crops, crops with enhanced medical traits (e.g. vaccine crops) and other crops that would allow significant social and environmental benefits will be favoured;
- For already available crops, a proven track record of improved agricultural performance while minimising environmental and human safety issues;
- Proven use of the precautionary principle when handling GM technologies;
- Transparency over the impacts of technologies used and scientific advances;
- Ability of the governments where the technology will be used to provide good governance over the technology;
- Transparency over labelling and traceability beyond legislation;
- Engagement with and educating stakeholders, particularly the farmers and consumers;
- Risk/benefit analysis compared with alternatives approaches.

**Water management solutions for increasing yield**

Water demand is expected to outstrip supply by 2030. Given that the agricultural sector is one of the biggest consumers of water (70% of total withdrawals), it will be sensitive to any changes in water supply. As such, if we are to ensure global food security, it is essential that we also secure the world's water supply.

The study focused on two main solutions, those aimed at **conserving water** and those which **provide alternative sources of water suitable for agriculture.** Solutions designed to conserve water include techniques such as **smart irrigation, water loss reduction strategies and conservation agriculture.** Those that make available alternative sources of water encompass technologies such as **desalinisation, wastewater treatment and water reservoirs.** Of the two categories, greater effort should be directed toward increasing water efficiency and promoting water conservation as these have a more direct impact on agriculture. While these solutions have already been available on the market for some time, adoption remains relatively low due to high initial investment costs, rarity of the skills needed to implement the technologies, and little or no incentive for farmers to adopt more efficient practices as water prices remain low. Consequently, improving education and increased awareness amongst farmers can and should play an important role in accelerating adoption of these solutions.

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# 1 | Basic Concepts of Food Security

## 1 | 1 World Food Situation

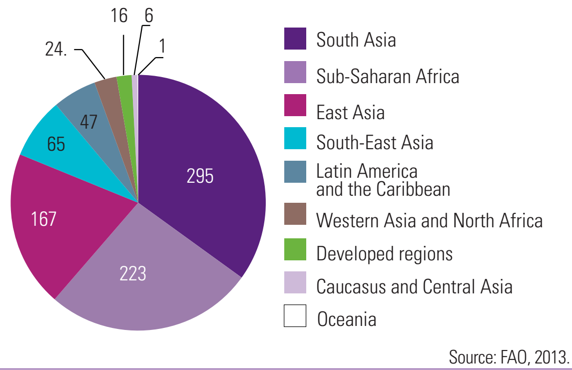
Debate over the link between world population growth and the ability to provide everyone with sufficient food to conduct a decent life has continued unabated since Malthus raised the question in the 18th century, if not before. To date, world food production has grown faster than population. Over the last decades in particular, significant progress has been made in increasing food consumption per person: the world average per capita food availability has risen from about 2,220 kcal/person/day in the early 1960s to over 2,770 kcal/person/day today, with developing countries recording a leap from 1,850 kcal/person/day to over 2,619 kcal/person/day (Alexandratos & Bruinsma, 2012). Increased caloric intake has been accompanied by significant changes in diets worldwide, with a strong shift from staples such as grains, roots and tubers to higher consumption of animal proteins (meat / dairy) and vegetable oils. In theory, enough food is available to ensure a food supply adequate for the entire world's population. Yet hunger remains an abiding problem. The current world food situation is characterised by significant imbalances and cannot be described as 'secure'.

Despite decades of economic growth, hunger, defined as chronic undernourishment (i.e. regularly not having enough food to conduct an active and healthy life) is still prevalent in the world. The 1996 World Food Summit (WFS) set a goal of halving the number of chronically undernourished people by 2015, as compared to 1990-1992 levels. The 2002 United Nations Millennium Campaign established as one of the key targets for achieving the first of its eight Millennium Development Goals (MDG) to halve by 2015 the proportion of people who suffer from hunger compared to 1990 levels. According to the latest estimates (FAO, IFAD and WFP, 2014), as of 2014, the MDG hunger target seems within reach, but the WFS goal is unlikely to be met by 2015. Indeed, between 1990-92 and 2012-14, a 40% decrease in the prevalence of undernourishment has been achieved; yet, over the same period of time, the number of undernourished people has declined by only 20%. As a result, in 2012-14, about 805 million people (one in every nine persons worldwide) still regularly lack enough food to cover their minimum dietary energy requirements.[3] At the other end of the spectrum, the ballooning number of overweight people has surpassed this figure.

While progress is slow at the global level, since 1990-92, 63 countries have met the MDG hunger target and 25 the more stringent WFS objective. Most undernourished people live in emerging countries of Asia and Africa, with Asia accounting for more than 65% of the total number of individuals. However prevalence is higher in African countries.

3. *Minimum Dietary Energy Requirements (MDER) are defined by the FAO, and differ according to gender, age and level of physical activity. They thus vary both by country and over time. As an indication, for the period 2006-2008, MDER ranged between 1690 and 2000 kcal/person/day.*

**Figure 1.** Undernourishment in 2011-2013, by region (millions of people)




Source: FAO, 2013.

### 1 | 1 | 1 Current food systems

As defined by the FAO (Food and Agriculture Organization of the United Nations), food systems 'gather all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes' (HLPE, 2014). There remains an acute need for reliable data for these components, however, it is difficult to obtain accurate assessments of food availability and use, because there are both formal and informal economies involved, and large disparities among populations even within a single geographical area. Furthermore, even where reliable statistics are available it is hard to make comparisons, because there are many ways to look at food challenges, and measures appropriate for one context may be less meaningful for another.

Issues such as survival and undernourishment, smallholder farming and subsistence crops determine approaches to analysing food systems in developing countries. In developed countries, different concerns predominate, mainly those linked to dietary patterns, food waste or intensive farming. In addition, studies differ significantly in terms of the crops covered, depending on the aim of the study.

**Panel 1. How are different foodstuffs rendered comparable? What units are appropriate for evaluating food systems?**

Statistics are oriented towards either a food production perspective or a human consumption perspective. To further complicate the issue, food products such as meat, oil and milk, which are secondary foodstuffs, are not accounted for in the same way as direct agricultural production is. To avoid double counting, the FAO introduced the Crops Primary Equivalent KPI (key performance indicator), in order to deduct the portion of primary agricultural production that, through consumption (animal feed) or processing (dairy for example), changes its nature and becomes part of a different commodity group.

Unit choices are also dictated by the perspective adopted: production focuses on tonnes and currencies, whereas consumption figures are often given in kilocalories. To illustrate how important the choice of variable can be, Figure 2 presents a breakdown of world agricultural production by commodity. Food consumption, in terms of kcal/person/day, is a KPI of the food access situation.

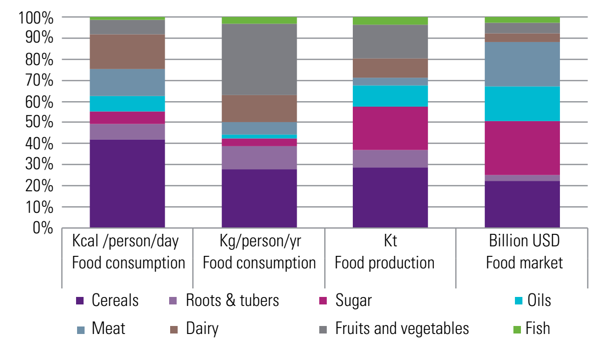
Food production, calculated as tonnage produced, is more meaningful when considering the environmental concerns raised by agricultural activities. Differences arise between food consumption calculated in calories and that computed in tonnes due to the differing energy content of commodities. Furthermore, there are divergences in figures, depending on whether commodity markets or gross tonnage is used as the basis for calculation. Consumption figures do not take into account crops grown for animal feed or biofuels, nor do they consider post-harvest losses, leading to disparities between consumption and production figures.

When assessing food systems from the perspective of food security, data on caloric intake appear to be the most relevant, despite the fact that this measure ignores other nutritional dimensions, such as micronutrients (vitamin A, iron, zinc, etc.).

However, for reasons of data availability, we have based our calculations on agricultural production figures from the OECD (Organisation for Economic Cooperation and Development) and the FAO Secretariats (OECD-FAO, 2013), although we would have preferred to use total direct human calorie consumption, as per the World Resources Institute's study (WRI, 2013). Consequently, this study does not aim at providing a precise dataset with exact figures on food trends. We seek rather to arrive at broad and average orders of magnitude in order to come up with a relevance-based classification of food availability solutions.



**Figure 2.** Breakdown of world agricultural production for the main food commodities




Sources: Mirova 2014 (based on Alexandratos & Bruinsma, 2012; OECD-FAO, 2013; FAO, 2013.

Based on FAO statistics, we estimate that roughly 8 billion tonnes of agricultural products were produced in 2013 worldwide. This figure includes all agricultural crops primarily intended for direct human consumption as well as those raised for animal feed, or destined for certain industrial uses (e.g. personal care, medicine, etc.).

Cereals are the most important food source for human consumption, as well as comprising over a quarter of all agricultural production. Of the 2.3 billion tonnes of cereals currently produced annually, 45% are consumed as human food, 30% are used as animal feed, and the remaining 25% are processed for industrial use, used as seed or wasted (FAO, 2013).

### 1|2 Challenges ahead

'Food crises' appear regularly on the World Economic Forum's Ten Global Risks of highest concern list[4] due to their position at the intersection of multiple global issues, such as demographic shifts, climate change, water scarcity, energy, health, international trade, income inequality, and biodiversity—to name only a few.

Given the complexity of the issue, how is the situation likely to develop over the next ten or twenty years? Below are the main driving forces that are expected to affect both food demand and availability over the coming decades.

On the demand side:

➜ **Population growth:** the world population is expected to rise at a slower pace than previously; nonetheless, an increase of 2.25 billion people is expected by 2050, and by 2025 the world population is expected to be 1 billion greater than in 2012.

➜ **Shift in consumer diets:** an increase of the middle class, expected to expand by more than 2 billion people by 2030, all turning to diets higher in protein and caloric intake, is likely to result in unprecedented pressure on ecosystems to produce the amounts of feed required for greater meat and dairy production.

➜ **Increasing demand for non-food uses** of agricultural output: mainly driven by demand for biofuels, which are expected to consume a significant amount of the total world production of certain major staples, such as sugar cane (28%), vegetable oils (15%) and coarse grains (12%) by 2022 (OECD-FAO, 2013).

On the supply side:

➜ Factors limiting the availability of land

- **Global urbanisation:** this worldwide trend leads to an increased reliance on processed food, while reducing the number of farmers and limiting the land available to grow food staples.

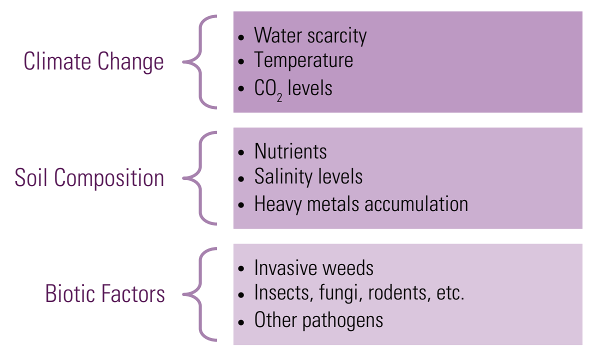
- **Increasing conflicts over access to land:** these occur when foreign investors or corporations buy arable land to export food from the country of production; this generally takes place in countries where hunger is already prevalent, further compromising the local population's access to food.

➜ Factors limiting agricultural productivity

The literature highlights three categories of factors that can have a significant impact on yields: climate change, soil composition and biotic factors.

4. *Global Risks report, WEF, 2014, 2013, 2012*

**Figure 3.** Factors affecting yields




Source: Sustainalytics 2014.

- **Climate change** is expected to negatively impact food production and significantly reduce yield increases for several of the world's major crops, including wheat, rice and maize,[5] which are already exhibiting a tapering effect. Higher $CO_2$ levels can affect crop yields as well as their nutritional quality. A recent Stanford study (Moore & Lobell, 2014) estimates that yields of wheat and barley across Europe could fall by more than 20% between now and 2040, due to the effects of climate change. The anticipated yield loss for corn is 10%. Another study reveals a link between higher $CO_2$ emissions and lower nutritional value. Wheat, rice and soybeans contained smaller concentrations of iron and zinc when exposed to high $CO_2$ levels (Myers, 2014).

- **Depletion of natural resources:** Many strategic resources (water, soil, biodiversity, arable land, energy) are being depleted at alarmingly high rates by unsustainable agricultural practices. Among these, soil quality is particularly key for sustained productivity. According to Liebig's law,[6] crop growth is constrained by the scarcest nutrient available in soil, and not by the total amount of resources available. Without adequate levels of soil fertility, high yields cannot be sustained. Fertility can be preserved in several ways, including via crop rotations and the targeted application of nutrients, such as nitrogen (N), phosphorus (P), or potassium (K). Salinity levels are likely to be a further constraint. According to FAO, areas affected by high salinity levels accounted for over 6% of all land on Earth in 2009. Given the current demographic growth forecast, and the anticipated effects of global warming on soil salinity, high salt tolerance might become a vital property in certain regions.

- **Biotic factors:** Improper pest management can result in substantial yield losses. The threat posed by various pests, such as, fungi, insects, rodents or invasive weeds, has been exacerbated by the prevalence of monocultures.

*5. Climate Change 2014: Impacts, Adaptation, and Vulnerability, IPCC, 2014.*
*6. Liebig's law, or the law of the minimum, developed by Carl Sprengel and Justus von Liebig at the end of the 19th century, has been widely used in agronomy. It states that plant growth depends on the scarcest resource (called the limiting factor) rather than the total amount of available resources.*

It is further noted that other driving forces, such as poor economic governance (inducing income inequalities and vulnerability), globalisation of food markets (exposing local producers to international brand competition) or increased food price volatility will also be obstacles to any secure access to food for poor people.[7]

### 1.1.3 Defining sustainable food security

The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) similarly define food security as existing **'when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to maintain a healthy and active life.'**[8]

Food security is a complex concept and its drivers are interdependent, such that the sufficient production of food alone does not, in any given country, guarantee an end to hunger. Both endogenous and exogenous factors can affect the three pillars of food security identified as:

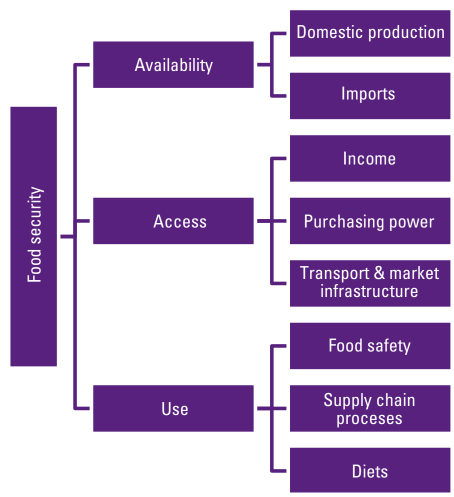
- **Availability:** sufficient quantities of food, available on a consistent basis;

- **Access:** having sufficient economic and physical resources to obtain appropriate foods;

- **Use:** appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation. Food security encompasses the notion of food safety.



**Figure 4.** The three dimensions of Food Security




Source: Mirova & Sustainalytics 2014.

Additionally, some authors include a fourth pillar, stability, whereby limitation of price variation and securing incomes for vulnerable populations are also incorporated.

Food security is defined here in a manner that suggests a static outcome. However, food systems have to be flexible and constantly changing to meet the similarly fluctuating

*7. Global Food Security, Challenges for the Food and Agricultural System, OECD, 2013.*
*8. FAO, World Food Summit 1996 definition.*

needs of a population over time; they also need to be sustainable to ensure stability and guarantee food security not only today, but also for the 8 billion people our planet will need to support 2025.

As defined by the FAO (HLPE, 2014), a 'sustainable food system (SFS) is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised.'

These various dimensions of food security relate to different spheres of responsibility and influence. For the purpose of this study, we will limit our understanding of food security to the notion of providing enough food to meet future requirements with constrained resources. Therefore, we will focus on increasing food quantity in a sustainable manner, and will leave aside quality aspects (i.e. those relating to nutritional value).

Therefore, the aim of the present research is to focus on solutions that can contribute to food availability and access through the optimisation of production modes.

## 2 | Food Availability: How to close the food gap in 10 years?

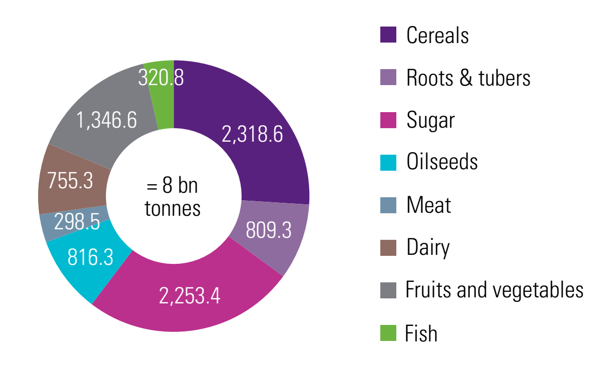
### 2 | 1 How much more food will the world need within ten years?



According to projections published by the FAO, a 70% total increase in agricultural production is needed to feed over 9 billion people in 2050 compared to 2006 production levels, representing an annual increase of 1.5% over the period to 2030 and 0.9% over the 2030/50 period (Bruinsma, 2012).

As mentioned earlier, roughly 8 billion tonnes of agricultural products were produced in 2013, worldwide (see Figure 5). This includes all agricultural crops primarily intended for direct human consumption (non-food crops such as cotton are not included).[9]

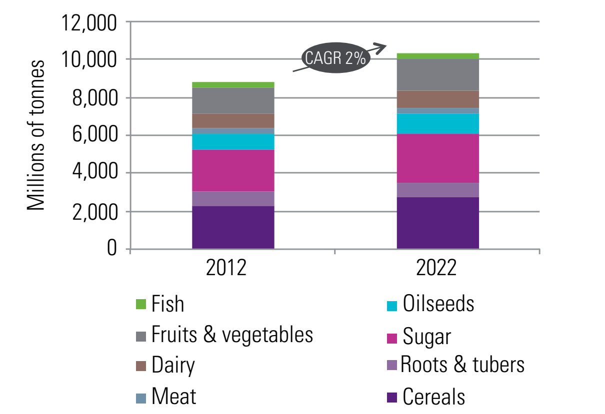
**Figure 5.** World agricultural production in 2013 (in millions of tonnes)




Source: Mirova 2014 (based on FAO and OECD data, 2013).

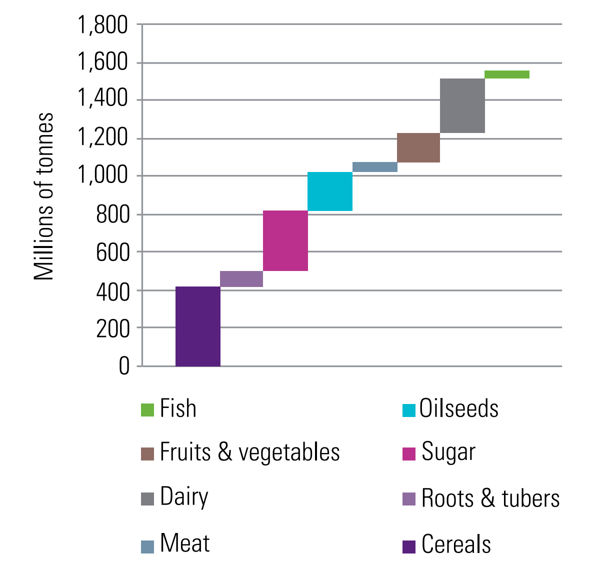
According to the OECD and FAO database (OECD-FAO, 2013), roughly 1.560 billion tonnes of agricultural products are projected to be produced over and above 2013 production rates by 2023 (baseline scenario); this is in line with the projections made by the FAO as to future need for agricultural products. This corresponds to a 2% compounded annual increase in (CAGR) food production (see Figures 6 and 7). Production increases are expected to mainly come from cereals and sugar, which are already the most produced agricultural commodities.

**Figure 6.** Projected agricultural food production in 10 years compared to 2012 levels, by commodity




Source: Mirova 2014 (based on FAO and OECD data, 2013).

**Figure 7.** Additional production needed over the next 10 years, by commodity




Source: Mirova 2014 (based on FAO and OECD data, 2013).

Looking at the situation historically, this 2% increase in food production has been consistently achieved since what is known as the Green Revolution: the average rate of growth for agricultural production has remained close to 2.2% per year since the 1970s.

So, why are we concerned about food availability? The chief reason is that the availability and quality of water and land resources are being reduced, resulting in a need to produce more

*9. For reasons of data availability, we used production data, which includes non-food uses, biofuels among them. However, despite increases in biofuel demand, feed and food uses will still represent the bulk of production for these crops (over 80%)*

with less. Urbanisation, climate change, overuse of chemical inputs (mainly crop protection chemicals and fertilisers), and inadequate or inappropriate investment all lead to land and soil degradation and are all serious problems. Furthermore, water, a crucial input in agricultural production, is becoming increasingly scarce. By 2025, according to the FAO (2012), 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world's population could be living under water stressed conditions.[10]

It should also be noted that the FAO's projections on the available food required in 2050 do not fully reflect the objective of eliminating undernourishment, which entails even greater levels of production (WRI, 2013).

In light of these changing circumstances, our focus here is to present solutions that will enable an increase in agricultural production combined with an efficient and sustainable use of resources. The report is focused on remedies specific to primary agricultural production (cereals, roots and tubers, sugar, oilseeds and fruits/vegetables), since other food commodities (meat, dairy, and farmed fish) are reliant on this primary production.

### 2|2 Where will the additional food come from?

Solutions for closing the food gap are likely to come from both production innovations and changes in consumption trends: on the one hand, it is essential that we increase the supply of food, on the other, there is real potential for a reduction in demand of certain commodities. Based on a review of key research (Alexandratos & Bruinsma, 2012; FAO, 2013; Fuglie & Nin-Pratt, 2012; OECD-FAO, 2013; WRI, 2013), we have estimated a broad range of sources liable to provide additional growth in the next ten years. These have been aggregated in Table 1 and Figure 8.

As concerns the augmentation of production, which roughly corresponds to the availability pillar of food security described in section 1, Bruinsma (Bruinsma, 2012) proposes distinguishing three broad avenues for increasing crop production:

- Cropland expansion: cultivating new areas, or extending irrigation to unused areas (especially in Africa and South America);
- Cropping intensification: increasing the number of crop rotations and/or shortening fallow periods;
- Yield increase: adopting technologies and practices that result in higher output from existing resources.

We have split the question of yield increase into several solutions, based primarily on the International Food Policy Research Institute's list of key technologies for 'sustainable intensification' (Rosegrant, 2014). Some solutions appear important enough to bear mention, even where we do not have robust estimates for how much they can contribute to increasing food production. Indeed, in our view, a dedicated in-depth analysis is needed to fully reveal the potential for seed productivity and bioprotection, which is why we have retained some question marks in our estimates (See Table 1).

The consumption aspect concerns primarily the access and use pillars of food security; here, we have based our analysis on solutions presented by the WRI. The WRI (Ranganathan, 2014) also considers fertility issues, in view to achieving a replacement birth rate; however, this has been excluded from our study as falling outside the scope of the private sector's potential impact.

Table 1 presents our estimations of the relative production growth potential for the various types of solutions identified. Detailed information concerning the methodology employed in arriving at these estimates is presented in the Appendix.

*10. The FAO defines water stressed conditions as water resources of between 500 and 1,000 m³ per year per capita, whereas water scarcity is set at levels of 500 m³ or less. See: http://www.fao.org/nr/water/topics_scarcity.html*

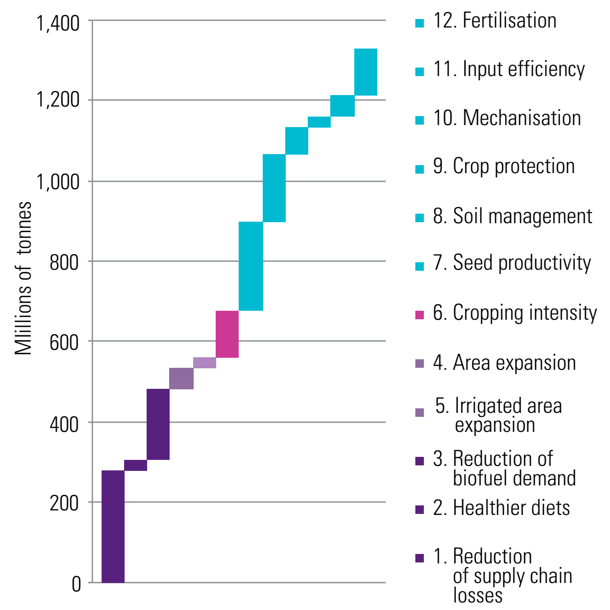
**Table 1.** Breakdown showing sources of production growth for the next ten years (percentages represent estimated growth attributable to each solution)

| Lever | Sources of growth | Solutions | Measures | Description | Source |
|---|---|---|---|---|---|
| Consumption (38%) | Reduce supply chain losses (22%) | | | Close to the farm solutions (postharvest, storage, transportation) and close to the fork solutions (processing, retail, shelf life) each present half of the potential for growth of this solution. | WRI |
| | Shift to healthier diets (2%) | | | Beef is the least efficient source of calories and protein. Shifting just 20%t of the anticipated future global consumption of beef to other meats, fish, or dairy could save hundreds of millions of hectares of forest and savannah. | WRI |
| | Reduce biofuel demand and favour food crops (14%) | | | Biofuels compete with foodstuffs for the use of land and crops. Producing enough biofuel to cover 10% of all transport fuel needs by 2050, as planned by some governments, would consume 32% of global crop production but produce only 2% of global energy. | WRI |
| Production (62%) | Cropping intensity (9%) | | | Increase number of crop rotations. | Bruinsman |
| | Expand cropland (6%) | Irrigated area expansion (4%) | | Irrigated area expansion requires access to water and infrastructure. | Bruinsman |
| | | Area expansion (2%) | | Area expansion means turning land that was not previously cultivated into arable land. Often it requires infrastructure to access the land, and/or deforestation. | Bruinsman |
| | Increase yields (47%) | Mechanisation (2%) | | Mechanisation refers to the use of tractors, harvesters, threshers etc. instead of human or animal labour. | Fuglie |
| | | Soil management (13%) | | Soil fertility management is a set of agricultural practices aimed at improving soil quality; these include the use of crop rotation and intercropping with legumes, but also the combined use of mineral fertilisers, locally available soil amendments (such as lime and phosphate rock) and organic matter (crop residues, compost and green manure) to replenish lost soil nutrients. Another soil management technique is no-till farming. Whereas conventional tillage consists of multiple disruptive stages: ploughing, disking, and running a cultivator, seeding and cultivating again, with no-till, there is only one stage: planting and spraying. This prevents soil erosion by reducing leaching, keeping nutrients longer in the soil and preventing erosion. | Fuglie |
| | | Seed productivity (>15%) | Conventional seed productivity (>10%) | Conventional seed productivity measures consist predominately of conventional breeding, seed treatment, native trait breeding and hybridization<br>Conventional breeding involves selecting the most suitable plants to meet given criteria and reserving their seeds for planting. This practice has been used for hundreds, even thousands of years and makes it possible to grow more resistant, highler-yield plants; however, this process is extremely lengthy.<br>Seed treatment consist in treating the seed prior to planting in order to reduce waste and pollution.<br>Native Trait breeding represents the latest innovation wave for the seed industry. This type of "smart" breeding does not involve inter-species transfer of genes to confer a specific benefit. Rather, a trait is transferred from one plant (e.g. a wild relative) through crossing, sometimes supported by genetic markers. Innovative Native Traits are also obtained by combining a high number of trait-conferring alleles, which previously only existed in separate varieties. Legislative debate has not determined the exact status of theseprocedures, which employ biotechnology to transfer genetic material. The most recent EU white paper considers them a subset of GM.<br>Intraspecific hybridization is hybridization between different sub-species within a species.<br>Reverse breeding and doubled haploids are methods for efficiently producing homozygous plants (carrying a single version of an allele) from heterozygous starting plants (multiple versions of the allele), thereby ensuring expression of the desired trait. | |
| | | | GM breeding (5%) | GM breeding employs techniques other than pollinization to introduce genetic material into seeds. This potentially allows crops to be designed to have heat and drought tolerance, among other traits, although the focus of GM has largely been on herbicide resistance, pest tolerance and yield increase. | IFPRI |
| | | Crop protection (>3%) | Chemical crop protection (3%) | Chemical crop protection consists of protecting crops from diseases, weeds and insects using synthetic substances. Each type of treatment is considered to participate equally in the effectiveness of this solution. | Rosegrant/ IFPRI |
| | | | Bioprotection (>0%) | Bioprotection is a natural alternative to chemical pesticides. | |
| | | Input efficiency (4%) | Water use efficiency (>1%) | The best-known water use efficiency technique is drip irrigation. Drip irrigation consists in irrigating drop by drop from a pipe near the plants' roots, minimizing water wastage. | IFPRI |
| | | | Water harvesting (<1%) | Water harvesting is the collection of rainfall for use. | IFPRI |
| | | | Precision agriculture (3%) | Precision agriculture consists in bringing the exact inputs needed to grow a particular crop given the local climatic, biological, and soil conditions, which involves significant data collection. | IFPRI |
| | | Fertilisation (9%) | Fertiliser intensification (3%) | Fertilisers supply essential nutrients needed for crop growth, including nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. These nutrients are naturally present in healthy soil, however and addition of inorganic fertilisers can disturb natural cycles. | Fuglie |
| | | | Nitrogen use efficiency (6%) | Nitrogen Use Efficiency involves increasing the ratio of nitrogen exported from the field in the form of crops to Nitrogen applied, whether through mechanical or biological solutions. | IFPRI |

Source: Mirova, 2014.

Derived from the above analysis, Figure 8 presents the production increase in millions of tonnes expected to result from each of the solutions identified. This was calculated by multiplying the solution's expected contribution as a percentage of agricultural production by 1,300, which is the number of millions of tonnes of additional cereals, roots and tubers, sugar, oilseeds and fruits / vegetables that need to be produced over the next 10 years (here, fish, meat and dairy have been deducted from the total 1.56 billion tonnes referred to in section 2.1).

**Figure 8.** Food gap for the next 10 years by source of growth




Source: Mirova, 2014.

At the **consumption level**, reductions to supply chain losses are divided into close to the farm solutions, which mainly concern developing countries, and close to the fork solutions, which are important primarily in developed countries. We estimate that close to the farm (losses) and close to the fork (waste) solutions each account for half of all supply chain losses. This is an approximation for the sake of simplicity at this stage; further details are presented in section 4 of this study.

Another major challenge is the competition for land and crops due to increasing production of biofuels. Certain current governmental policies for biofuel use in the transport sector call for biofuels to constitute 10% of all transport fuels by 2050. This trend would require 32% of the world's crop production, but would produce only 2% of the global energy needed for transport. Conversely, ceasing the use of 1st generation crop-based biofuels for transportation would close the food gap by roughly 14% (WRI, 2013). A more sustainable alternative to 1st generation biofuels are 2nd generation biofuels, which are produced from agricultural and organic waste. These 2nd generation biofuels do not compete with food in terms of agricultural production, and constitute a practice in keeping with a circular economy.

**Shift to healthier diets** mainly refers to reduced consumption of animal products such as meat and dairy (in particular beef). However, this solution is only expected to have minor effects on reducing the food gap, considering the lack of access to animal proteins currently suffered by the poorest populations.

At the **production level**, limited scope exists for **area expansion** (cropland and irrigated area). Alexandratos & Bruinsma (2012) found that the total additional land that could be employed for cultivation between now and 2050 amounts to an area equivalent to only 7% of existing agricultural land, most of it located in Latin America and Africa. Furthermore, this solution raises sustainability issues as land expansion often requires deforestation, leading to losses of biodiversity and ecosystem services such as $CO_2$ capture.

It is often claimed that yields of major cereal crops have begun to decline, after reaching their limit in farmers' fields. Some commentators even claim that food is subject to the same profile as oil and gas production, and refer to a 'peak food' situation. Nevertheless, while achieving productivity growth in developed countries has become challenging, many developing countries can still experience large jumps in productivity by using classic drivers of growth (i.e. conventional breeding, irrigation, mechanisation and chemical inputs) (Fuglie & Nin-Pratt, 2012). Solutions for closing the food gap vary widely among countries, depending on their climate, level of development, and available resources, and it should be remembered that we emphasize on an overall picture of the main issues rather than micro-level effects.



The central and most general lever for increasing food availability remains yield improvement, which contributes almost half of the production gains (44% of total gains) in Table 1. Yield growth has been the mainstay of historic production increases and will continue to play this role in the future.

## 3 | The Private Sector and its Solutions

Access to food is a human right enshrined in Article 25 of the 1948 Universal Declaration of Human Rights. States and governments bear a responsibility to make sure that this right is upheld both within their populations and on an international scale.

In particular, states that are parties to the 1966 International Covenant on Economic, Social and Cultural Rights (ICESCR) have the obligation to respect, promote and protect this right, and to take appropriate steps to progressively achieve a full realisation of the right to adequate food.

**Panel 2. 1948 Universal Declaration of Human Rights, Article 25**

Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control.

As a global strategic issue recognised by the United Nations as a Sustainable Development Goal (SDG) for 2030,[11] food security is today assessed using a growing assortment of increasingly sophisticated tools by public and non-governmental organisations. There exist many initiatives, including those led by the UN and the FAO, to tackle this issue. Although the public sector bears responsibility for guaranteeing quality of life and dignity, governments cannot achieve food security alone, and require participation by the private sector. In its latest report assessing the private sector's contribution to the SDGs (UNCTAD, 2014), UNCTAD identifies food security and agriculture as being among the main areas where private sector contributions can have a significant impact.

The private sector already plays a major role in agricultural industries, with an average contribution ranging from 75% of all agricultural investment in developing countries to over 90% in developed economies (UNCTAD, 2014). The solutions we explore in this study in our role as responsible investors can further contribute to the achievement of food security.

Based on the main sources of production growth for the next ten years identified in the previous section (see Table 1), table 2 presents the sources of production growth in which we see the strongest potential for businesses to contribute; these are referred to as 'solutions'.[12]

**Table 2.** Sources of growth by potential for corporate contribution

| Lever | Sources of growth | Measures | Significant business exposure |
|---|---|---|---|
| Consumption | Reduce supply chain losses | Reduction of supply chain losses | √ |
| | Shift to healthier diets | Shift to healthier diets | |
| | Reduce biofuel demand for food crops | Reduce biofuel demand for food crops | √ |
| Production | Expand cropland | Irrigated area expansion | √ |
| | | Area expansion | √ |
| | Cropping intensity | Increase crop rotation | |
| | Yield increase | Conventional seed productivity | √ |
| | | GM breeding | √ |
| | | Soil management | √ |
| | | Chemical crop protection | √ |
| | | Bioprotection | √ |
| | | Mechanisation | √ |
| | | Water use efficiency | √ |
| | | Water harvesting | |
| | | Precision agriculture | √ |
| | | Fertiliser intensification | √ |
| | | Nitrogen use efficiency | |

Source: Mirova 2014.

### 3|1 Priorities for private investment

Schmidhuber and Bruinsma (2011) have identified the principal areas in which public spending on agriculture is needed to close the food gap by 2025. Expanding rural infrastructure and market access, expenditures for safety nets, developing and conserving natural resources are the priority areas for public investment to eradicate poverty. But what about private investment; how should private sector choices be prioritised? What type of additional investment should capital owners focus on to close the food gap?

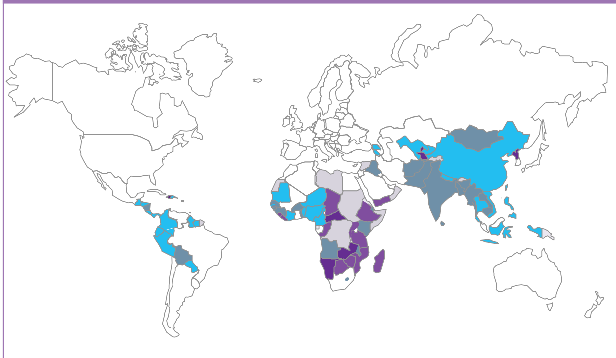
#### 3|1|1 Priority to developing countries

**Agricultural investment is positively correlated to food security**

Insofar as we seek to prioritise investments in food security, developing countries are obviously a strong area of focus. Not only is this where the most urgent issues of food security lie (see Figure 9), but it is also where investments are the most needed and can have the highest impact.

Despite wide variations across countries and commodities, it is important to bear in mind that the bulk of food products are produced and consumed locally (on average, less than 20% of world production flows through international trade).

**Figure 9.** Developing countries are also the most vulnerable to food insecurity




Source: Mirova (based on FAO, 2014).

Overall it is estimated that over two-thirds of all private investment needed to achieve the UN Sustainable Development Goals will be concentrated in developing countries. As concerns food security and agriculture in particular, relevant investments are currently estimated at around US$ 220 billion per year. Meanwhile, the annual investment gap for the 2015-2030 period is estimated at US$ 260 billion (UNCTAD, 2014).[13] Corporate investment in the agricultural sectors of developing countries thus represents an opportunity to fill this large investment gap, or to support the creation of infrastructure as well as the transfer of technology and knowhow.

*11. The Sustainable Development Goals are a new set of proposed global targets for the development of our societies, which build upon the Millennium Development Goals, established for 2015-2030. They were formulated in the wake of the Rio+20 Conference, held by the UN in June 2012 with the objective of defining 'the future we want'.*

*12. Sources of growth that rely predominately on consumer and/or farmers' habits have not been retained.*

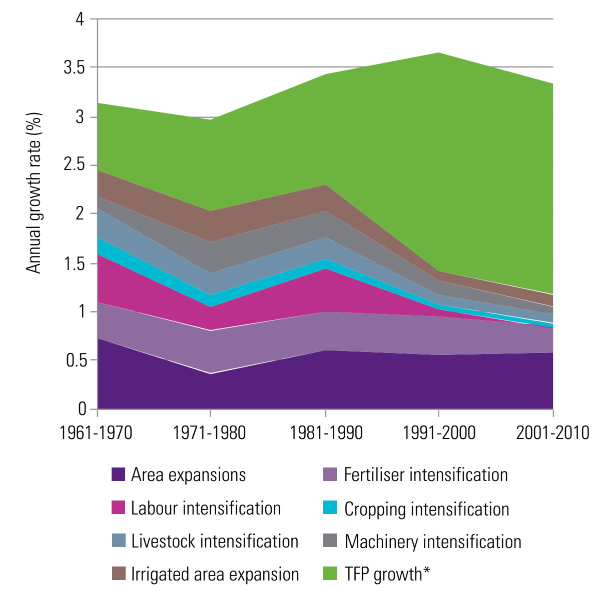
*13. It should be noted that data on needed investments to achieve food security vary significantly according to the definition of food security that is used. Here UNCTAD refers to a broad definition, which includes elements such as rural development or safety nets, which might be larger than the scope of our study.*

The range of eligible actors includes agro-enterprises as well as private equity firms and other financial institutions, including government-linked companies.

In terms of impact, economic studies have found high returns for investments in agricultural research in developing countries. For instance, the World Bank's investments in developing countries over the last years have shown extremely good returns on investment, ranging conservatively from a 175% return on investment to almost 900% (World Bank, n.d.).

The FAO's recent studies also show a positive correlation between levels of investment in agriculture and food security and poverty reduction in developing countries. With respect to our table of possible mechanisms for reducing the food gap, the sources of growth characteristic of developing countries are not significantly different from those identified in worldwide findings. Productivity gains remain the most powerful vehicle for growth. We would note a stronger than average but declining need for intensification in low-income countries, as some regions, especially in Africa, are not fertilised or mechanised 'enough'.

**Figure 10.** Agricultural production growth in developing countries over the past 50 years




Source: Mirova (adapted from Fuglie, 2012).

*TFP, or Total Factor Productivity, is the portion of output not explained by the quantities of inputs employed in production. As such, its level is determined by how efficiently and intensely inputs are utilised in production (Comin, 2006).

**Ensuring positive outcomes from private sector investment**

While the private sector's contribution to food security offers great potential, it can also be the source of negative impacts that have to be guarded against. Some business models can carry risks for local communities, with environmental degradation, water depletion and land rights or access being the most likely negative impacts of investment from a local stakeholders' perspective (World Bank, 2014). For example, globalisation has led to situations in which companies may be preventing states from acting in a manner that respects the right to food.

In several developing nations, local production cannot compete fairly with products offered by subsidised international brands imported from richer countries. Likewise, a number of dubious land deals have attracted severe criticism because of detrimental social and environmental outcomes. The global concern over palm oil is one illustration of the growing awareness surrounding this issue.

In order to monitor the best practices available in the private agricultural sector, stakeholders have drafted a set of **Principles for Responsible Agricultural Investment** that are in the process of being tested and adopted by the international community (see Table 3).

Based on detailed research into private sector investment impacts and best practices in law and policy, the Principles are intended to provide a framework for regulations, investment agreements, individual investor contracts, and, most importantly for this study, global corporate social responsibility initiatives. These principles will serve as a guideline for determining how companies in the agricultural sector behave in terms of their contribution to a sustainable food system.

**Table 3.** Principles for Responsible Agricultural Investment (PRAI)

| | |
|---|---|
| Principle 1: Contribute to Food Security and Nutrition | Investments do not jeopardize food security but rather strengthen it. |
| Principle 2: Contribute to sustainable and inclusive economic development and the eradication of poverty | Investments generate desriable social and distributional impacts amongst employees, farmers and local communities, provide for inclusive growth and should not increase the vulnerability of these people. |
| Principle 3: Foster gender equality and women's empowerment | Investments encourage the advancement of women's equal rights through measures such as adopting approaches that enhance women's meaningful participation in important roles |
| Principle 4: Engage and empower youth | Investments allow the youth to be drivers of improvement in agriculture and food systems. |
| Principle 5: Respect tenure of land, fisheries, and forests, and access to wate | Investments recognize and respect existing rights to land and associated natural resources that are in line with the relevant guidelines. |
| Principle 6: Conserve and sustainably manage natural resources, increase resilience and reduce disaster risks | Investments, at the same time, conserve natural resources through preventing, minimizing and preventing negative impacts, and increase the resilience ot the effects of climate change through the integration of traditional and scientific knowledge with best practices and technologies. |
| Principle 7: Respect cultural heritage and traditional knowledge, and support diversity and innovation | Investments do not further isolate vulnerable populations such as indigenous tribes and smallholder farmers but rather should promote the fair and equitable sharing of benefits arising from the utilization of genetic resources for food and agriculture. |
| Principle 8: Promote safe and healthy agriculture and food systems | Investments moves current agriculture and food systemes towards one that is safe and healthy through supporting sustainable practices in animal health and welfare, and plant health, reducing risks to public health, enhancing awareness and knowledge and enabling consumer choice through availability and access to proper and nutritious food. |
| Principle 9: Incorporate inclusive and transparent governance structures, processes and grievance mechanisms | The process of investment is free of corruption, transparent and monitored, includes an effective and meaningful consultation with indigenous people and other vulnerable populations, and takes the proper steps to respect human rights and legitimate tenure rights |
| Principle 10: Assess and address impacts and promote accountability | The process of investment includes mechanisms to assess and adress economic, social, environmental, and cultural impacts, respects human rights and promotes accountability of each actor to all relevant stakeholders. |

Source: Mirova 2014.

Consequently, our assessment of companies' contribution to increasing food availability in developing countries will take these guidelines into account. In particular, critical issues include the need to respect the rights of existing users of land, water and other resources, protecting and improving livelihoods at the household and community level, and avoiding harm to the environment. To this effect, activities involving large-scale land acquisition will be assessed with caution, as these raise serious concerns regarding any likelihood of positive local impact (World Bank, 2014). Conversely, we will favour companies that provide local social services such as education, healthcare, rural and farming infrastructure, or establish local water provision schemes and access to financing.

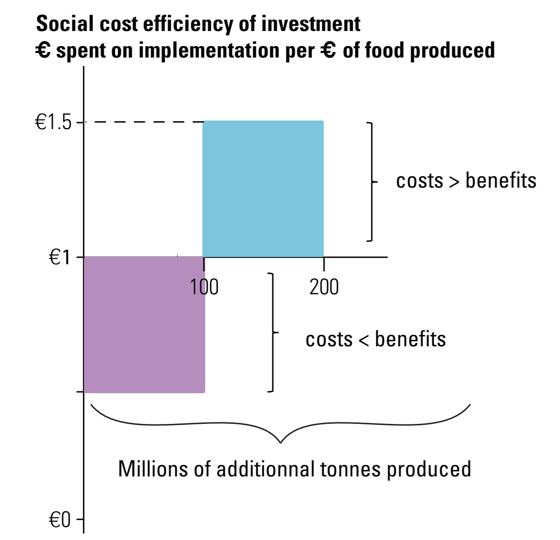
### 3|1|2 Cost-effective and sustainable solutions

Having prioritised the areas for investment, we can turn our attention to considering which solutions and technologies show the greatest potential. Amongst the many innovations (seed technologies, bioprotection, precision technologies), which are likely to be the most cost-effective in closing the food gap? Any answer to this question will, of course, need to recognise that not all solutions will fit each region or country, due to differences in climate, access to new technologies, and current yields.

**Panel 3. Cost efficiency curves**

From a food security perspective, the cost-effectiveness of a solution is the ratio of the costs involved to its contribution to closing the food gap, assessed in euros. If this ratio is inferior to 1, then the benefits are higher than the costs and the solution is cost-effective. If the ratio is greater than one it is not.

**Figure 11. Illustration of the gap production cost curve**




It should be noted that the cost/benefit ratio's equilibrium, or break-even point, is situated on the horizontal line that crosses the vertical axis at 1. This simply means that at this point, 1 euro spent produces 1 euro's worth of additional food production. For the solution coloured blue in Figure 11, this ratio is equal to 1.5, meaning that costs are higher than the return in terms of food value produced. The horizontal axis represents agricultural production increases attributable to the solution, as was the case in section 2's Figure 8. In the hypothetical case pictured in Figure 11, both solutions increase agricultural production by 100 tonnes; however, the purple one is cost-effective whereas the blue is not.

For each of the solutions to which a particular business sector is exposed, a cost-benefit analysis was performed to identify the most advantageous solutions from a business as usual perspective. Having done this, we then recalculated the cost curve, taking into account environmental and social considerations, in order to target solutions offering the most cost effective opportunities to contribute to sustainable food security.

**Assessing the cost-effectiveness of solutions**

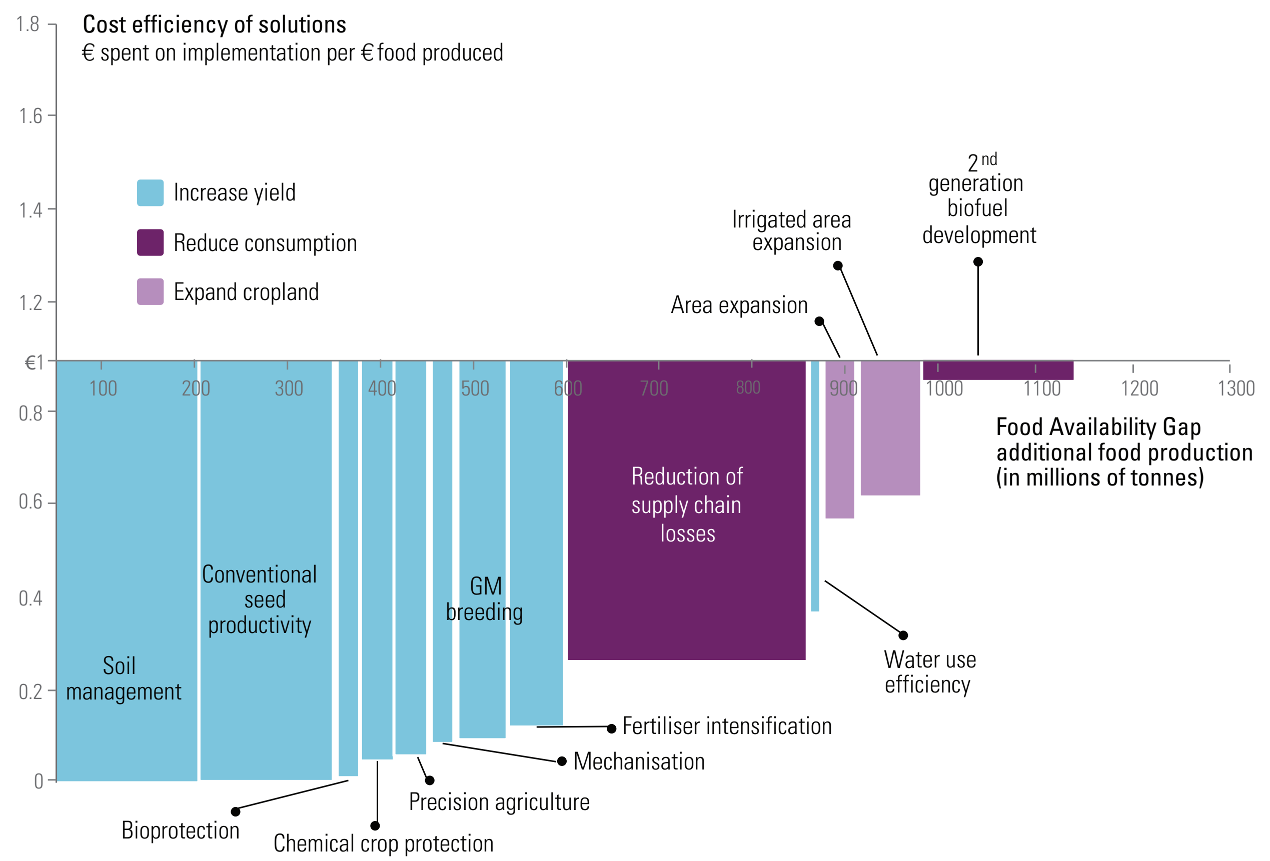
In considering the relative benefits of solutions, we based our calculations on the increased agricultural production (in tonnes) estimated for each one in section 2 (see Figure 8). We then monetised these quantities, multiplying the amounts expected from each strategy by an average food basket,[14] price of US$ 234 per tonne. We arrived at this price by applying an 8%,[15] discount rate to the nominal food prices forecast by the OECD and FAO (OECD-FAO, 2013); we then weighted the published prices according to the World Bank weights for the price index (Pink data set downloaded from world Bank, 2014). We recognise that this strategy entails a significant underlying assumption: that pricing reflects not only the market value, but also the use value of foodstuffs, their nutritional, caloric, social and satisfaction value. By the 'social value of food', we mean the benefits of healthy and sufficient food that enable people to expend energy at work and in a social life.

As concerns the costs associated with each solution, we took into account the cost of implementing the technology or process per tonne of food produced, and then multiplied by the estimated amount of production increase assigned to the solution, as per section 2 above (again, see Figure 8). The production increase attributed to each solution was calculated as for Figure 8. Costs were computed using data from Brookes & Barfoot (2014), the McKinsey Global Institute (2011), and Oerke (2010). The calculation itself is modelled on that of the McKinsey Institute.

The production cost curve presented in Figure 12 illustrates the general cost efficiency of each food production lever. This information can help direct investment priorities towards the most capital-efficient sources of growth in developed countries.

*14. This average basket is comprised of cereals, oilseeds and sugar, in keeping with the scope set for this study.*
*15. The 8% discount rate is relatively reasonable for a 10-year term from a private investor perspective.*

**Figure 12.** Food gap production cost curve for the next 10 years




Source: Mirova, 2014.

Our analysis suggests that all the solutions identified in section 2 are economically viable; that is, the annualised financial value of the additional food they would produce is higher than the cost of implementation (i.e. cost efficiency of the investment lower than 1). The graphic makes it possible to easily compare the various solutions, and indicates that the most cost-effective solutions are bioprotection, soil fertility management and seed productivity. Conversely, area expansion and irrigated area expansion are the least cost-effective, along with 2nd generation biofuel development. The additional costs associated with area expansion and irrigated area expansion relate to high entry costs in terms of infrastructure or adaptation to the conditions of production. For 2nd generation biofuels development, additional organisational costs come from the need to establish a circular economy. This solution also involves additional investment in infrastructure and plants to treat waste and recycle it into biofuel.

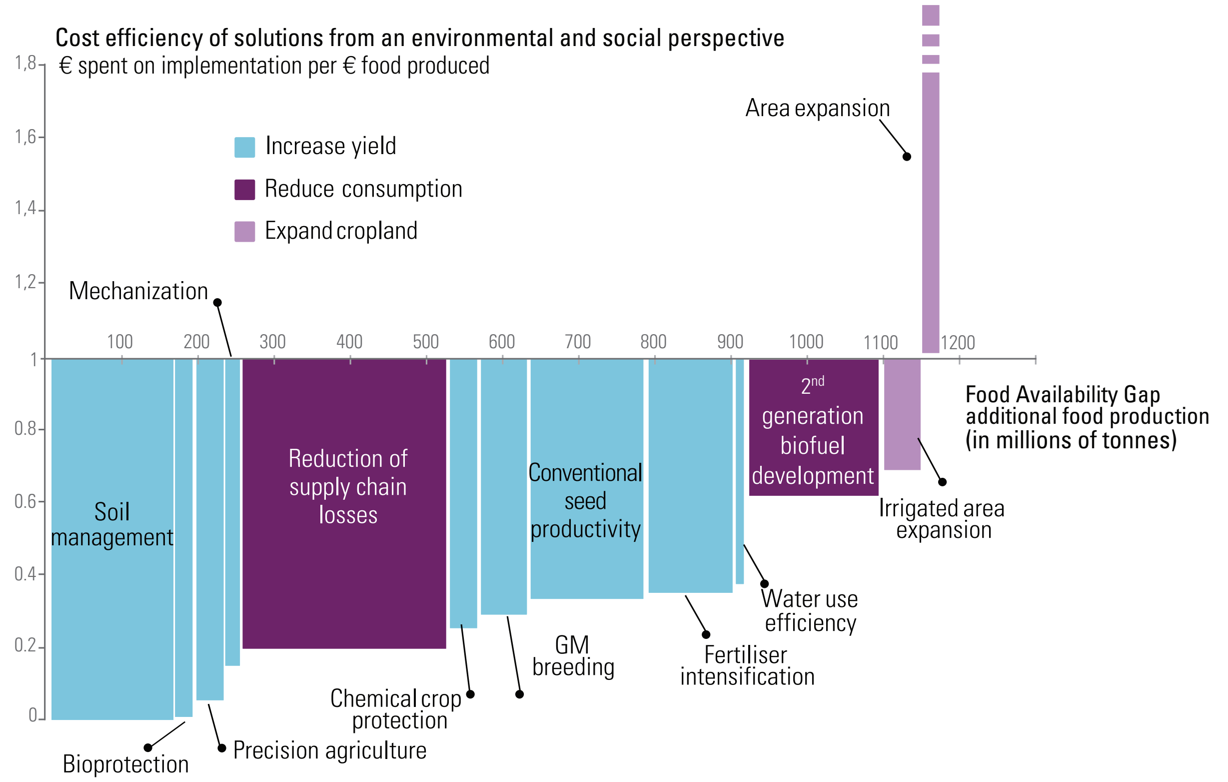
**Assessing the cost-effectiveness of the solutions from a sustainability angle**

However, this basic form of cost-mapping ignores environmental and social impacts that arise from implementing these various means of increasing food production. A responsible assessment needs to be based on life-cycle analysis, and take into account the wide-ranging effects of each solution beyond the frontiers of production itself, including environmental and social effects, both direct and indirect. A new cost curve that reintegrates environmental externalities reshapes the main outcomes and offers a more robust notion of the actual costs and advantages for each solution envisaged.

Our approach to incorporating these concerns consisted of the following. If the solution provides environmental benefits, we estimated the monetary value of such, and subtracted it from the cost of the solution. Where the solution threatens to cause environmental damage relative to current agricultural practices, the estimated environmental cost was added to the cost of implementation. Three environmental externalities are re-internalised in Figure 13, based on three assumptions.

- Climate change effects are calculated using a price of US$40 per tonne of $CO_2$ for carbon pollution.
- Environmental costs for water use are represented as a water tax inspired by the polluter pays principle (Rieu, 2005). An average water tax price of US$0.04/$m^3$ (Chinese levels) was employed in our calculations.
- The value of pollination services as an essential service to agricultural ecosystems is estimated at €22 billion for European agriculture (Gallai, 2009).

**Figure 13.** Food gap production cost curve for the next 10 years from a social and environmental perspective




Source: Mirova, 2014.



Once the environmental impacts of each solution are taken into account, bioprotection and soil fertility management remain the most cost effective solutions. Nevertheless, precision agriculture follows next, as it makes for a more efficient use of inputs, thereby saving resources. Conversely, crop protection, seed productivity and fertilisation become somewhat less cost-effective than they were under the basic cost analysis, since they involve significant water pollution and losses to biodiversity (especially crop protection). The development of 2nd generation biofuels becomes more cost effective once environmental externalities are adjusted for; this is due to the resource savings achieved through use of agricultural waste (rather than direct agricultural production which competes with food uses). The reduction of supply chain losses appears even more cost efficient in our second cost curve, as a result of including the waste of resources avoided, in addition to foodstuffs saved. Lastly, we see that area expansion ceases entirely to be cost effective when we take into account environmental externalities, because such expansion often drives deforestation, leading to losses in biodiversity and in $CO_2$ capture services.

**Panel 4. What is bioprotection and why is it the most cost-efficient solution?**

Bioprotection refers to mechanical or biological crop protection, as opposed to chemical crop protection. Bioprotection is used to designate solutions that have no negative environmental externalities and/or are inspired by or derived from nature. This mainly comprises biopesticides, but also includes other non-market solutions as natural predators of pests and scarecrows. Within the scope of our study, in discussing bioprotection we are referring to biopesticides. The Environmental Protection Agency (EPA) defines biopesticides as specific types of pesticides derived from natural materials such as animals, plants, bacteria, and certain minerals. Biopesticides are considered an effective pest control option for organic crop production, and are part of the general principles of integrated pest management (IPM). IPM is an ecosystem-based approach to crop production and protection that combines several management strategies and practices in order to promote healthy crops and minimise the use of synthetic pesticides. The FAO and the European Commission promote IPM as the preferred approach to crop protection, and regard it as a pillar of both sustainable intensification of crop production and pesticide risk reduction (FAO, AGP-Integrated Pest Management, 2014).

Bioprotection is thus among the sustainable agricultural practices that need to be promoted if we are to achieve a sustainable food system. This solution is very cost effective, since it is cheap to implement (US$ 17/ha for Green Muscle, a biopesticide made by BASF), and provides considerable environmental benefits compared to conventional crop protection, which contributes to water pollution and can affect biodiversity, while offering the same advantages in terms of crop protection and pest management.

It is thus an attractive sector for responsible investment. The global market for biopesticides was valued at US$ 1.3 billion in 2011, and is expected to reach US$ 3.2 billion by 2017, growing at a CAGR of 15.8% from 2012 to 2017. North America has dominated the global biopesticide market to date, accounting for around 40% of the global biopesticide demand in 2011. Europe is expected to be the fastest growing market in the near future, owing to the stringent regulation of pesticides, and increasing demand for organic products. (MarketsandMarkets, 2014).

Several listed companies have already established a presence in the biopesticide market: examples include Marrone Bio Innovations, Novozymes and Camson's bioprotection solutions, which are derived from natural sources. Bioprotection agents produced by Novozyme are based on microorganisms and naturally occurring fungi. Marrone Bio Innovations' biopesticides rely on naturally occurring substances, such as microbes, Bt bacteria, plant extracts, fatty acids or pheromones. Lastly, Camson's biocides are entirely derived from microbes. We can also mention Tyratech, whose products are not natural substances, but are formulated to be more selective than most synthetic pesticides. Tyratech uses chemicals that are detrimental only to insects and invertebrates, but have no adverse effects on mammals or humans. Nevertheless, Tyratech products could be detrimental to pollinators, and this remains a very important issue.

Through this second cost curve, our analysis highlights the most cost-effective solutions from a responsible investment perspective: precision agriculture, reduction of supply chain losses, and development of 2nd generation biofuels. Irrigated area and overall area expansion, however, offer even less significant sustainable opportunities.

It is important to note that these cost curves represent a work in progress. The key to improving their accuracy and relevance lies in incorporating several additional features.

- Geographical distinctions: Agricultural cost-structure, technology, practices & benefits differ significantly from one region to another.

- Finer distinctions in quantifying benefits: analysis of revenues from food production (based on an average food basket priced at US$ 158/tonne, per McKinsey Global Institute, 2011) could be further refined by distinguishing amongst food commodities.

- Valuation of further environmental externalities such as soil fertility.

- Valuation of social externalities such as life-expectancy changes and healthcare requirements.

### 3|2 Investment options for closing the food gap sustainably

The preceding analysis highlights certain solutions that deserve attention due to either geographical criteria cost efficiency, or their combination of cost & environmental efficiency. Given Mirova's inclination to favour investments providing positive environmental and social impacts, it seemed logical for us to focus on solutions that are efficient from both a sustainability and a cost perspectives.

Keeping in mind that our investment scope is limited to listed equities, de facto excluding a large spectrum of potential investment opportunities (private companies, small enterprises, public-private partnerships, etc.), we screened a large universe of listed companies to identify those involved in these solutions.

Therefore we selected companies exhibiting at least one of the following features:

- Innovative solutions contributing to sustainable agriculture, i.e. environmentally-friendly alternatives to conventional agricultural practices that answer the food security issue (biocontrol, biofertilisation, organic farming, precision agriculture, no-till seeding, water use efficiency, etc.);

- Business-as-usual solutions which help increase food availability and access with a strong exposure to developing countries (mechanisation, reduction of supply chain losses).

Table 4 gives examples of companies that are significantly exposed to such solutions and that would fit our investor constraints.



**Panel 5. Is monetisation a good way to analyse environmental impacts?**

We are aware of the fact that environmental evaluation is open to criticism. Ackerman and Heinzerling (Ackerman, 2005) argue that, with the environmental evaluation method, we know 'the price of everything and the value of nothing', as per the Oscar Wilde quip. Diamond and Hausman (Diamond, 1994) even ask: 'Is some number better than no number?' Nonetheless, we believe it is important to take environmental externalities into account, both positive and negative, when attempting to produce a sustainable view of solutions proposed to increase food security. Indeed, food production is closely linked to the environment, and the negative externalities created by intensive activities are no longer a matter for doubt. Hence, although pricing such externalities may not be ideal—contingent valuation, revealed preferences, ecosystem services and other environmental evaluation methods have many limits—it still provides fairly consistent estimates. These estimates represent the price, calculated as the price of $CO_2$, the price of water, or the price of biodiversity that corresponds to the toll human use of the environment takes on the world; this obviously does not include the intrinsic value of the environment. Nevertheless, assigning a monetary estimate of the environmental impact (positive or negative) involved in the implementation of various solutions acknowledges their effects and makes it possible to better capture their sustainability and potential risks, both of which are significant for a socially responsible investor.

**Table 4.** Examples of companies offering solutions to sustainable food security (within our investor constraints)

| | Value Chain | Examples of companies offering solutions creating sustainable opportunities | Country | Market capitalisation (€M as of 25/11/2014) | Exposure | Comment |
|---|---|---|---|---|---|---|
| Improving food AVAILABILITY-Farming efficiency | **Farm inputs** | | | | | |
| | Seeds | VILMORIN ET CIE | FRANCE | 1,604 | Medium | Vilmorin & Cie S.A. is a pure player on food security as it produces and markets conventional vegetables (~55% of revenues) and field seeds (corn, wheat, rape, sunflower, etc. accounting for 40%). The company has an ambitious growth strategy in Africa (~10% in 2013) with a lower exposure to GM seeds. |
| | Other inputs (fertilisers, crop protection, etc.) | NOVOZYMES AS | DENMARK | 11,852 | High | Novozymes offers various technologies contributing to sustainable agriculture, including enzymatic pesticides, microbial yield and fertility enhancers helping to produce healthier crops with higher yields. |
| | **Farming equipment** | | | | | |
| | Machinery | KUBOTA CORP. | JAPAN | 15,321 | High | With an estimated 40% of Kubota´s sales in countries with inefficient machinery, Kubota provides significant improvement of mechanisation rate in Asia (China, and South Asian countries). Kubota is also exposed to sustainable opportunities through its water and environment system segment (40% of Kubota´s sales), which contributes to a safe water supply. |
| | | DEERE & CO | UNITED STATES | 25,283 | Medium | John Deere has a significant implementation in lower-mechanized countries (~10% of its farm sales and > 30% of CAPEX in the last 3 years dedicated to Russia, India and China). Note that Deere is investing to become Africa's premiere tractor brand. Despite a lack of relevant data, we also appreciate John Deere´s efforts to develop precision agriculture and agronomic support to farmers. The company is also present in irrigation systems and equipment through their subsidiary, John Deere Water. |
| | | AGCO CORP. | UNITED STATES | 3,292 | Medium | As a farm machinery producer upgrading the level of agricultural mechanisation in Russia, Ukraine, China and Africa (representing a ~10-15% share of business done in these countries), Agco is significantly exposed to food security theme by equipping poorly mechanised countries. |
| | GPS and other technologies | TRIMBLE NAVIGATION LTD | UNITED STATES | 5,881 | Medium | Trimble Navigation Limited produces electronic products, enabled by Global Positioning System technology, that determine precise geographic location. The company is involved in precision agriculture mainly through its OmniSTAR subsidiary (estimated 25% sales). |
| | | TOPCON | JAPAN | 1,900 | Medium | Topcon is involved in precision agriculture through its GPS technologies applied to agriculture. Sales derived from these applications are estimated to be <15% of total net sales, but this is a growing focus area for the company. |
| | Irrigation | JAIN IRRIGATION SYSTEMS LTD | INDIA | 478 | High | Jain manufactures micro-irrigation systems, including both drip and sprinkler systems. |
| | | TORO | UNITED STATES | 2,978 | Medium | Toro offers agricultural irrigation systems, that regulate the flow of water for drip irrigation and increase water use efficiency, it also offers drip irrigation design software to help design the irrigation system. |
| | | VALMONT INDUSTRIES | UNITED STATES | 2,712 | Medium | Valmont manufactures centre pivots and linear irrigation equipment, with a some involvement in precision irrigation. |
| | | LINDSAY CORP | UNITED STATES | 871 | Medium | The company's irrigation segment generates revenue from three primary sources: 1) conversion of dry land to irrigation; 2) conversion from less efficient irrigation methods to mechanised systems; and 3) sales of replacement systems and parts. |
| | **Production** | | | | | |
| | **Farms/ Farming** | NA | | | | |
| Improving food ACCESS-Reducing food losses and waste | **Storage / Transportation / Refrigeration** | NA | | | | |
| | Packaging | MPACT LTD | SOUTH AFRICA | 444 | High | Mpact is a paper and plastic packaging business with operations in South Africa, Namibia, Mozambique and Zimbabwe. The company produces packaging products for food, beverage, personal care, agricultural and retail markets. |
| | | MONDI | UK | 6,594 | Medium | The Mondi Group is a fully integrated company across the packaging and paper value chain – ownership and management of forests to the production of pulp and paper. They additionally supply their customers with innovative packaging solutions. The company operates in several countries in Europe, the Americas, Asia, and South Africa. |

Building on this research, we have also identified companies which do not fit our investor constraints as of today (for reasons of either free float or liquidity, or because of the stock exchange where they are listed), but which do exhibit at least one of the above-mentioned features and as such, are indicative of potentially interesting areas for investment moving forward.
Table 5 presents examples of such companies.

**Table 5.** Examples of companies offering solutions to sustainable food security (outside our investor constraints)

| | Value Chain | Examples of companies offering solutions creating sustainable opportunities | Country | Market capitalisation (€M as of 25/11/2014) | Exposure | Comment |
|---|---|---|---|---|---|---|
| Improving food AVAILABILITY- Farming efficiency | **Farm inputs** | | | | | |
| | Seeds | NA | | | | |
| | Other inputs (fertilisers, crop protection, etc.) | PLANT HEALTH CARE PLC | UK | 103 | High | Plant Health Care PLC has a significant involvement in agricultural inputs with lower environmental impacts, including biofertilisers, water management products, and biopesticides. |
| | | MARRONE BIO INNOVATIONS INC | UNITED STATES | 50 | High | Marrone Bio Innovations Inc. Is a pure player in bioprotection. |
| | | CAMSON BIO TECHNOLOGIES LTD | INDIA | 50 | High | Camson Bio-Technologies Ltd. is an integrated agriculture bio-technology company with a significant involvement in bioprotection. |
| | | TYRATECH INC | UNITED STATES | 19 | Medium | TyraTech is involved in bioprotection through its offer of natural pesticide products. |
| | **Farming equipment** | | | | | |
| | Machinery | CLEAN SEED CAPITAL GROUP LTD | CANADA | 10 | Medium | Clean Seed Capital Group Ltd. manufactures farm equipment and is involved in no-till farming. |
| | GPS and other technologies | NA | | | | |
| | Irrigation | XINJIANG TIANYE WATER SAVI-H | CHINA | 44 | High | Xinjiang Tianye Water Saving Irrigation System Co Ltd. designs, develops, manufactures, sells, and installs water saving irrigation systems. |
| | | AMIAD WATER SYSTEMS LTD | ISRAEL | 43 | High | Amiad Water Systems Ltd. produces and supplies water filters and filtration systems for different markets, including agriculture. The company is involved in environmentally-friendly filtration solutions for industrial, municipal, and irrigation uses. |
| | | MODERN WATER PLC | UK | 23 | High | The first company to commercialize forward osmosis, a process that could reduce energy consumption by up to 30% versus reverse osmosis in the desalination process. |
| | | CAPTAIN POLYPLAST LTD | INDIA | 10 | High | Captain Polyplast Ltd manufactures and sells micro irrigation systems and allied products such as filters, fittings and valves. |
| | **Production** | | | | | |
| | Farms/Farming | ESTEEM BIO ORGANIC FOOD PROCESSING LTD | INDIA | 125 | High | Esteem Bio Organic Food Processing Limited is an agricultural company involved in organic production in rainfed areas in India. |
| | | ECO FRIENDLY FOOD PROCESSING PARK LTD | INDIA | 169 | High | Eco Friendly Food Processing Park Ltd is an agricultural company involved in organic production of wheat, rice, pulses and vegetables in rainfed areas in India. |
| | | KTG AGRAR SE | GERMANY | 88 | Medium | KTG AGRAR is involved in both conventional and organic production in Germany and Lithuania. |
| Improving food ACCESS - Reducing food losses and waste | **Storage / Transportation / Refrigeration** | PIMI AGRO CLEANTECH INC | UNITED STATES | 29 | High | The company is involved in researching environmentally friendly solutions as an alternative to chemical posthharvest treatment. |
| | | EASTERN MEDIA INTERNATIONAL CORP | TAIWAN | 169 | Medium | Eastern Media International stores and warehouses agricultural products such as wheat, barley, soybean and corn. |
| | Packaging | XINJIANG GUANNONG FRUIT & ANTLER GROUP CO LTD | CHINA | 987 | Medium | The company manufactures, processes and sells sugar products, fruits and vegetables in China. They also store and transport fruit within the country. |

Based on this screening, our first conclusion is that the number of listed and investable pure players is minimal on this thematic. Innovative sustainable solutions which contribute to the food security challenge are either developed within small divisions of large corporations involved in very diverse activities, or within small (and often unlisted) enterprises. As such, the choice of investments that strongly and positively affect movement towards ensuring sustainable global food security remains restricted.

Therefore, if the food gap is to be closed, it is still vital to invest in companies providing business-as-usual solutions that help increase global food security. Nevertheless, where solutions pose environmental and social risks, the companies' capabilities to minimize and manage these risks must be meticulously analysed (see for example Mirova's previous study on palm oil).

Table 6 cites examples of companies that offer such business-as-usual (BaU) opportunities to help secure the global food supply.

**Table 6.** Examples of companies offering BaU solutions contributing to food security (within our investor constraints)

| | Value Chain | Examples of companies |
|---|---|---|
| Improving food AVAILABILITY - Farming efficiency | **Farm inputs** | |
| | Seeds | KWS Saat AG |
| | Other inputs (fertilisers, crop protection, etc.) | Mosaic Co./The, K+S AG, Auriga Industries |
| | **Farming equipment** | |
| | Machinery and other agricultural technologies | Bucher Industries, CNH, Exel industries, Titan International |
| | **Production** | |
| | Farms/Farming | Select Harvests Ltd, NBPO Ltd, Fresh Del Monte Produce Inc, China Modern Dairy, Adecoagro, SLS Agricola |
| Improving food ACCESS Reducing food losses and waste | **Storage / Transportation / Refrigeration** | Canadian National Railway Co. |
| | Packaging | Brambles, Mayr-Melnhof Karton AG, Winpak Ltd, Rock-Tenn Co., Packaging Corp of America |

Finally, as a responsible investor, Mirova would subjects all companies identified to further environmental, social and governance (ESG) risk reviews as well as an in-depth analysis of their economic and financial potential before they could be considered investable companies from all aspects.

In the next sections of this report, the following three areas have been selected for more in-depth attention:

- Post harvest losses: as indicated in section 2.2, 22% of the food increase required to close the food gap could be achieved through the mere reduction of supply-chain losses, half of this amount from the reduction of postharvest losses alone.



- Biotechnology: We have also chosen to devote a focus section to biotechnologies, as an area in which there has been a high degree of controversy, even outright confusion, and where there is not, as yet, a scientific consensus on key issues of safety and environmental impact.

- Water management: Section 2.2 highlighted the potential of water solutions, even though they contribute little to production growth directly. Our interest here stems from the fact that water scarcity is an increasing problem, and is linked to the key sustainability challenge of climate change. Even if drip irrigation, sprinkler irrigation and water harvesting will not per se increase food production, they will help to ensure consistent yields while using less water, due to their efficiency. This is in line with our objective to promote a sustainable food system.

## Focus #1. Solutions for Tackling Postharvest Losses

While the globe produces enough food to 'feed the world', the United Nations estimates that about 1.3 billion tonnes are wasted or lost every year (FAO, SAVE FOOD: Global Initiative on Food Loss and Waste Reduction, 2011), or close to a third of all food production. According to the FAO, such losses and waste are worth over US$ 750 billion based on 2009 producer prices, and represent the consumption of approximately 173 billion cubic meters of water and 198 million hectares of cropland each year (Lipinski, 2013). Given their magnitude, food losses and wastage have real implications for all three dimensions of food security. First, harvest and post harvest losses directly reduce food availability. Second, losses and waste along the supply chain contribute to reducing access and put pressure on the food market. Furthermore, the inefficient use of resources associated with lost or wasted foodstuffs can have a negative impact on future food production and sustainability (HLPE, 2014).

In defining postharvest losses, it is important to establish the distinction between food waste and food loss (World Resources Institute, 2013).

Food waste refers to food that is of good quality and fit for consumption, but is not consumed because it gets discarded at the retail or the consumer level, before or after it spoils.

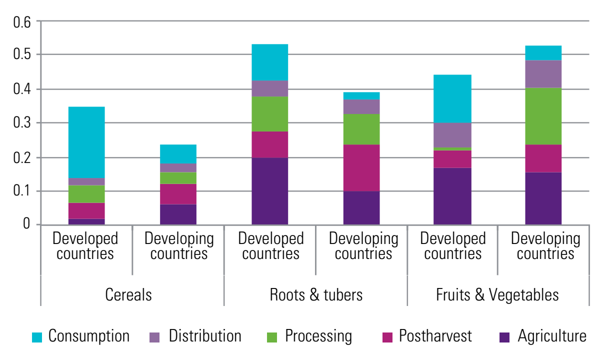
Food loss refers to food that spills, spoils, incurs an abnormal reduction in quality such as bruising or wilting, or otherwise gets lost before it reaches the consumer.

Figure 14 illustrates this distinction and identifies the various types of damage associated with each phase of the supply chain (note that the illustration is not scaled to represent the relative importance of components).

Food Losses and Waste (FLW) occur throughout the supply chain, from initial agricultural production to end consumption No geographical area is exempt from FLW, although their form and extent may vary greatly by region and product (Figure 15).

Food waste (at the distribution and consumption stages) takes place primarily in developed countries and stems from behaviour patterns: quality standards are widely imposed throughout the supply chain, incurring food wastage for aesthetic or calibration reasons. Furthermore, poor dietary habits lead to overconsumption of food. To tackle these issues, attitudes must change, as highlighted by the World Resource Institute (WRI, 2013). This involves moving towards healthier diets and reduced consumption of meats, better food storage and management at home, clearer labelling, etc. These issues need to be addressed through quantitative monitoring of waste, but efforts efforts are needed at the cultural level to shape healthier and more sustainable attitudes towards food.

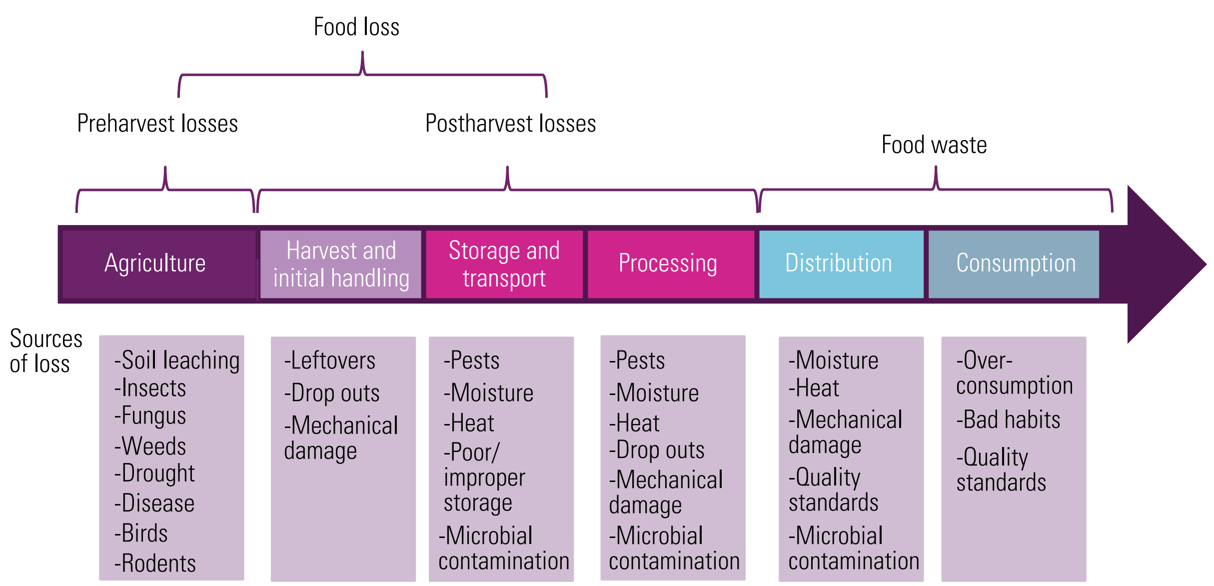
**Figure 14.** Food loss and waste by region and crop as % of production




Source: Mirova (based on FAO 2014, Save Food!, 2011).



**Figure 15.** Food losses and food waste




Source: Mirova 2014.

Contrary to waste, food losses occur mostly in developing countries between the harvest and the processing of foodstuffs, and are the result of poor farming practices, pests, fungal damage, inadequate conservation measures, etc. Most of these losses can be addressed through technological support and education. Since tackling food losses has the highest potential to increase world food availability where it is most needed, the current chapter will set aside the food waste component (waste taking place during distribution and consumption) and focus on technologies that deal with losses foods undergo before they reach the distribution stage.

As we refine our definition, a further distinction between pre-harvest and postharvest stages needs to be made. Generally speaking, the definition of food losses includes the production stage, indexed to an expectation, the 'potential production'. For example, a seed that is planted but leached by the rain and thus prevented from growing is considered a pre-harvest loss. In this focus, we will be interested more precisely on solutions available for reducing the food losses incurred once crops are ripe, also known as postharvest losses (PHL).

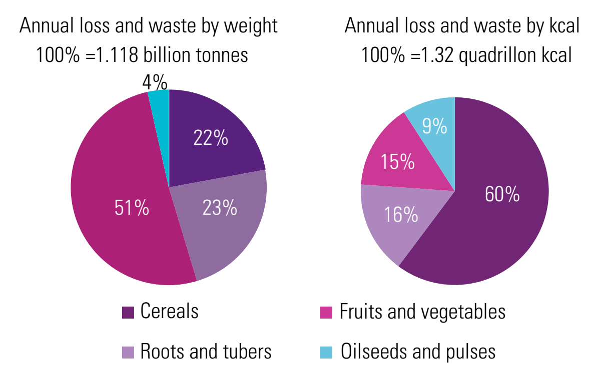
1. **What solutions are there for reducing agricultural losses?**

Based on Figure 15, the main areas where technologies show potential for impact lie at the harvesting, storage and transportation stages (postharvest and processing), and mainly in developing countries.



Below, we present an array of currently available techniques, tools and technologies (again referred to as solutions) for tackling the PHL issue. Given this objective, our focal point will be on crops that both suffer considerable damage and represent a high proportion of calorie intake. As it happens, these are primarily cereals (see Figure 16). Roots, tubers, fruits and vegetables will be treated secondarily, and only in order to describe the best solutions in terms of efficiency and food gains. These solutions, applicable mostly to developed countries, are aimed at extending shelf life to reduce losses and waste during storage, retail and in the consumer's home.

**Figure 16.** Annual food loss and waste




Source: Mirova (from WRI analysis, 2013; and FAO, 2011d).

Many solutions already exist, but we will focus on those that are the most efficient and represent the greatest potential for increasing available food. At the harvesting stage, improved and innovative mechanisation techniques to thresh and dry the cereals might be developed. During storage, pest management, moisture control and cooling are the avenues offering the greatest promise of reductions to food losses. Transportation presents similar issues to storage, with the additional problem of limited infrastructure (roads, docks…). At all stages, access to electricity plays a key role by making possible an unbroken cold chain from the farm to the point of distribution. However, in the absence of electricity, alternate solutions can be implemented, such as a high-pressure environment that reduces oxidation. In developing countries, there exist both small-scale farmers and large-scale agriculture, the one producing for the household and village, the other operating as part of a larger supply chain. Solutions must be adapted and/or adaptable to every production scale in order to increase food availability at every level.

Finally, almost all these technological solutions need to be combined with ***an educational campaign***. Knowledge is a major lever and sharing expertise a solution per se for increasing food availability by reducing food losses. Several NGOs, governments and firms are developing training courses, guidebooks (sometimes with pictures for a potentially illiterate target audience), and even phone applications to provide farmers with the information they need to optimise their practices. The NGO Savanet in northern Ghana, for instance, offers an Audio Conferencing for Agricultural Extension application that allows small farmers in situ to consult experts in agricultural and veterinary sciences (Savanet, 2014). However, while knowledge is a very important lever for increasing food availability, governments and NGOs are the main actors leading implementation of this solution. To date, no commercialised education initiatives have emerged, although we remain alert to the possibility of private sector efforts and favour companies that provide education and training for users of their products and/or services.

### 1. Harvesting more efficiently

At harvest time, some losses occur when crops are left in the field because of poor differentiation between ripe and immature states. Cereals are also sometimes intentionally left in the field for drying, however, this leaves crops vulnerable to attack by pests. First of all, increasing access to knowledge could significantly reduce these losses, helping farmers know exactly when and how to harvest most efficiently. Secondly, mechanisation presents high potential to decrease harvest losses and PHL. Indeed, mechanisation allows for faster harvesting, which makes it possible for farmers to wait for optimal ripeness to begin the process.

In order to prepare cereals for storage, some crops need to be threshed (threshing is the removal of a grain's protective casing) and winnowed (winnowing separates the grain from the inedible chaff) to conserve only the edible part of the plant. Threshing and winnowing are very important stages in preparing the harvest for storage, and prolong conservation as well as preserving the grain's quality. Mechanisation has an important role to play in the effectiveness of these processes. However, this does not apply to all crops; for millet, sorghum and some varieties of maize, to take a few examples, threshing may inflict some degree of physical damage to the grain, and so increase the risk of pest attacks and bio-deterioration by humidity and diseases.

***Drying cereals*** properly (rather than field drying) reduces PHL. Indeed, drying cereals ensures proper humidity levels for optimal storage (11% to 13% depending on the cereal), decreased biological deterioration, and the elimination of insects and many microorganisms by heat. The simplest operation involves solarisation of the cereal on a plastic sheet, with regular rotation and churning under constant supervision to avoid attacks by rodents and birds. Technologies for accomplishing this already exist, and are easily available. Thus reducing PHL is primarily a matter of education, however, it remains a complex undertaking since each crop and variety requires a treatment specific to its characteristics.

### 2.Storing foodstuffs more efficiently

During storage, losses can occur as a result of pest attacks and because of biological deterioration from increased moisture content, bacterial or fungal infections and excessive heat. The solutions presented earlier for the harvest stage are essential to guarantee good storage conditions.

Solutions for preventing infestation by pests (fungi, insects, rodents and birds) can be considered to fall into two categories: eliminating pests and preventing them from eating the harvest. ***Pesticides, insecticide***s, and ***integrated pest management (IPM)*** are chemical or natural ways of killing pests. One can also prevent pest attacks by protecting the harvest through hermetic storage technology, e.g. ***plastic crates, hermetically sealed polythene bags*** or ***metal silos***, the reby dispensing with pesticides.

During storage, ***humidity and temperature monitoring*** are key, especially for perishable goods; this can be undertaken using hygrometers, but careful attention is just as essential. Simple ways exist of increasing or decreasing humidity levels, spraying water or ventilating for example. Temperature regulation also influences the humidity. Controlling the heat by ***cooling*** is a key means to tackle PHL. Indeed, the higher the temperature, the faster the natural degradation processes will occur, leading to loss of colour, flavour, nutrients and changes in texture. As a rule of thumb, the rate for most of the degradation processes doubles with for each 10°C temperature increase: this is known as the Q10 quotient. A simple way to cool the harvest, when the humidity and climate conditions allow it, is the ***evaporative cooler:*** the idea is to store the harvest in a double-walled room, with wet sand placed between the two walls. The heat outdoors causes the water contained in the sand to evaporate, an endothermic reaction that cools the sand, cooling the walls and, ultimately, the room.

### 3.Transporting foodstuffs more efficiently

Transport can be the journey from the farm to a large storage facility, or to the retailer. It is a significant cause of loss, as it introduces an additional time lag between production and consumption, and can cause mechanical injury, in particular for fresh products. Transport should be undertaken with care to maintain the quality of the harvest.

The issues that arise during transport are largely the same as during storage: controlling for pests, humidity and heat. Two additional concerns apply when foodstuffs are relocated: the ***quality of the transportation environment*** and access to the ***infrastructure*** required. While the problems raised are similar, storage units are not always designed to be moved, and special devices suitable for transport are often needed. Plastic crates, for example, are as good for storage as for transport, but a metal silo stays on the farm. Some of the losses particular to transporting foods involve mechanical damage during transit due to improper packing or containers leads; this is especially true for perishables such as fruits and vegetables. For every commodity transported, containers should be appropriate for the contents. Containers for moving foodstuffs should be designed for easy handling and efficient use of space. These measures would improve the prognosis for food in transit, since a transporter takes the maximum load possible to save on transport costs, leading to conditions that are potentially damaging for the commodity (FAO and APO, 2006).

Furthermore, many losses occur because a lack of infrastructure prevents supply and demand from meeting: a harvest spoils in one location while elsewhere people suffer from hunger. ***Access to infrastructure*** is therefore a major issue, both to permit transportation of goods, and to ensure the safe transit of food. In particular, infrastructure can make it possible to maintain an uninterrupted cold chain. Also, the access to markets offered by judicious infrastructure almost guarantees increased revenues for farmers, who can plough some of these returns into developing more efficient postharvest technologies, creating a virtuous cycle.



### 4.New technologies for fruits and vegetables in developed countries

The solutions presented above are relevant primarily to developing countries, which is where the highest postharvest losses reduction potential lies. Nevertheless, several new technologies bear mention that are appropriate for developed countries. These are applicable to perishable food such as fruits and vegetables and help increase the shelf life of foodstuffs:

- ***Food irradiation*** is the process of exposing food to a controlled amount of energy known as 'ionizing radiation'. This kills microorganisms inside a foodstuff without significantly raising its temperature. Food irradiation is regulated under the label Radura delivered by the Food and Drug Administration in the USA and has been approved by the WHO; nevertheless some controversy remains over the long term effects on health of irradiated food.

- ***Pulsed-electric fields*** are a non-thermal method that uses short pulses of electricity for microbial inactivation on the surface of the solid food. This technology for the treatment of food is still experimental, and many unsolved problems remain, such as damage to intact cells of the food as well as microbes. Furthermore, most bacterial spores are very resistant to this treatment, which limits the efficiency of the technology.

- Treatment with ***1-methylcyclopropene*** inhibits ethylene action, and so slows down the maturation of fruits and vegetables. However, not all fruits and vegetables respond to this treatment in the same way: it is very efficient for apples and kiwi fruits, but has no effect on apricots or pineapple. Consequently we cannot consider this a high potential solution for reducing PHL among all fruits and vegetables.

➜ ***Modified atmosphere*** is the solution that generates the greatest consensus as to its potential effectiveness. Packaging or storage in a modified atmosphere lowers respiration and ethylene production rates, reduces ethylene action, delays ripening and senescence, retards the growth of decay-causing pathogens and controls insects, thanks to an optimum oxygen and carbon dioxide concentration. This technology also has the merit of being applicable in developing countries; in fact, it is already used in India (HLPE, 2014).

As shown in Figure 15, 10% to 20% of vegetable and fruit losses take place at the processing stage. This is mainly due to the fact that fruits and vegetables are widely imported and exported all over the world, given that consumption habits do not follow seasonal or climatic constraints. Europeans eat bananas, mangoes and other exotic fruit that do not grow in their region, and also insist on produce such as tomatoes during the winter. Since considerable lag is induced by the long distance transport this involves, solutions for increasing shelf life can reduce the losses incurred during processing, but eating habits are inextricably involved, and changes of consumption habits have a role to play.



### 2. How will these solutions help increase food availability?

To summarize, PHL reduction can increase food availability and access in two main areas:

➜ By shifting the quantity of food available closer to the presumed potential yield;

➜ By increasing the shelf life of the harvested crop.

Overall, estimates suggest that 120-170 kg/capita/year could be gained in sub-Saharan Africa and South/South-East Asia if PHL and, food losses more broadly were reduced to zero (HLPE, 2014). Because very few studies have attempted to express food gains in terms of calorie intake, we have tried to illustrate potential benefits in the form of a case study. Also, as of today, research has failed to take into account the issue of quality in the question of FLW reduction (i.e. micronutrients or bioactive components beyond calorie content).

**Potential increase in calorie intake: example of Africa**

Table 7 identifies the crops that suffer most from PHL in Africa (Aphlis 2013), while Table 8 presents those that most contribute to per capita calorie intake worldwide.

**Table 7.** Crops suffering the most PHL in Africa

| Cereal | PHL in tonnes in Africa | PHL as % of total production |
|---|---|---|
| Maize | 7,526,871 | 18 |
| Sorghum | 1,651,159 | 13.9 |
| Rice | 1,136,943 | 12.9 |
| Millets | 845,360 | 12.4 |
| Wheat | 729,436 | 12.4 |
| Teff | 438,060 | 11.8 |

Source: Mirova (from APHLIS, 2013).

**Table 8.** World food production and corresponding caloric intake for major crops

| Commodity | Food supply (tonnes) | Food supply (kcal/capita/day) |
|---|---|---|
| Rice (Milled Equivalent) | 354,603,098 | 536 |
| Wheat | 439,418,035 | 532 |
| Sugar, Refined Equiv | 121,612,250 | 194 |
| Maize | 113,981,080 | 141 |
| Roots & Tuber Dry Equiv | 95,523,129 | 136 |

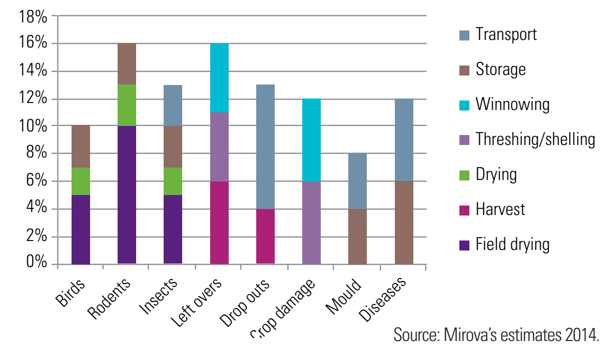
Source: Mirova (from FAO, FAOSTAT-Crops Primary Equivalent, 2012).

Based on Table 7 and 8, reducing postharvest losses for maize, rice and wheat in Africa to zero would produce an increase of 85 kcal per capita per day for the entire population of the continent (calculation based on a world population around 7 billion and African population of 1 billion), representing 3.4%, 4.25% and 5.7% of the average recommended daily intake for moderately active men, women and children, respectively. To put this number into perspective, while bearing in mind that average daily calories available are not indicative of either true intake, or of regional and socioeconomic differences, let us remember that in the US, the average number of calories available daily is 3,600 kcal, in Europe it is 3,400 kcal, in Asia 2,650 kcal, and in Sub Saharan Africa 2,180 kcal.

**Case Study: impact of PHL reducing techniques on maize in Africa**

Figure 17 presents the distribution of PHL for maize according to the type of damage at each postharvest stage. Distinguishing losses by cause allows us to estimate the potential food availability increase we can expect from each proposed solution.

**Figure 17.** Breakdown of PHL for maize by postharvest stage and cause (100% of PHL represents 30% of all production)




Source: Mirova's estimates 2014.

Figure 17 indicates that transport and storage represent a significant share of PHL. This highlights the need for solutions specific to these stages, namely cooling—to reduce mould and diseases (10% of PHL), and packaging, to prevent pests attacks (around 10% of the PHL) and dropouts (around 20% of PHL). Cooling would then allow reducing PHL by at least 10% and packaging by at least 30%.

Harvest per se represents 10% of all PHL, hence the importance of mechanisation, but mechanisation at the harvest stage has a further advantage. To take an example, rice, when harvested at maturity, involves a 3.4% grain loss; a mere week after maturity, grain loss counts for 5.6% of total production. Three weeks after maturity, 40.7% of the grains are lost. Thus harvesting on time, carefully, and with the help of mechanisation, allows farmers to decrease losses, and so increase food availability.

Mechanisation also reduces loss during the threshing and winnowing processes, where dropouts and crop damage represent 20% of overall PHL.

**Summary of solutions**

From our review of the available options, we conclude that mechanisation, cooling and packaging are the key solutions in developing countries, and increasing the shelf life in developed countries. Technologies for maintaining the cold chain, and packaging solutions from hermetic seals to more innovative modified atmosphere packaging or smart packaging, have the potential to reduce FLW at many stages of the supply chain.

**Table 9.** Summary of solutions

| Postharvest stage | Solution | Details of the technologies | Examples of firms proposing solutions |
|---|---|---|---|
| From production to storage | Mechanisation | Two-wheel tractor<br>Tractor<br>Combined harvester<br>Rice thresher<br>Tiller | AGCO Corporation, Golden Growers Coop, Dae dong industrial Co Ltd, First tractor Co Ltd, CNH Industrial |
| Storage, processing, transportation | Cooling | Evaporative cooler<br>Fridge<br>Cold room<br>Refrigerated transport<br>Freezing | Ingersoll Rand, Siem Shipping, Maersk Line |
| Storage, processing, transportation | Packaging | Metal silos<br>Polythene bags<br>Smart packaging<br>Plastic crates<br>Modified atmosphere | Linde AG, Trans-Nationwide Express, JBT FoodTech, Air Water, Mpact Ltd |
| Storage, processing, transportation (retail, consumption level) | Shelf-life | Biopesticides and other preharvest biotreatments | Pimi Agro Cleantech, Marone Bio Innovations, Novozymes |

Source: Mirova estimates 2014.

3. **How do these solutions compare to 'business as usual' (ESG dimension)?**

Increased mechanisation has a potentially negative environmental impact compared to business as usual where it means replacing animal labour and manpower by machines that generate greenhouse gas emissions. Nevertheless, mechanisation usually triggers significant positive social impacts. In addition to lightening the physical labour of farm work and producing improved health outcomes for farmers, it also has positive impacts on the schooling of children on smallholders' farms, when they adopt the technology, because of a decreased need for labour and significantly increased efficiency. Mechaniszation also creates employment opportunities in the retailing and maintenance of machinery.

The solutions proposed here are not controversial and all garner consensus as to their environmental and social impacts.

4. **What are the barriers to developing the solutions?**

For some solutions, technical and very specific barriers exist, but in general, the same barriers seem to impede the development of all PHL reduction solutions, namely: aversion to change, prevalence of old habits, lack of knowledge about, or access to, the technologies involved, the organizational costs of implementing new practices, and the monetary expense involved.

Legislation and lack of governmental policies can sometimes be a barrier too. For instance, governments' tax policies are the primary barrier to adoption of plastic crates: many countries tax farmers or intermediaries on a per-package basis, encouraging them to present as few items as possible. This results in foodstuffs being packed into enormous containers that provoke impact damage and make cooling impossible (Agrilinks 2014).

Mechanisation also poses another difficulty. Machines are often not well adapted to small farms, which in any case have little incentive to implement mechanisation since they possess a disproportionately high labour force. For instance, a combined-harvester only offers an economic advantage when the area under cultivation exceeds a minimum of 70 hectares. To this dearth of incentive, we might add dissuasive monetary costs and a lack of access to the technology as the main barriers to isolated farmers' adoption of mechanisation.

## Focus #2. Biotechnology for Enhanced Agricultural Yield

As outlined at the beginning of this study, world food production is facing numerous challenges to achieving food supply to meet future demand. In its report, 'Reaping the benefits', The Royal Society (2009) enumerates several constraints on global food-crop production where the biological sciences can play an important role:

➜ **Water**

Of all the stresses to agricultural yield, drought is considered to have the most limiting effect (Boyer, 1982). While in some regions, the availability of water is expected to decrease, other regions will have the opposite effect and experience a decrease in available water. Moreover, even in areas where water is plentiful, water quality can be a limiting factor. While reducing agricultural water usage is best addressed by technologies discussed in the water solutions section later in this study, biological sciences can also contribute by lowering the requirements of certain crops.

➜ **Temperature**

Temperature plays an important role in the development of any plant. When analysing temperature and its effects on crop yield, it is necessary to take into consideration possible extremes, especially when they occur during important stages of development; different stages of growth vary in sensitivity to temperature extremes. With global temperatures rising and increasing volatility, heat and drought will limit crop protection (Ronald, 2011).



➜ **Soil factors**

Soil is subject to loss by erosion, and damage by industrial pollutants or physical compaction. Additionally, land that could be used for agricultural purposes is being lost to urbanization, salinization, desertification, and environmental degradation (Ronald, 2011). Finally, the loss of nutrients in the soil due to certain activities such as over cropping and from leaching is increasingly becoming a point of concern. The availability of land with quality soil for agriculture is a necessary factor in meeting production demands and, as such, current production and predictions of production are dependent on upon the maintenance and improvement of soil quality (The Royal Society, 2009).

➜ **Pests, disease and weed competition**

Worldwide losses due to weeds, pests and disease have been estimated at 26-40% for eight major crops: wheat, barley, rice, maize, soy, cotton, sugar beet and potato (The Royal Society, 2009). Moreover, a majority of these losses occur when most or all of the land and water required have already been invested.

In light of these challenges, the role of biotechnology is construed as being to alter current food crops to the changing environment such as rising temperatures, limiting availability of quality water or even abundance of water, and evolving pathogens & insects.

### 1. Biotechnology and agriculture

#### 1. Defining biotechnology

In a broad sense, biotechnology encompasses all types of human manipulation of living organisms or their components in order to generate commercially viable products. Article 2 of the UN Convention on Biological Diversity defines biotechnology as 'any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.' It can be applied to all types of organisms and is becoming more prevalent in modern medicine, agriculture and industry.

Although it may seem like biotechnology has only arisen with the modern world, techniques such as fermentation and brewing have been used for several thousand of years. More recent applications are modern detergents and hard cheese. Table 10 illustrates the evolution of how farmers and pastoralists first started using live organisms (such as plants and animals) to modify products for agricultural purposes.

Since the beginning of agriculture, biotechnology has been employed to produce superior crops or animals. Today, it is being used to address the challenges that agricultural production and processing are currently facing. Modern agricultural biotechnology encompasses a range of tools employed to understand and manipulate the genetic make-up of organisms for use in the production or processing of agricultural products (FAO, 2005). The manipulation involved includes processes such as human selection (in traditional breeding) and direct manipulation (in genetic engineering). The Cartagena Protocol on Biosafety, adopted in 2000, further narrows the definition of 'modern biotechnology' into two components:

➜ The direct modification of an organism's genetic composition via DNA manipulation, or

➜ The creation of new varieties that cannot be achieved via traditional breeding and selection techniques.

#### 2. Applications for agriculture

Biotechnology has many applications for agriculture, some more widely accepted than others. In order to achieve food security and address the issues outlined at the beginning of this section, none of these technologies should or may be overlooked. Their application, **in the context of sustainable food systems**, will be needed to feed the world's growing population. Nevertheless, for the purpose of this study, we have decided to focus on crops that are produced or transformed by deliberately modifying an organism's characteristics via manipulation of its genetic material. These crops are known by various names in the literature, including genetically engineered plants or crops, bio-engineered plants, biotech plants, but are most commonly known as genetically modified organisms (GMOs) and genetically modified (GM) crops (Uzogara, 2000). Throughout this study, the names will be used interchangeably. However, the term GMO has a very specific meaning when it comes to regulations, and these may vary in different countries. This will be discussed in a section dedicated to regulation. Given the current climate of debate surrounding genetically-modified organisms (GMO), we believe the topic merits more attention in order to promote a better understanding of the technology itself, the risks and opportunities directly linked to it, and the associated risks to market.

**Table 10.** Biotechnology in agricultural history

| Technology | Era | Genetic Interventions |
|---|---|---|
| Traditional | ~ 10,000 BC | Civilizations harvested from natural biological diversity, domesticated crops and animals, began to select plant materials for propagation and animals for breeding |
| | ~ 3,000 BC | Beer brewing, cheese making and wine fermentation |
| Conventional | Late 19th century | Identification of principles of inheritance by Gregor Mendel in 1865, laying the foundation for classical hybridization theories |
| | 1930s | Development of commercial hybrid crops |
| | 1940s - 1960s | Use of mutagenesis, tissue culture, plant regeneration. Discovery of transformation and transduction. Discovery by Watson and Crick of the structure of DNA in 1953. Identification of genes that detach and move (transposons) |
| Modern | 1970s | Advent of gene transfer through recombinant DNA techniques. Use of embryo rescue and protoplast fusion in plant breeding and artificial insemination in animal reproduction |
| | 1980s | Insulin as first commercial product from gene transfer. Tissue culture for mass propagation in plants and embryo transfer in animal production |
| | 1990s | Extensive genetic fingerprinting of a wide range of organisms. First field trials of genetically engineered plant varieties in 1990 followed by the first commercial release in 1992. Genetically engineered vaccines and hormones and cloning of animals |
| | 2000s | Bioinformatics, genomics, proteomics, metabolomics |

Source: Mirova (from FAO, 2005).

### 3. Genetically Modified Crops

Genetic engineering is the process of incorporating new DNA into an organism through bypassing the natural reproductive processes, with the goal of adding one or more desirable traits currently not exhibited to create a genetically modified (GM) crop (Qaim, The Economics of Genetically Modified Crops, 2009). It differs from conventional breeding in the following ways '(1) *genetic engineering implants specific plant genes coding for the desired characteristics into a plant species (2) it can also implant genes from other species, such as animals, into a plant.*

While conventional breeding has been successful in introducing desirable traits into organisms, undesirable traits may also be created, as this process relies on the application of classic genetic principles (FAO, 2005). These undesirable traits may eventually be eliminated through successive generations of breeding, but require many generations before the desired trait combination is achieved. Genetically engineering a crop, in a way, bypasses this process. Additionally, since genetic engineering permits gene transfers between two different species, traits that were impossible to integrate can be incorporated.

GM crops can be categorised into several ways. In their report 'The State of Food and Agriculture', the FAO categorizes GM crops through process used to create the crop:

1. **'Distant transfer' or transgenic:** genes are transferred between organisms of different species that are not sexually compatible, even between different kingdoms (e.g. bacteria into plants).

2. **'Close transfer' or cisgenic and intragenic:** genes are transferred among sexually compatible species or varieties.

3. **'Tweaking':** genes already present in the organism are manipulated to change the level or pattern of expression.

Another way to categorise GM crops is according to the traits they carry (Qaim, The Economics of Genetically Modified Crops, 2009):

1. **First-generation GM:** improvements in agronomic traits such as better resistance to pests, diseases and changing temperatures.

2. **Second-generation GM:** enhancements of quality traits, such as higher nutrient content of food products.

3. **Third-generation GM:** production of special substances for pharmaceutical or industrial purposes.

The basic techniques of plant genetic engineering were first developed in the 1980s and commercialisation of the first GM crops began in the 1990s (Qaim, The Economics of Genetically Modified Crops, 2009). Since then, the adoption, research and development of GM crops have rapidly increased, reaching around 10% of all cultivated area today. Compared to 1996, cultivated acreage has been multiplied by more than 100, from 1.7 million hectares in 1996 to 175 million hectares in 2013. Of the 18 million farmers cultivating biotech crops, over 90% were in developing countries (ISAAA, 2014). Table 11 presents examples of certain GM crops that are either currently on the market or in development.



**How can genetically engineered crops contribute to increased yields?**

GM technology can be used to increase intrinsic yields, reduce crop vulnerability to environmental stress factors, provide higher nutritional value or decrease reliance on fertilisers and pesticides. Following Qaim's categorisation based on the traits exhibited by GM crops, here are examples of ways in which the different generations of GM can contribute to increased yields.

### First Generation GM

Most of the GM crops commercially available fall under this category. Crops that are insect, herbicide or virus resistant are being grown in different parts of the world. **Insect resistant crops** were developed to reduce reliance on insecticides that have been proven harmful to humans and the environment. The use of insect resistant crops allows farmers to use less insecticide without sacrificing yields. **Herbicide tolerant crops** are resistant to the broad-spectrum herbicides used to kill weeds that compete with a crop for necessary soil nutrients and sunlight. If the crops were not herbicide tolerant, they too would be killed by the same broad-spectrum herbicides. **Virus resistant crops** are immune to certain diseases that pose a threat to their full maturation.

Other first generation GM crops on the horizon include seeds that would better tolerate environmental stresses such as drought (in the case of African countries) and intense flooding (frequent in countries such as India and Bangladesh). While the seeds would still need both sunlight and appropriate amounts of water, their stages of development would be less sensitive to the lack or abundance of these natural elements, thereby easing meteorological threats to farmers' yields. Another GM crop on the horizon would extend the shelf life of vegetables and fruits after harvesting so as to reduce post-harvest losses, particularly in developing countries.

### Second Generation GM

Biofortification is the process of enhancing food crops to achieve higher nutrient content either through conventional breeding or GM technology. The best known GM biofortified crop project is Golden Rice, which contains significant levels of vitamin A. Other biofortification projects include sorghum, cassava and banana with multiple additional nutrients (Qaim, The Economics of Genetically Modified Crops, 2009). Other possibilities include medicinal GM crops which could be grown to biologically produce vaccines for certain diseases.

While nutrient enhancement does not in and of itself increase yields, it does decrease demand by making it possible for people to ingest the right amount of nutrients without having to consume more food.



**Table 11.** Examples of GMOs

| | Genetically Conferred Trait | Sample Organism | Description |
|---|---|---|---|
| Approved Commercial Products | Herbicide tolerance | Soybean | Plant is modifed to carry a genetic trait that is expressed as a tolerance for glyphosate (a.k.a. Roundup) - a common herbicide used to control weeds. Farmers growing this specific plant can consequently spray the herbicide without harming their crops. |
| | Insect resistance | Maize | Crop is engineered to produce proteins from a soil bacteria (Bacillus thuringiensis, Bt) that kills key pests threatening these crops. |
| | Altered fatty acid composition | Canola | Crop was altered to no longer have two undesired traits that limited its use in food. |
| | Virus resistance | Plum | Crop is engineered to be immune to certain plant diseases, somewhat similar to the effects of a vaccine on humans. |
| Products still in development | Vitamin enrichment | Rice | Crop is modified to have a higher vitamin A content in order to address vitamin A deficiencies in developing countries. |
| | Oral vaccines | Maize | Crop is engineered to vehicle vaccines that are usually directly injected into the blood stream. |
| | Drought tolerance | Maize | Crop is altered to be more tolerant to drought, and thereby not as sensitive to lack of water. |

Source: Mirova, 2014.

## 2. GM technology in a sustainable food system

Genetic modification technology has the potential to contribute to achieving food security by 2050. From ensuring a higher nutritional value to guaranteeing fewer operational losses, there are several ways that genetically engineered seeds can increase agricultural productivity. At the same time, risks, such as safety for human consumption and environmental impacts directly linked to the technology may also appear. Evaluating the role of genetically modified technology in global food security needs to be conducted in the context of sustainable food systems, taking into account both the opportunities and the risks. This section investigates how GM technology can be applied within a sustainable food system, addressing opportunities and risks ***directly associated*** with GM technology. Other factors that are indirectly linked to GM technology but need to be considered, such as consumer perception and regulation, will be treated in the following section.

Despite GM technology's having been around since the 1990s it continues to fuel ardent debate over whether it can contribute to global food security. Some believe that GM crops play an important role in reducing hunger and increasing food availability, while others believe otherwise. It is interesting to note that '*solid empirical evidence to support either of these views is thin*' (Qaim & Kouser, Genetically Modified Crops and Food Security, 2013). This leads to the question of why, after more than 20 years of existence, there appears to still be no widely accepted position on GM technologies, most particularly on their safety for human consumption. While this section explores the reasons for this, it is worthwhile to also understand issues plaguing the availability and quality of information regarding the effects of GM technology, as these are a contributing factor.

Studies on GM technology are abundant, with two decades of research supplying arguments for both sides of the debate. While current studies have shown that the GM crops available on the market are safe to eat (Ronald, 2011) and that GM crops are not any riskier than crops derived from conventional breeding (Qaim & Kouser, Genetically Modified Crops and Food Security, 2013), there are still doubts in the scientific community regarding the validity of these conclusions, as shown by the statement made by the European Network of Scientists for Social and Environmental Responsibility (ENSSER) on how there is no scientific consensus on GMO safety or on the environmental risks of GM crops (2013). The studies on GMOs are generally contested for either or both of the following reasons:

- The position of the organisation funding and/or the person(s) executing the research: people do not trust that the personal view of the organisation/ people is not reflected in the results of the study.
- Certain aspects of the study: people question the pertinence of certain aspects of the study such as its model, methodology, duration, etc.

In order to have a better understanding of the effects of GM technology on society, human health and the environment, more long-term studies need to be conducted in a manner that is 'honest, ethical, rigorous, independent, transparent and sufficiently diversified to compensate for bias' (ENSSER, 2013).

Nevertheless, studies to date have provided enough information to permit discussion of how GM technology can be applied in the context of a sustainable food system.

1. Opportunities and risks

When considering genetic modification, it is important to not view the process as a single technology—both its potential benefits and complications depend in part on the gene that is being transferred, the mechanism employed and the plant receiving the gene (The Royal Society, 2009).

Consequently, when discussing the opportunities and risks brought about by GM technology, not every opportunity and risk outlined in the section will apply to all GM crops. Further analysis would be required in order to understand the exact opportunities and risks one specific GM crop has. The aim of this section is, then, to give readers a broad overview of the potential opportunities and risks directly linked with GM technologies.

**Opportunities arising from GM crops**

There are several potential benefits that suggest GM technology can contribute to attaining global food security. Discussed here are those already been demonstrated by GM crops now commercially available, and additional benefits that GM crops in development can provide. While this list does not aim to be exhaustive, it does seek to provide a better understanding of which specific food security issues GM technology can help address.

### Faster development of crops

As previously mentioned, GM technology, like most technologies within biotechnology, manipulates crops to better withstand environmental conditions that pose a threat to their full development. The main advantage that GM technology has is that it employs a shortcut to results that would take conventional breeding much longer to achieve. While GM technology allows for direct introduction of a desired trait, conventional breeding results in the introduction of random genetic combinations into the newly created plant, including both genes with the desired trait and genetic material with unwanted characteristics. The difference in time, of course, varies according to the crop. For example, it took seven or eight years of genetic engineering to create GM wheat, whereas it is estimated to take conventional breeding around eleven to twelve years to achieve a similar result.

### Lower insecticide use

Farmers planting GM insect-resistant crops are able to use less insecticide without sacrificing yields. This is significant, as the overuse or misuse of certain insecticides can lead to detrimental environmental and health impacts. Even today, thousands of insecticide poisoning incidents are reported yearly (Ronald, 2011). The U.S. Department of Agriculture (USDA) Economic Research Service discovered that Bt,[16] corn adopters use an average of 8% less insecticide per planted acre compared to non-adopters (Ronald, 2011). Similarly, studies on Bt cotton in developing countries have demonstrated significant reductions in countries like India (-41% insecticide use on average compared to conventional crops since 2002) and China (-65%) (Qaim, The Economics of Genetically Modified Crops, 2009). Table 12 shows how planting insect resistant maize and cotton has lessened these crops environmental impact on a global scale due to a reduction in the use of insecticide.

### Use of less harmful herbicides

The primary herbicides used over the past 50 years are considered toxic or slightly toxic to humans and animals. Newer herbicides have lower toxicity in addition to breaking down easily in the environment and are therefore not carried into ground water. The use of GM herbicide tolerant (HT) crops allows farmers to spray the less harmful newer herbicides without harming their crops. Table 12 illustrates how the planting of herbicide tolerant soybeans, maize, canola, cotton and sugar beet have lessened the environmental impact of their cultivation on a global scale due to the use of less harmful herbicides.

**Table 12.** Impact of GM crops on the use of herbicides & insecticides worldwide, 1996-2012

| | Trait | % change in active ingredient used on GM crops | % change in environmental impact associated w/ herbicide & insecticide use on GM crops |
|---|---|---|---|
| GM insect resistant | Maize | -47.9 | -45.1 |
| | Cotton | -25.6 | -28.2 |
| GM herbicide tolerant | Soybeans | -0.2 | -15 |
| | Maize | -9.8 | -13.3 |
| | Canola | -16.7 | -26.6 |
| | Cotton | -6.6 | -9.0 |
| | Sugar beet | +29.3 | -2.0 |

Source: Mirova (from Brookes & Barfoot, 2014).

### Soil fertility management

The use of herbicide tolerant crops has made it easier for farmers to control weeds, and decreased their need to rely on soil cultivators and seed-bed preparation for weed control. This has allowed farmers to switch to no-till or reduced till farming systems leading to better soil quality and a reduction in soil erosion.

### Reduction of greenhouse gas (GHG) emissions

The use of insect resistant and herbicide tolerant crops has contributed to lower levels of GHG emissions by the following (Brookes & Barfoot, 2014):

- Reduced fuel consumption from less frequent herbicide/insecticide applications;
- Reduction in the energy requirements for soil cultivation;
- Carbon sequestration benefits coming from more carbon remaining in the soil due to the adoption of no till or reduced tillage systems.

16. *Bacillus thuringiensis (Bt) is a soil bacterium that kills key pests that attack certain crops.*

### Increased income for farmers

The use of GM technology has positively affected the income of farmers via enhanced productivity and efficiency gains (Brookes & Barfoot, 2014). Additionally this income increase was experienced by farmers in both developed and developing countries. Table 13 shows the gross impact on margins for farmers planting GM crops in both developed and developing countries during the year 2012.

### Improvement in fruit and vegetable shelf life

Crops can be genetically engineered to delay the ripening, softening, and rotting process of the fruit. In fact, the first GM food approved for human consumption, the Flavr Savr tomato, was so designed. While not directly pertinent for yield, this reduces the food gap by eliminating waste.

### Improved nutritional quality and health benefits

GM crops can be modified to carry certain nutrients not originally found in the plant, making it possible to fortify certain foods to be healthier and more nutritious. One example would be to modify oils to increase the proportion of unsaturated fatty acids in commonly used oils such as sunflower and peanut oil (Uzogara, 2000).

**Table 13.** GM crop farm income benefits 2012: developing and developed countries (in millions of US$)

| | | Developed countries | Developing countries |
|---|---|---|---|
| GM insecticide resistant | Maize | 5,327.5 | 1,400.3 |
| | Cotton | 530.7 | 4,800.7 |
| GM herbacide tolerant | Soybeans | 2,955.4 | 1,842.5 |
| | Maize | 654 | 543.9 |
| | Cotton | 71.4 | 75.8 |
| | Canola | 481 | - |
| GM virus resistant papaya & squash and GM herbicide tolerant sugar beet | | 86.3 | - |
| Total | | 10,106.3 | 8,663.2 |

Note: Developing countries include all countries in S. America as well as Mexico, Honduras, Burkina Faso, India, China, the Philippines and South Africa

Source: Mirova (from Brookes & Barfoot, 2014).



### Increased crop yield and protection

There are also several ways in which GM crops can increase crop yields. GM crops can be made resistant or tolerant to pests, weeds, herbicides, viruses, insects, salinity, pH, temperature, frost, drought and weather. Drought resistant GM crops, for example, could be used in arid regions where water scarcity is high. Increasing a crop's ability to tolerate extreme weather conditions and stresses can permit growers to farm on land currently unsuitable for cultivation (Uzogara, 2000). Additionally, other traits added to GM crops could allow crop production to absorb less farm acreage and reduce the use of agro-chemicals. As of today, studies conducted on existing GM crops (mainly Bt and Ht) confirm that GM adoption has had a positive impact on yields in most regions (Qaim, 2009), although empirical evidence regarding the effect of Ht crops on yields is more mixed compared to Bt crops in the US (US Department of Agriculture, Economic Research Service, 2014).

## Risks associated with GM crops

Despite its many benefits, the cultivation of GM crops continues to generate significant controversy around issues such as the unknown long-term effects on human health and the environment as well as the threat to crops' genetic diversity, which potentially reduces their resilience in the face of catastrophic change. Many of these risks are not specific to GM technology and would also occur using more traditional methods. The risks that are exclusive to GM technology have not yet been conclusively demonstrated, and as such remain a matter of speculation. Consequently, the biggest risk directly linked to GM technology is uncertainty itself, particularly since risks vary depending on the match between a gene and receiving plant. The following list of risks does not aim to be exhaustive, but rather tries to provide a better understanding of the risks that GM crops can involve.

### Growing immunity of insects and weeds

After the introduction of insect-resistant and herbicide tolerant GM crops into the environment, evidence has shown that target organisms (i.e. the insects and weeds) have developed some level of immunity to the toxin or herbicide. This, however, is not an effect restricted to GM crops; it is a limitation of using any type of insecticide or herbicide (whether organic, synthetic or genetically engineered)—target insects and weeds will eventually evolve to resist it. Nevertheless, this can be counteracted by employing better farming practices and by implementing strategies that help to delay the development of resistance.

### Safety for human consumption

While current studies indicate that the GM crops now commercially available are safe for human consumption, there are still certain doubts regarding the effects coming from long-term human consumption. Additionally, considering that each GM technology brings with it its own risks, then it is hardly prudent to say that all future GM crops would be safe. The main concerns with respect to health and safety are related to the potential transfer of allergens, antibiotic resistance markers, or toxic proteins from GM food crops to human beings and the long-term effects thereof.

### Consequences for the environment

Environmental concerns include the effects of cross pollination, the impacts on biodiversity and the potential creation of new viruses and toxins. Environmentalists are concerned with cross-pollination between GM crops and wild species as it could unintentionally create new, unwanted, plant species. Nevertheless, there are ways to minimise the risk of cross pollination one of which is through careful field planning. Another risk is that of jeopardising biodiversity, where long-term effects are yet to be known. Risks to crop genetic diversity becomes more of a concern considering that current agricultural practices already favour adoption of few crop varieties with higher commercial value. Finally, plants engineered with virus particles could actually facilitate the creation of new viruses (Uzogara, 2000).

### General 'fear of the unknown'

Considering that the science of genetic engineering has been around for less than 50 years, there are still many unknowns regarding its impact particularly to our ecosystem as a whole. The fear of a potential systemic risk in the ecosystem make some believe it is a risk too big to take.

### 2.Genetic Modification: not a panacea for global food security issues

There is no one technology that will solve the global challenge of securing a sustainable food production system. If food security is truly to be attained, a mixture of different technologies will need to be implemented. Moreover, regardless of the technology employed there will always be trade-offs and local complexities (The Royal Society, 2009). Science and technology can bring about improvements in food production and crop yield, but in order for these improvements to be sustainable they must take into account the three elements of sustainability (social, environmental and economic factor) and must be accompanied by proper ecological farming practices and good governance (The Royal Society, 2009) (Ronald, 2011).

GM technology is no different. While supporters of the technology believe that GM crops can play an important role in securing the global food supply, they also emphasise that it should not be the only technology under consideration, other types of technologies and options should and must also be explored (Qaim & Kouser, Genetically Modified Crops and Food Security, 2013; The Royal Society, 2009). GM technology should be considered as a tool towards reaching global food security and not an end in itself (The Royal Society, 2009; Leyser, 2014).

**Adapting to local conditions**

Agriculture is a fairly local industry. Climate and soil conditions are very specific to each region, such that certain agricultural techniques and technology cannot always be easily transferred from one place to another. This is the case for GM seeds. A seed which was engineered for use in Spain will not produce identical results in regions with different climate, biotic strains and soil characteristics. Thus, when developing seeds through GM technology, scientists need to take into account local environmental conditions (e.g. climate, soil composition, local pests and insects).

Additionally, the introduction of GM seeds into the market should be combined by ecological farming practices specific to where they are being used (Ronald, 2011). The sustainability of the technology depends significantly on the people using it. Farmers not having used GM seeds before would have to alter their practices to use less insecticides or change the herbicide being used, etc. They would additionally need to alter their farming practices in order to minimise certain risks, such as the evolution of nature to herbicides and/or pesticides. Moreover, the use of GM seeds could require other practices that they are currently not accustomed to. The education and training of farmers using the seeds plays an important role when considering GM technology in a sustainable food production system.

**Outcomes-based analysis**

When considering different approaches to certain issues, rather than focusing on the specific tools and techniques, solutions need to be evaluated based on their outcomes (The Royal Society, 2009), with trade-offs being considered and compared. The difficulty with GM technology is that positive outcomes are slightly more visible than their negative counterparts, making it difficult to conduct such a comparison accurately, and highlighting the importance of further independent scientific research. The unknown would, in some form, have to be considered – are the benefits of GM technology worth the known and potential risks compared to the benefit-risk trade-off provided by other approaches? Moreover, GM technologies are diverse and employ a range of genetic engineering processes, each with their own product-specific risks and benefits. Rather than placing all GM solutions under the same umbrella, a case-by-case approach should be favoured when deciding whether or not it would be beneficial to use a certain GM crop.



## 3. GM technology from a market perspective

A lot has changed within the past century. Farmers today have access to a wide array of seed products which enable them to increase agricultural yields. Nevertheless, a number of barriers still impede the market adoption of GMOs. The main hurdles consist of increasing the availability of quality seeds in the most needful areas, regaining consumer confidence, overcoming regulatory differences, and improving the quality and objectivity of the information available.

### 1.Access to GM seeds

The global seed industry is highly consolidated. In 2011, the world's top ten companies controlled more than half of the market. This can be explained by significant entry barriers arising from high upfront costs and the long timeframe required for recovering initial investments. The global GM seed market was valued at USD 15.6 billion in 2011 and is expected to grow by 94% by 2018.

Nevertheless, despite a high level of corporate control over the global seed commerce, the vast majority of farmers feeding around 70% of the world's population operate independent of the commercial seed industry. Although figures vary considerably by crop and region, it is estimated that 80-90% of the seeds planted by farmers in the southern hemisphere come from the informal sector (ETC Group, 2013). On a global scale, over half of the seeds may be self-produced by farmers (Dattée & Pelletier, 2014).

The significant share of seeds still supplied via the informal sector, coupled with the prospects of a looming food crisis, represent an enormous potential for growth in the agritech sector, and the main industry players are racing to invest in innovative seed technologies. Table 14 provides an estimation of how much companies are spending on R&D in agricultural biotechnology research.

**Table 14.** R&D expenses of 5 main biotech companies

| Company | R&D expenses (millions of US$) (1) | R&D expenses as % of net sales (1) | % of R&D devoted to biotech (2) |
|---|---|---|---|
| Monsanto | 1,533 | 10% | 80% |
| DuPont | 2,153 | 6% | 50% |
| Syngenta | 1,380 | 9% | 15% |
| Bayer | 1,137 | 10% | 89% |
| Dow | 1,747 | 3% | 85% |

(1)From the companies' 2013 annual report.
(2)Estimates by Hope Shand (ECT Group) based on Fuglie et al. 2011.

Source: Mirova (from Companies' annual report and Shand, 2012).

Nevertheless, smallholder farmers are not able to afford these types of seeds. While certain companies have in place programs to provide smallholder farmers with access to their seeds, the impact of these programs is yet to be known.

### 2. Public knowledge of GMOs

The perception and acceptance of GM technology varies from country to country, and among farmers and regulators in the US, Brazil, Canada, Argentina and Australia, all huge agricultural producers, have a positive view of the technology. Most countries in Europe have quite the opposite view. Denmark, Austria and Norway were the first three countries to oppose the marketing of GM canola in the EU, because of concerns that GM pollen would spread to locally-grown conventional varieties.

In the early days of GM food production, however, the vast majority of the population remained largely unaware of their potential impact. The introduction of bioengineered crops was met initially with relative indifference by public opinion and regulatory agencies. The Flavr Savr tomato was the first GM food crop to be approved for sale in the US in 1994. A year later, Belgium approved the cultivation of Ht-tobacco. By 1996, 35 approvals for the commercial cultivation of nine transgenic crops had been granted in six different countries, including the EU.

Over the years, several highly visible events have created considerable suspicion amongst a wide body of the public, based on a range of religious, cultural and ethical concerns. Apart from environmental NGO campaigns, Pusztai was one of the first scientists to dispute the safety of GM crops. In 2012, controversy around GMO arose when Seralini published a high profile article in *Food Chemical Toxicology* (FCT) on the effects of the long-term consumption of herbicide-tolerant maize. However, the study was widely contested by the scientific community, and FCT decided to retract it on grounds of design and methodology flaws.

However, despite some lack of clear evidence on safety issues, the European public opinion remains largely negative. While 44% europeans were in favour of the development of GMOs 15 years ago, only 23% remain so today (Boy, 2012).

If GM technology is to be adopted, the public needs to be provided with accurate information in order to form an opinion based on scientifically proven research. Currently, this type of information is not readily available, further highlighting the importance of independent and in-depth scientific research.

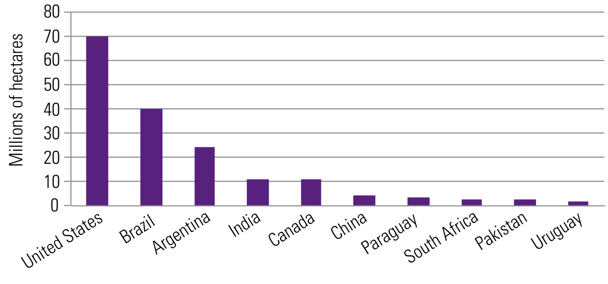
### 3. Regulatory environment

For the adoption of GM technology, restrictive and varied regulatory frameworks rank high on the barrier list. A study conducted by McDougall in 2011, based on information provided by six major biotech developers (i.e., BASF, Bayer, Dow Chemical, DuPont, Monsanto and Syngenta), concluded that the average time associated with registration and regulatory affairs increased 47% between 2002 and 2011. McDougall also estimates that 37% of the total time and 26% of the R&D funds were spent on regulatory testing and registration (2011).

In certain cases, if regulatory approval is not granted companies find themselves forced to drop their GM lines. In 2013, after years of research and field tests, BASF decided to halt the development of GM potatoes in the EU. Regulatory uncertainties impact not only market entry decisions but also the types of crops considered as most profitable to develop. The majority of food crops that have been genetically engineered so far are staple crops, such as, maize, soybeans, and wheat. Additionally, good governance of GM technology on the part of the government is important in order for it to be considered in a sustainable food production system.

Technological adoption varies widely for GM products. In 2013, 27 countries including the US, Canada and Brazil had embraced the large scale cultivation of GM food crops, while others including most of the EU countries, adopted a more conservative approach. As of May 2014, 26 nations, including Switzerland, Australia, Austria, France, Germany, Hungary, Luxembourg, Greece, Bulgaria, Poland, Italy, Mexico, and Russia had banned either all GMOs or certain types of GM food products. Furthermore, even though the rate of GM crop cultivation has increased in developing countries, in underdeveloped regions, adoption rates remain low.

**Figure 18.** Top Ten Countries using GM technology (area in millions of hectares)




Source: Mirova (from ISAAA, 2014).

**North America:** In the US and Canada, GM products are considered "substantially equivalent" to their conventional counterparts. Whenever a new type of food is deemed equivalent to an existing product, it can be treated in a similar manner when conducting safety assessments. Substantial equivalence hence implies that no systemic risks are associated with the newly developed food item. With the exception of Vermont state (Reuters, 2014), the rest of the US and Canada do not require labelling of GMOs.

**Central America:** Mexico placed an indefinite ban on the cultivation of GM corn in October 2013, over concerns that it might affect the country's native corn production and exports. Due to NAFTA provisions, GM imports are still allowed, however labelling is mandatory (Reuters, 2013).

**European Union:** Within the EU, countries have adopted different positions regarding the cultivation and commercialisation of GM seeds. As of today, only 2 types of GM have been authorised for cultivation in the EU (MON810 corn seeds and BASF's Amflora potato whose authorisation has been removed in 2013). However, only Spain is effectively producing MON810 crops (around 140,000 ha). In June 2014, EU environment ministers backed a proposal that gives national governments the possibility to opt out of the EU-wide GM regulations framework. The final decision rests with the European Parliament, however, it is expected that the plan will be endorsed. This can give countries, such as the UK, the possibility to open up their markets to GM crop cultivation, while other countries, such as France, could opt for a total ban on GM products (Reuters, 2014).

However, imports of over 40 GM varieties (mainly soy, corn and cotton) are authorised in the EU. This is accompanied by strong regulations on traceability and labelling (mandatory above 0.9% of GM in the final product).

**Emerging Economies:** Brazil is the leader among the four high growth economies in terms of GM cultivation. Around 85% of Brazil's soybean crops are GM, and the Centre for Sugarcane Technology (CTC) is currently working on the development of GM sugar cane varieties (Bloomberg, 2013). India and China allow the cultivation of certain GM varieties, but have banned other GM cultivars. Russia on the other hand is considering a ban on all GM food products and has called for similar measures at UN level (Global Meat, 2014).

### 4. GM technology from a responsible investment perspective

The topic of GM technology is not an easy one. The technology itself is fairly complicated and the environment surrounding it even more so. Nevertheless with seed companies spending a significant amount of their R&D into the area, it is increasingly becoming an issue for responsible investors. GM technologies present a wide variety of opportunities for sustainable development: increased food availability, more efficient use of natural resources, increased in farmer income. At the same time, they also present broad array of potential risks. Our aim here is then to describe from an investors' point of view how these technologies should be considered. Below, we describe how Mirova, as a responsible investor, will take into account GM technology with a focus on outcomes. Additionally, in Table 15, Sustainalytics explains the best practices for developing and offering genetically modified seeds.

As a responsible investor, Mirova endeavours to integrate all these elements in its assessment of seed companies. While acknowledge the significant public mistrust surrounding GMOs and more broadly vegetal biotechnologies, it appears that these technologies have a role to play in achieving a sustainable agriculture providing for food security and nutrition which should not be overlooked. By enabling more efficient plant breeding and offering possibilities which cannot be achieved by conventional breeding techniques, biotechnology should not be considered a reason for exclusion ex ante. As seen before, biotechnology embraces a large number of techniques, some of which have been applied for decades. Some emerging technologies may raise concern, and scientific evidence of their innocuity must be produced. However, despite significant environmental and social issues linked to the current GM crops (using mainly transgenesis), a direct link between the technique used and the observed externalities over the last past 15 years (resistance to pests, pollinisation, etc.) has by no means been demonstrated by scientific research. In the absence of sufficient scientific conclusions regarding techniques, we seek to assess companies on the sustainability of the outcome where GM crops are concerned.

As each GM crop is unique, a case by case analysis will be needed. The following factors will be considered:

- Traits of the GM crop: bio-fortified crops, crops with enhanced medical traits (e.g. vaccine crops) and other crops that would allow significant social and environmental benefits will be favoured.
- For already available crops, proven track record of improved agricultural performance while minimising environmental and human safety.
- Proven use of the precautionary principle when handling GM technologies.
- Transparency over the impacts of technologies used and scientific advances.
- Ability of governments where the technology will be used to provide good governance over the technology.
- Transparency over labelling and traceability beyond legislation.
- Engagement with and educating stakeholders, particularly the farmers and consumers.
- Risk / Benefit analysis compared with alternative approaches.

**Table 15.** Sustainalytics' suggested Best Practices for development and marketing of genetically modified seeds

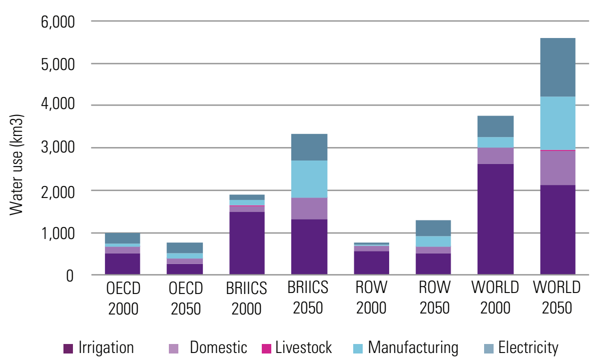
| Core Elements | | Description |
|---|---|---|
| Policy commitments | Precautionary Principle | Commit to adopt a precautionary approach towards the safe transfer, handling, use, and trans-boundary movement of GM seeds. Acknowledge and act upon scientific evidence that points at GM risks. |
| | Transparency and Disclosure | Commit to address stakeholder concerns via continuous engagement, support clear labelling that allows users to make informed decisions. |
| Programmes / management systems | Executive and Operational Oversight | Set-up cross-functional teams and manage processes locally, while maintaining corporate-level executive oversight. High level executives abstain from serving on regulatory boards and biosafety committees. |
| | Testing of GM crops | Require stepwise testing, with strict controls in place to prevent accidental or premature releases. Make results from each step publicly available. |
| | Impact Assessment | Assess impact on stakeholders throughout a crop's lifecycle. Evaluate contamination paths and scale of unintended release. |
| | Corrective Actions | Monitor health and environmental risks and report findings to dedicated staff. Establish protocols for corrective actions and emergency response plans. |
| | Laws and Regulations | Adhere to domestic and host country regulatory standards when GM crops are introduced on the market. In case of conflicting standards, the stricter standard should prevail. |
| | Stakeholder Engagement | Notify stakeholders of proposed releases and provide a reasonable timeframe for stakeholders to respond. Encourage feedback and implement response mechanisms. |
| | Training and Awareness | Raise community awareness about GM crops and increase understanding of GM technologies among stakeholders via training sessions on risks and benefits. |

Source: Sustainalytics, 2014.

## Focus #3. Water Solutions for Enhancing Agricultural Yield

With an increasing global population and the shift towards more water-intensive behaviour (such as the shift in dietary habits towards more meat), the demand for water will simultaneously increase – with the OECD projecting demand to rise by 55% between 2000 and 2050 (2012). While, historically, irrigation has constituted the majority of the world's demand for water, this is likely to decrease in the near future as other uses, such as electricity and manufacturing, continue to increase (see projections in Figure 19 below).

**Figure 19.** Global water demand: 2000 vs. 2050 (baseline scenario)




Note: BRIICS = Brazil, Russia, India, Indonesia, China & South Africa RoW = rest of the world

Source: Sustainalytics (from OECD, 2012).

Moreover, water demand is likely to outstrip supply by 2030 (EIU, 2012). The effects of climate change, such as increasing temperatures and dry weather, water pollution, and the lack of adequate water infrastructure, will add further stress on local supplies. This will lead to certain actors (e.g., farmers, cities, and industries) experiencing increased in competition for their daily water needs. It is estimated that water requirements for food production will need to increase by 50% from 2002 levels to meet the UN 2015 hunger target. Water scarcity represents one of the main constraints on agriculture, and can account for significant yield losses.

As such, if we are to secure the global future food supply it is also of equal importance to secure the water supply. The importance of solutions that increase the efficient use and conservation of water resources in agriculture (such as micro-irrigation, geo-synthetic liners, and agricultural techniques that conserve water in the soil) without compromising on yield and the development of alternative sources of water is not to be underestimated.

### 1. What are the water-related solutions that increase agricultural yield?

Below we highlight a series of water technologies and solutions, as well as farming techniques that we believe can help achieve maximum yields in areas where food insecurity is or can become an issue. Some of the technologies and techniques described in this section are more innovative than others. This is the case for pulsed irrigation and deficit irrigation, which are more novel than, say, canal lining or no-till farming. However, all the technologies and techniques highlighted have a key role to play in ensuring food safety as the opportunity for implementing them is significant, particularly in developing countries. As the costs related to these technologies constitute the greatest impediment to implementing them, innovative financing solutions need to be developed.

The water management technologies and solutions presented in this section are categorised into two groups:

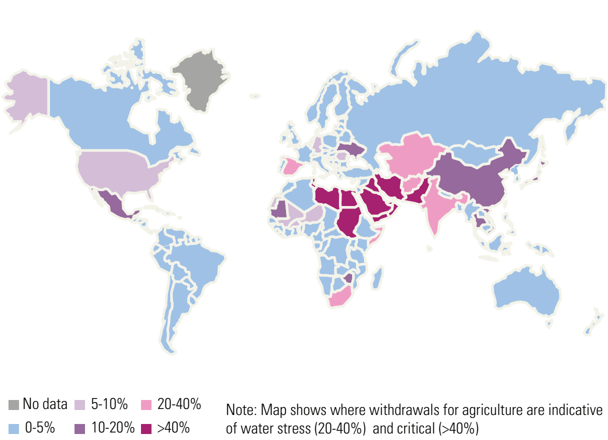
- Water use efficiency solutions,
- Solutions aiming at developing alternative sources of water.

#### 1.Water use efficiency solutions and solutions aiming at conserving water

Agriculture is the largest user of water globally (constituting 70% of the world's water withdrawals (AQUASTAT-FAO) and will remain so even as its percentage of the overall use is bound to decrease (as seen in Figure 20). Furthermore, water use in the sector remains highly inefficient, with only a fraction going to plant growth and the remainder being either drained or lost through evapo-transpiration. Consequently, the agricultural sector is under intense pressure to limit its negative impact on the environment, such as the pollution of water systems and its contribution to soil infertility and erosion caused by the intensive depletion of water sources (FAO, 2014).

**Figure 20.** Agricultural water withdrawals as a % of total renewable water resources

Agricultural water withdrawals as a percentage of total renewable water resources




Note: Map shows where withdrawals for agriculture are indicative of water stress (20-40%) and critical (>40%)

Source: Sustainalytics (from FAO, Water, 2014).

As the world's biggest consumer of water, the agricultural sector has an obligation to better manage its water usage so as to ensure global food security.

Water use efficiency solutions and solutions aiming at conserving water include the techniques of smart irrigation, water loss reduction solutions, and conservation agriculture.

**Smart Irrigation**

Agriculture accounts for 70% of global water use. Up to 60% of this water is wasted through inefficient irrigation systems (Department-FAO). The FAO estimates that irrigated land in developing countries will increase by 34% by 2030, but the amount of water used by agriculture will increase by only 14%, thanks to improved irrigation management and practices (FAO, Water, 2014). Smart irrigation is key to improving water productivity and achieving more crop per drop. Careful study of all of the relevant factors, including land topography, soil, water status, and crop and agro-climatic conditions is needed to determine the most suitable type of irrigation system. Smart irrigation techniques include micro-irrigation (including subsurface drip irrigation and pulsed irrigation), sub-irrigation, and deficit irrigation:

➜ Micro-irrigation: also known as trickle irrigation, drip irrigation, or localised irrigation - delivers water directly to the base of the plant. Properly installed and managed, **drip irrigation** helps achieve water conservation by reducing evaporation and deep drainage when compared to other types of irrigation such as flood or overhead sprinklers, since water can be more precisely applied to the plant roots. It is estimated that drip irrigation is 30% to 70% more efficient than conventional flooding or sprinklers. Drip irrigation is mainly used by farms and commercial greenhouses and has been adopted extensively in areas of acute water scarcity. Micro-irrigation fits ideally with the plant's agronomic requirements: it directs water and nutrients directly to the root zone; it optimizes moisture and aeration conditions; and it leads to a condensed and efficient root zone that saves water and improves yields. Micro-irrigation is ideal for sensitive hedging plants, including coconuts, grapes, bananas, eggplant, citrus fruits, strawberries, sugarcane, cotton, maize, and tomatoes. Drip irrigation may also use devices called micro-spray heads, which spray water in a small area, instead of dripping emitters. These are generally used on tree and vine crops with wider root zones.



➜ Another micro irrigation technique is **subsurface drip irrigation**, or SDI. SDI uses a buried dripper line located below the plant roots. This technique is popular for row crop irrigation, especially in areas where water supplies are limited or recycled water is used for irrigation. Farm operations also become free of impediments that normally exist above ground along with other pressurised irrigation systems. Since the water is applied below the soil surface, the effect of surface infiltration characteristics, such as crusting, ponding water in a saturated condition, and potential surface runoff (including soil erosion) are eliminated. With an appropriately sized and well-maintained SDI system, water application is highly uniform and efficient. Wetting occurs around the tube and water moves out in all directions.

In very arid regions or sandy soils, the preferred method is to apply the irrigation water as slowly as possible in order to reduce runoff or deep percolation. In this context, **pulsed irrigation** is the best available technique. Pulse drip irrigation operates by passively letting water flow into a reservoir at a controlled rate in order to steadily build pressure within the reservoir. When the pressure reaches a predetermined level, the valve on the reservoir opens and water is discharged. While the water is discharging, the pressure within the reservoir decreases. When the decrease in pressure in the reservoir reaches the predetermined level, the valve closes and the charging phase resumes. The charge-discharge cycling continues as long as the flow rate coming in through the inlet is less than the expulsion rate of what that passes out through the outlets while the valve is open.

**Table 16.** Water Savings: drip vs. flood irrigation

| Water Demand*: | Flood Irrigation | Drip Irrigation | Estimated Water savings (%) |
|---|---|---|---|
| Papaya | 7,500 - 8,000 | 3,000 - 4,000 | 55% |
| Potato | 2,400 - 3,200 | 1,200 - 1,600 | 50% |
| Sugarcane | 7,000 - 9,000 | 3,600 - 4,600 | 49% |
| Pomegranate | 5,500 - 5,800 | 3,200 - 3,500 | 41% |
| Tomato | 2,800 - 3,200 | 1,600 - 2,000 | 40% |
| Watermelon | 3,000 - 3,200 | 1,800 - 2,000 | 39% |
| Onion | 1,700 - 2,500 | 1,100 - 1,500 | 35% |
| Banana | 6,000 - 8,000 | 3,600 - 5,200 | 38% |
| Cotton | 2,400 - 4,000 | 1,500 - 2,500 | 38% |
| Capsicum | 2,400 - 3,200 | 1,500 - 2,000 | 38% |
| Grapes | 3,400 - 3,600 | 2,100 - 2,400 | 36% |
| Chili | 2,000 - 3,000 | 1,500 - 2,000 | 29% |
| Mango | 5,000 - 5,500 | 3,500 - 4,500 | 24% |

* in cubic meters per acre per year

Source: Mirova (from Keesen Crop Management, 2014.

**Sub-irrigation:** In agriculture, sub-irrigation, also known as seepage irrigation, is a method of irrigation where water is delivered to the plant root zone from below the soil surface and absorbed upwards. Sub-irrigation is used in growing field crops such as tomatoes, peppers, and sugar cane in areas with high water tables and in commercial greenhouse operations. Sub-irrigation is different from subsurface drip irrigation, where, as mentioned above, water is delivered through a buried dripper line located below the plant roots. In greenhouses, three types of sub-irrigation systems are used for potted plants: ebb-and-flow (bench-mounted enclosures holding pots are filled and then drained); trough (water is flowed through bench-mounted, slightly sloping enclosures containing pots); and flooded floor (special sloped concrete flooring is flooded and drained). On the field, sub-irrigation consists of raising artificially the water table, either through blocking ditches or by supplying water through the perforated pipes that are also used for subsurface drainage.

An area of R&D that is related to sub-irrigation is **subsurface vapour transfer irrigation**. This technology utilizes subsurface pipes that can be filled with almost any type of un-purified water, such as brackish, salted, polluted, industrial wastewater, or agricultural run-off. The pipes are lined with a hydrophilic material that allows water vapour - which cannot carry salts - to diffuse through the pipe walls, while the contaminants are retained within the pipes.

**Deficit irrigation** is a strategy in which irrigation is applied during the drought-sensitive growth stages of a crop. Outside these periods, irrigation is limited. While this inevitably results in plant drought stress and consequently in production loss, deficit irrigation maximizes irrigation water productivity. In other words, "deficit irrigation aims at stabilizing yields and at obtaining maximum crop water productivity rather than maximum yields" (Zhang and Oweis, 1999). The correct application of deficit irrigation requires a thorough understanding of the yield response to water. Not every crop will benefit equally from such treatment. Furthermore, responses, and thus procedures vary from one crop to another, and thus extensive knowledge is required. In regions where water resources are restrictive it can be more profitable for a farmer to maximise crop water productivity instead of maximizing the harvest per unit of land. The saved water can be used for other purposes or to irrigate extra units of land.

**Water loss reduction solutions**

Water loss due to seepage in unlined irrigation canals has been reported as being as high as 50%.[17] The US Bureau of Reclamation has ascertained that by lining canals, the loss can be decreased by, depending on the system used, between 70 and 95%.[18] A lined irrigation canal is provided with a lining of impervious material on its bed and banks to prevent seepage of water. The material used to line canals is generally concrete. Over the last four decades, the geosynthetics industry has developed a wide range of materials for use in the construction of irrigation and drainage projects. All geo-membrane materials are effective in reducing water seepage, and they allow increased flow rates. However, in practice, they may not be totally leak-tight. They differ in their abilities to lay and remain flat as temperatures change; in their abilities to conform to rough subgrades and differential settlement without impacting durability; in their tolerance for installation damage; UV radiation, and oxidation; and in their ability to be easily installed and repaired.

**Conservation agriculture**

Conservation agriculture is the term used to cover a variety of farming techniques that conserve rainwater in the soil (in situ water harvesting). According to the FAO, conservation agriculture is 'a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment' (FAO 2007). No-till farming (also called zero tillage or direct drilling) is one of the most prominent conservation agriculture techniques. No-till farming is a way of growing crops without disturbing the soil through tillage. No-till increases the amount of water that infiltrates into the soil by preventing the compaction of the soil due to tillage. In addition, crop residues left intact help both natural precipitation and irrigation water infiltrate the soil. The crop residue left on the soil surface also limits evaporation, conserving water for plant growth.

*17. http://www.landandwater.com/features/vol49no4/vol49no4_2.html.*
*18. The Canal Lining Demonstration Project 10 Year Final Report.*

**Irrigation scheduling solutions**

Irrigation scheduling aims to determine the exact amount of water to be used in the irrigation and the exact timing for application (SAI, 2010). According to (Evans, 1996), it uses water management strategies to prevent over-application of water while minimizing yield loss due to water shortage or drought stress. Irrigation scheduling requires knowledge of: the soil, the soil-water status, the crops, the status of crop stress, and the potential yield reduction if the crop remains in a stressed condition. Hence, the farmer needs to be able to measure the soil-water and the crop stress in order to know when and how much to irrigate. There are many different methods and devices for measuring soil water. These include the feel method, the gravitational method, tensiometers, electrical resistance blocks, neutron probes, Phene cells, and time domain reflectometers. Once the farmer has all the data, he can decide when and how much to irrigate depending on the crop, the soil characteristics, and the moisture level, thanks to guidelines provided by companies or organizations. There are also controllers that the farmers can programme to set off the irrigation at given intervals. An example of such a tool is the irrigation controller of the Irritrol brand (The Toro Company). This controller makes the irrigation scheduling easier, even if the farmer needs to change the watering schedules as plants become established, with the changing seasons, and when it rains.

## 2. Solutions aimed at developing alternative sources of water

While increasing water efficiency and promoting water conservation should remain the main focus when it comes to tackling water shortage issues, the need to look for other sources of water is increasing in importance, particularly in certain regions of high water stress and considering that freshwater accounts for only 2.5-3% of the global water supply and that 69% of this water is caught in glaciers or lies in very deep groundwater, and consequently only 0.5% of the world water is usable (Rodda, 2003). Additionally, the development of alternative sources of water could also allow for the development of an agricultural sector that otherwise would not be possible due to lack of access to water (for example, the installation of a desalinisation plant in Saudi Arabia made possible the expansion of the agricultural sector in the country).

There are significant opportunities for water treatment solutions that process water for a specific end use, namely desalinization, wastewater treatment, and water reservoirs.

**Desalination**

The desalinisation process converts seawater into fresh water that is suitable for several uses. While the water from desalinisation plants is mainly used for providing drinking water, it is increasingly being considered for irrigation purposes. Desalinisation is mainly relevant in dry countries, such as Australia and countries in the Middle East.

There are two commonly used methods for desalinization: (1) reverse osmosis (RO) and (2) multi-stage flash distillation

(MSF). In reverse osmosis, a semipermeable membrane is used to purify the water. The end result is highly concentrated brine on one side of the membrane and the purified water on the other side. Multi-stage flash distillation desalinates water by turning portions of the water into steam in multiple stages.

**Seawater farming**

Seawater farming is a technology whereby seawater is evaporated using solar energy in greenhouses to produce fresh water. The technology involves pumping seawater (or allowing it to gravitate if below sea level) to an arid location and then subjecting it to two processes: First, the evaporation serves to humidify and cool the air, and second the vapor produced by solar heating is distilled to produce fresh water. The remaining water and humidified air are expelled from the greenhouse and used to improve growing conditions for outdoor plants. Seawater farming can be used to support crops such as potatoes, cucumbers, and certain fruits in the world's driest regions using seawater, a virtually infinite source of $H_2O$.

**Wastewater Treatment**

When quality water is scarce, treated wastewater can be an alternative source. Wastewater and sewage treatment processes remove contaminants from the wastewater, resulting in effluent water that is safe for other uses and sludge. The principal technique used to treat wastewater is activating sludge, using bacteria to cause the degradation of the organic materials contained in the water. This technique allows treating high volumes of water but requires regular monitoring. For small villages, green wastewater treatment solutions exist, such as lagoon and reed filters that require no electricity, or intensive monitoring. Sewerage utilities can be complementary with the agricultural sector. Indeed, some wastewater treatment plants are endowed with silos to store so-called dead mud in order to dry it for use as organic fertiliser. The effluent water can also be used for irrigation.



**Water Reservoirs**

Many areas that experience droughts also have excessive rainfall during the rainy season. If the rainwater is saved, it can provide enough water to irrigate a farmer's land throughout the dry season. Capturing this water and storing it as surface water is called rainwater harvesting. The most widespread technology used to harvest rainwater is roof catchment, and the water is then stored in surface or underground tanks. By conserving the rain, farmers can increase the area they irrigate, grow crops in the dry season, support livestock, and even recharge groundwater. Water reservoirs make it possible to smooth water consumption during the year in regions with intermittent runoff so as to reduce the risk of drought. However water needs to be properly stored to avoid any contamination of the resource, for example by bird droppings.

**2. How will these solutions help increase food availability?**

The water-related solutions identified above may enable an increased and steady production of agricultural produce. First, these water efficiency solutions help ensure global water security by contributing to the decrease in water demand in an industry that is known for using a lot of water. Additionally, ensure a timely and appropriate supply of water through efficient irrigation makes it possible to maximise agricultural output, as shown for certain crops in the Table 17 below.

**Table 17.** Water productivity gains due to shifting from conventional to drip irrigation in India

| Crop | Increase in yield (%) | Decline in water application (%) | Gains in water productivity |
|---|---|---|---|
| Bananas | 52 | 45 | 173 |
| Cabbage | 2 | 60 | 150 |
| Cabbage (evapotranspiration) | 54 | 40 | 157 |
| Grapes | 23 | 48 | 134 |
| Okra (evapotranspiration) | 72 | 40 | 142 |
| Potatoes | 46 | ~0 | 46 |
| Sugarcane | 22 | 49 | 155 |
| Sweet Potatoes | 39 | 60 | 243 |
| Tomatoes | 28 | 33 | 95 |

Note: Water productivity is measured as crop yield per unit of irrigation water supplied, or as the ratio of yield to evapotranspiration where evapotranspiration is indicated in parenthesis.

Source: Mirova (from IWMI, 2007).

Furthermore, the use of new sources of water in areas under water stress such as desalinated or treated water make it possible to expand agriculture where it has traditionally been little developed.

**3. What are the advantages and disadvantages of these solutions versus 'business as usual'?**

Beyond the increase in the supply of agricultural commodities and in agricultural yields, the solutions identified in section 6.1 have additional advantages that may increase agricultural yields further:

➜ Micro-irrigation decreases the risk of certain diseases linked to high humidity (e.g., fungi) in comparison with full irrigation. It also reduces weed growth as it applies water to the root zone of plants; the spaces in between the plants remain dry, preventing weed seed germination. If the soil remains dry, most seeds will not germinate. In addition, some crops may benefit from the additional heat provided by dry surface conditions, producing more crop biomass, provided there is sufficient water in the root zone. Micro-irrigation also reduces the use of energy for water pumping and labour & machinery requirements for field treatments (e.g. with fertilizers).

Furthermore, it enables enhanced planning and timing of crops and ensures optimal use of land through usage of marginal land. Finally, micro-irrigation reduces soil erosion and the need for the use of fertilizers that can contaminate reservoirs and aquifers.

- Subsurface vapour transfer irrigation enables agriculture to make use of brackish or saline water without the need for expensive purification, desalinization, fine filtering, or pressurizing.

- Deficit irrigation reduces nutrient loss by leaching of the root zone, which results in better groundwater quality and lower fertiliser needs than cultivation under full irrigation; however, since irrigation is applied more efficiently, the risk for soil salinisation is higher under deficit irrigation as compared to full irrigation.

- No-till farming increases organic matter retention and cycling of nutrients in the soil. No-till dramatically reduces the amount of erosion in a field, as much less soil is displaced.

- Seawater farming presents several benefits. The fresh water distilled from seawater in the greenhouse does not need chemical treatment. Seawater evaporation also has a biocidal effect on the ventilation airflow, thus eliminating the need for pesticides. Seawater farming also enables the development of land normally considered unsuitable for agriculture, such as arid coastal areas.

The alternative sources of water identified above (i.e., desalinization, wastewater treatment, reservoirs) free up additional water for non-farming use such as industrial use or use for household needs.

**These solutions also present some risks:**

- Agricultural expansion: technologies that increase the availability of water through increased water efficiency (e.g., micro-irrigation) or new sources of water (e.g., desalinization) may enable the expansion of agriculture. The expansion of agriculture to previously unexploited land may pose a risk to local biodiversity.

- Apart from requiring a significant level of initial investment, desalinisation is also energy intensive. Traditionally, due to lower costs and higher purification effectiveness, MSF was the preferred method. However, since 2001, new technologies have been introduced that allow RO to be the preferred method for desalinization, for the following reasons: (1) lower energy input, (2) simpler construction materials, lowering costs and (3) the use of modular units, allowing for better scalability. Today, MSF desalination plants typically consume 80.6 kWh of heat energy and 2.5-3.5 kWh of electricity per cubic meter, while large-scale RO desalination plants require 3.5-5.0 kWh of electricity per cubic meter. The cost of desalinisation has been gradually decreasing, and is now typically around US$ 0.50/cubic meter, while market prices for desalinated water range between US$ 1-2 per cubic meter (International Renewable Energy Agency, 2012). Also, there are three other technologies that can further increase the energy efficiency of the desalination process. These are forward osmosis, carbon nanotubes, and biomimetics. The closest to commercialisation is forward osmosis. Forward osmosis causes the water to pass through a porous membrane and into a solution that has more salt than seawater but evaporates more easily. The other two technologies involve a novel use of the membrane, by using carbon nanotubes as pores or by using the membranes of living cells. These three technologies promise to reduce desalinization's energy consumption by 30% (Lange, 2010).

- Finally, apart from the GHG emissions linked to its energy usage, desalination plants also emit highly concentrated brine that, if its reintroduction to the sea is not well-managed, can cause negative impacts on marine life.

- Like desalination plants, sewage treatment plants require a large initial investment. It is also energy-intensive and indirectly emits GHG.

- More intensive agriculture linked to increased water availability may lead to soil nutrients drainage. To compensate the loss of nutrient more fertilisers may be required. This in turn may increase water and soil pollution.

### 4. What are the barriers to developing the solutions?

There are three main barriers to developing these solutions:

- Cost: Building reservoirs, investing in smart irrigation solutions or in a desalination plant are capital intensive. Micro irrigation is more expensive than traditional irrigation techniques and hence it is profitable to premium or expensive crops only. Also this technology is mainly used by farmers in developed countries. Farmers in developing countries may not be able to afford this technology.

- Lack of skills to implement these technologies. For example in deficit irrigation an exact knowledge of the crop response to water stress is imperative for deficit irrigation to be effective. Maintenance skills are also an issue since some of the technologies described in this section may require on-going maintenance.

- Low levels of farmer acceptance and lack of incentive. The main reason driving this is that water remains inexpensive for many farmers, therefore not giving them enough of a business case to use more water efficient irrigation practices. As Table 18 below shows, prices for irrigation and agriculture are low, even lower than prices for household or for industrial and commercial uses. While governments are beginning to consider and implement cost increases to better manage their water supply, much still needs to be done in order to better encourage farmers to adopt water efficient practices. Doubtless, increased education will play an important role in this regard.

**Table 18.** OECD Estimates of Prices for Water by Broad Sector Usage (US$ per cubic meter)

| OECD Nation | Household Water | Industrial & Commercial | Irrigation & Agriculture | Average Price of Water |
|---|---|---|---|---|
| Australia | $1.64 | $1.64 | $0.02 | $1.10 |
| Austria | $1.05 | $1.05 | $1.01 | $1.04 |
| Canada | $0.70 | $1.59 | $0.01 | $0.77 |
| France | $3.11 | $0.95 | $0.08 | $1.38 |
| Greece | $1.14 | $1.14 | $0.05 | $0.78 |
| Hungary | $0.45 | $1.54 | $0.03 | $0.67 |
| Netherlands | $3.16 | $1.08 | $1.44 | $1.89 |
| Portugal | $1.00 | $1.26 | $0.02 | $0.76 |
| Spain | $1.07 | $1.08 | $0.05 | $0.73 |
| Turkey | $1.51 | $1.68 | $0.01 | $1.07 |
| United Kingdom | $2.28 | $1.68 | $0.02 | $1.33 |
| United States | $1.25 | $0.51 | $0.05 | $0.60 |

Note: Data not available for all OECD member nations. Prices are in US$ per cubic meter of water. Includes water supply only and excludes wastewater charges and taxes.

Source: Mirova (from Canada West Foundation, 2011).



### 5. How can these solutions reach the market?

Most of the solutions described are currently available on the market. However, the barriers mentioned in section 6.4, mean that more is required to ensure that the technologies are used by those who need them the most. While the private sector can play an important role, other actors are needed to ensure that these solutions are properly adopted. Governments, international organizations, and NGOs all have a contribution to make to ensure that these solutions reach those who would most benefit from them.

For political reasons and to ensure food security at a national level, governments have historically supported agriculture. As mentioned, the solutions described above may require large amount of investment and are thus often contingent on government subsidies. They may also be part of a government's plan to upgrade the national agriculture. Additionally, when it comes to finding alternative sources of water, the solutions provided are aimed at ensuring water security in general and are not just for the agricultural sector. As such, they would require investment at the national level rather than locally.

International organisations and NGOs can help by providing access to the capital and expertise necessary to implement these solutions. Additionally, they can help by increasing acceptance and awareness among farmers of new technologies, and training people in the skills necessary to use them.

# APPENDIX

## I1 Public and private initiatives to tackle food security

The 2010 Millennium Development Goal Summit initiated the process of defining the global development agenda beyond 2015. The 2012 Rio+20 Conference on Sustainable Development initiated an inclusive process to develop a set of Sustainable Development Goals (SDG). The two processes are now merged into a global sustainable development agenda. In the initial draft of SDGs, goal number 2 is intended to **end hunger, achieve food security and adequate nutrition for all, and promote sustainable agriculture.** The goals, which are still in the process of being finalized, will be presented at the UN General Assembly in September 2014.

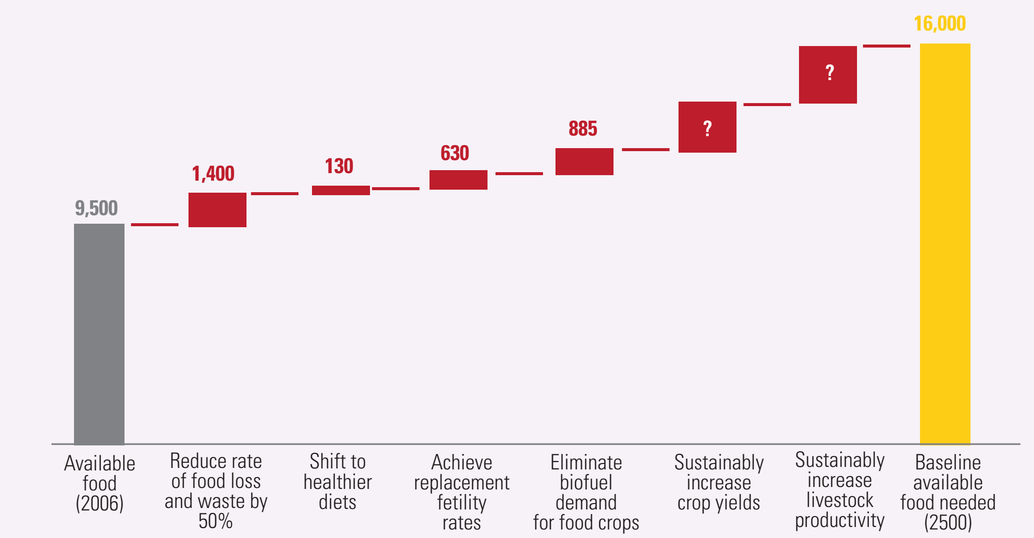
FAO's annual State of Food Security in the World assesses undernourishment in terms of the number of people affected and their prevalence within the population of each country. The World Food Programme's Food Security Analysis Assessment Bank gathers the food security assessments of the WFP, the food aid arm of the UN, to prevent and monitor food crises in vulnerable areas. Finally, the Global Food Security Index launched by The Economist Intelligence Unit (EIU) and Dupont in 2012 assesses the affordability, availability, and utilisation of food in 107 countries. Building on these assessments, a growing body of frameworks and soft laws have emerged to help all stakeholders (states, companies, NGOs, farmers, and municipalities) address food insecurity in a comprehensive and complementary manner.

In parallel, the UN has launched the Zero Hunger Challenge to address the issue of food insecurity after 2015. The challenge is based on the human right to food and embodies the different components of food security. Of these components, the most relevant to the study are that all food systems be sustainable and that there be zero loss or waste of food.

## I2 Estimation methodology for the role of each solution in increasing agricultural production.

The WRI (Ranganathan, 2014) estimates that to close the food gap, 38% of the solutions found (without taking into account the replacement fertility rate) will need to be on the consumption side and 62% on the production side (see Figure 22). The WRI has also identified the extent to which a reduction in supply chain losses, shifting to healthier diets and modifying biofuel demand, will be needed to close the food gap that we have presented.

**Figure 21.** Menu items helping to close the food gap (Global annual crop production in trillions of kcal)



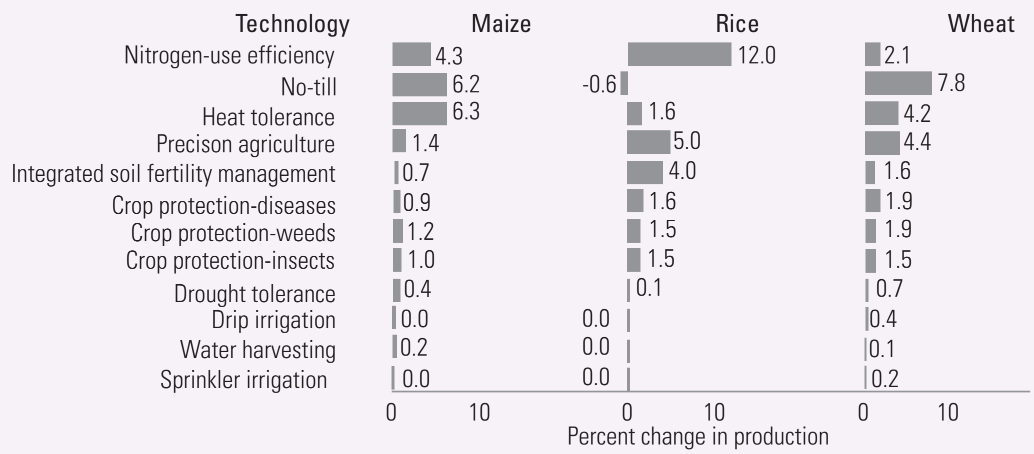

Source: (Ranganathan, 2014).

According to Bruinsma (2012), expanding croplands represents 9% of the growth in crop production that are expected by 2050, while increases in cropping intensity represent 14%, and yield increase represents 77%. This concerns the production side; in order to take into account the consumption side, we multiplied these three percentages by the share the production side is expected to have in the closing of the food gap; that is, 62%. The numbers for area expansion and irrigated area expansion are derived in the same way from Bruinsma. Illustration of this computation for the expansion of croplands: 9% of 62% comes to 6% of the whole.

Concerning mechanisation and fertilization, as they are not new solutions, we estimated their food production growth potential based on Fuglie's work. He estimated that between 2001 and 2010, agricultural production grew by 3.3% per year, of which 0.13% was due to fertilisers and 0.08% due to mechanisation. By multiplying, we find that fertiliser intensification contributed 3% to agricultural growth, and mechanisation 2%. We made the assumption that these contributions were likely to remain the same over the next 10 years, given that developing countries still have some growth potential in these areas.

Concerning these last solutions, IFPRI presents a detailed list of solutions and estimates the potential for food production increase from each for maize, rice, and wheat. We weighted the results by the share of each of these crops in the cereal production to obtain global estimates (Figure 22 and Figure 23).

**Figure 22.** Global change in production compared to the baseline scenario, by technology and crop, 2050 (%)




Source: (Rosegrant K. C., 2014).

**Figure 23.** World production of three major cereals

| | World production in 2013 (tonnes) | Share of production |
|---|---|---|
| Maize | 1,016,431,783 | 41% |
| Rice | 745,172,064 | 30% |
| Wheat | 713,217,069 | 29% |
| Total | 2,474,820,916 | 100% |

Source: MIROVA (based on FAOSTAT).

An illustration of our computation for precision agriculture is as follows: 1.4*0.41+5*0.3+4.4*0.29=3%.

This computation only gives an estimate, since it takes rice, wheat, and maize production as a proxy for global agricultural production; but this is a rather acceptable assumption since rice, wheat, and maize represent 89% of the world's cereal production (FAOSTAT).

## GLOSSARY

**Body mass index (BMI).** The ratio of weight-for-height measured as the weight in kilograms divided by the square of height in metres. (SFI, 2014).

**Dietary energy requirement (DER).** The amount of dietary energy required by an individual to maintain body functions, health and normal activity (SFI, 2014). Dietary energy requirements are expressed as kilocalories per person per day and are determined by age, sex and level of activity. See also Minimum dietary energy requirement (MDER).

**Food gap.** The difference between current food production and future needs based on the projections for 2022 in OECD-FAO. (2013). (Agricultural Outlook 2013-2022).

**Food insecurity.** A situation that exists when people lack secure access to sufficient amounts of safe and nutritious food for normal growth and development and an active and healthy life. It may be caused by the unavailability of food, insufficient purchasing power, inappropriate distribution or inadequate use of food at the household level. (…) Food insecurity may be chronic, seasonal or transitory. (SFI, 2014). See also Food security.

**Food security.** A situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time. (SFI, 2014). See also Food insecurity.

**Food system.** A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outputs of these activities, including socio-economic and environmental outcomes. (HLPE, 2014). See also Sustainable food system (SFS).

**Hunger.** For the purposes of this report, hunger is considered synonymous with a prolonged and/or chronic state of undernourishment. See Undernourishment.

**Macronutrients.** The proteins, carbohydrates and fats that are available to be used for energy. They are measured in grams. (SFI, 2014). See also Malnutrition and Micronutrients.

**Malnutrition.** An abnormal physiological condition resulting from an inadequate consumption of nutrients, whether insufficient (undernutrition), excessive (overnutrition), or unbalanced (micronutrient deficiencies). It can be caused by either the inadequate availability of nutrients (due to an inadequate diet) or their inadequate utilization (due to illness) at the cellular level. See also Macronutrients, Micronutrients, Overnutrition and Undernutrition.

**Micronutrients.** Vitamins, minerals and certain other substances that are required by the body in small amounts. They are measured in milligrams or micrograms. (SFI, 2014) See also Macronutrients and Malnutrition.

**Minimum dietary energy requirement. (MDER)**. The minimum amount of dietary energy required to meet the energy needs of an individual at a minimum acceptable BMI engaged in low physical activity. (See Body mass index (BMI).) Minimum dietary energy requirements are expressed as kilocalories per person per day and are determined by age and sex. (See also Dietary energy requirement (DER).) When referring to an entire population, the MDER is the weighted average of the minimum energy requirements of the different age/sex groups (SFI 2014). For further details on the standard methodology used to estimate MDER thresholds. See SFI (2014: 48).

**Nutrition security.** A situation that exists when secure access to an appropriately nutritious diet is coupled with a sanitary environment, adequate health services and care, in order to ensure a healthy and active life for all household members. Nutrition security differs from food security in that it also considers the aspects of adequate caring practices, health and hygiene in addition to dietary adequacy. (SFI, 2014). See Food security.

**Obesity.** The state of having a BMI of 30 or more. See Body mass index (BMI); see also Overweight and Underweight.

**Overnourishment.** Food intake that is continuously in excess of dietary energy requirements. (SFI, 2014). See Dietary energy requirement (DER); see also Undernourishment.



**Overnutrition.** A result of excessive food intake relative to dietary nutrient requirements. (SFI, 2014). See Dietary energy requirement (DER), Macronutrients, Malnutrition and Micronutrients.

**Overweight.** The state of having a BMI of more than 25 but less than 30. See Body mass index (BMI); see also Obesity and Underweight.

**Sustainable food system (SFS).** A food system that ensures food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised. (HLPE, 2014) See Food security, Food system and Nutrition security.

**Sustainable intensification.** Raising the general efficiency of agricultural systems through the use of new technologies or by improving agricultural practices in order to achieve increased yields while using fewer resources and minimizing or reversing environmental impacts. (Rosegrant, 2014).

**Undernourishment.** A state, lasting for at least one year, of inability to acquire enough food (…) to meet dietary energy requirements. (SFI, 2014). See Dietary energy requirement (DER); see also Hunger.

**Undernutrition.** The outcome of undernourishment, and/or poor absorption and/or poor biological use of nutrients consumed as a result of repeated infectious disease. It includes being underweight for one's age, too short for one's age (stunted), dangerously thin for one's height (wasted) and deficient in vitamins and minerals (micronutrient malnutrition) (SFI, 2014). See

Macronutrients, Malnutrition, Micronutrients, Undernourishment and Underweight.

**Underweight.** Low weight for age in children, and BMI of less than 18.5 in adults, reflecting a current condition resulting from inadequate food intake, past episodes of undernutrition or poor health conditions (SFI, 2014). See Body mass index (BMI) and Undernutrition.

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## Glossary resources

Glossary Definitions are taken from or inspired by:

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**NATIXIS ASSET MANAGEMENT**
Limited Company - Share Capital: € 50 434 604,76
Regulated by AMF: GP 90-009
RCS Paris n°329 450 738
Registered Office: 21 quai d'Austerlitz - 75634 Paris