

Global Food and Nutrition Scenarios

Final Report

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1. Background

The world population was estimated 6.07 billion for 2000 and it is projected to grow to around 9 billion by 2050 (UN, 2010). Such population growth imposes profound challenges in meeting future food requirements. According to FAO projections, a 70% increase in food consumption is expected, driven by the above-mentioned large increase in world population, but also by a relevant increase in PC kcal consumption. Globally, diets are also changing rapidly, with a clear tendency towards an increasing consumption of meat. For 2050, FAO has estimated meat consumption to be around 4.65 billion ton. More specifically, it is projected that by 2050, 2.3 times more poultry meat and between 1.4 and 1.8 times more of the meat of other livestock products will be consumed as in 2010 (FAO, 2009). This increase in meat consumption can be attributed to assumed increases in income and relates to the increase in average calorie intake. The world's average daily calorie availability is projected to rise from 2 789 kcal per person per day in 2000 to 3 130 kcal per person in 2050, a 12 percent increase. The current level of food waste is around 30% to 50% as estimated by FAO and the Institution of Mechanical Engineers (IME).

This report outlines a series of scenarios that are then simulated with the Threshold21 (T21) model and analyzed in order to address two fundamental questions regarding global long-term (2050) food requirements:

- (1) How much would agriculture production need to increase to meet food requirements, assuming a general shift towards more sustainable diets?
- (2) How much would agriculture production need to increase to meet food requirements, assuming a reduction in food loss and waste?

Section 2 provides a qualitative description of the scenarios; section 3 identifies key indicators for scenario assessment; in section 4 results from T21 Business as Usual scenario are compared with baseline projections from FAO to 2050; in section 5 scenarios are characterized quantitatively; in section 6 simulation results are reported and discussed; and in section 7 conclusions are drawn.

2. Qualitative scenario description

Table 1 provides a qualitative overview of how such two fundamental questions will be addressed by crossing assumptions regarding the level of sustainability of diets and the amount of food loss and waste.



Type of Diet 	Meat rich diet	Low animal food diet
Proportion of Food Loss and Waste 		
High proportion of Food Loss and Waste	Scenario 1	Scenario 3
Low proportion of Food Loss and Waste	Scenario 2	Scenario 4

Table 1: qualitative scenario matrix

Scenario 1: Business-As-Usual

The Business-As-Usual (BAU) scenario provides endogenous long-term projections for major social, economic and environmental development indicators, with a special emphasis on agriculture-related indicators. The BAU is based on the assumption that no major policy shift or shocks on mineral resources supply will take place, and that food consumption patterns will continue to evolve along the current path.

The BAU scenario is characterized by diets that are rich in meat and other animal products as well as high proportion of food loss and waste at the supply and demand side. These diets have already been labeled unsustainable in the literature because they further intensify the use of natural resources and subsequently exacerbate environmental degradation. This scenario also assumes a high proportion of food loss and waste at the processing, distribution, and households' level.

The BAU scenario investigates the impact of such unsustainable diets by following the trend in meat consumption as projected by FAO (2009, 2011a, b) and provides a benchmark against which results from the scenarios can be compared.

Scenario 2

This scenario investigates the impact of unsustainable diets by following the FAO projections on meat consumption. Compared to Scenario 1, this scenario assumes lower levels of food loss and waste at the processing, distribution, and households' level. The purpose of this scenario is to gain further insight into the impact of food waste reduction at the supply and demand side, while food consumption patterns will continue to evolve along the current path. This would imply a decrease in the amount of production needed to satisfy food demand. While total food production decreases and food consumption patterns continue to evolve along the current path, it is assumed that consumers will waste less food and therefore buy less food.

Scenario 3

This scenario investigates the impact of adopting more sustainable diets on food production and consumption against the backdrop of a high proportion of food loss and waste at the processing, distribution, and households' level. The scenario is supposed to provide further insight into the impact of reducing meat consumption in high-income countries on food production while sustaining a low level of meat consumption in low-income countries. Of potential interest is to analyze a reduction in meat consumption, while keeping the nutritional content of the resulting diet at satisfactory levels in high-income countries and allowing for only a slow increase in the content of meat as income rises in today's low-income countries without compromising sufficient nutritional content.

Scenario 4

This scenario includes the ideal projections for sustainable food production and consumption. Similar to scenario 3, this scenario analyzes the impact of sustainable diets on food production. However this analysis will be done against the backdrop of a low proportion of food loss and waste at the processing, distribution, and households' level. The analysis serves a similar purpose as outlined in scenario 3 but it combines a reduction in meat consumption and food loss and waste at the demand and supply side. This scenario can be seen as an ideal scenario for sustainability because it considers a change in meat consumption necessary to keep the nutritional content of the resulting diet at satisfactory levels in high-income and low-income countries. In addition, this scenario considers consumption waste is reduced gradually in high income countries and processing and distribution losses decrease in developing countries (where consumption waste is also kept below the target waste level for developed countries).

3. Indicators & driving mechanisms

Results of the different scenarios will be analyzed and assessed based on a set of selected indicators. Such indicators have been selected based on their relevance with respect to the key

questions being addressed. Table 2 provides the list of selected indicators, a brief description of each indicator, and its major driving forces within T21.

Indicator	Description	Driving forces
Total population	The sum of global population (disaggregated in the model into 81 age cohorts and by gender)	Total fertility rate, life expectancy at birth.
Total harvested area	The sum of harvested area for all different types of crops.	Demographic pressure, available land for agriculture.
Total crops production in tons	The sum of all crops production (disaggregated in the model into 11 types of crop), in physical quantity (tons).	Capital, labor, soil nutrients, water availability, health, education, research and development, energy availability.
Animal food production in tons	The sum of all animal production (disaggregated in the model into 4 types of products), in physical quantity (tons).	Availability of pasture area, availability of animal feed products.
Total food waste and loss	The sum of all food process, transportation, distribution and household waste and loss.	Food production in tons, process, transportation and distribution efficiency, households food availability
Calories per person per day	The amount of calories consumed per person, per day.	Animal food consumption, vegetal food consumption and total population
Total daily pc calories animal food	The amount of calories from animal food consumed per person, per day.	Animal food consumption and total population
Total daily pc calories vegetal food	The amount of calories from vegetal food consumed per person, per day.	Vegetal food consumption and total population
Proportion of population undernourished	Includes food consumption classes below minimum energy requirements, as a share of total population	Food production in tons and food distribution by class.

Table 2: Indicators selected for scenario analysis

4. Comparison of T21 base run with FAO projection to 2050

For the BAU scenario to be a reliable benchmark against which results from the scenarios can be compared, it is important that the T21 base run is in line with FAO projection to 2050. The Comparison Table below presents the results for the above-mentioned indicators.

The Comparison Table indicates that FAO’s projection and T21 projection for 2050 are similar on most indicators, including total population, total harvested area, PC calorie daily intake, and the breakdown of calorie intake between vegetal and animal food. Similarly, the proportion of

population undernourished is also very similar for the two scenarios. Such indicators are the most fundamental ones that are used to develop further scenarios and assess their results.

Table 3 shows a discrepancy between the T21 base run and FAO projection for some indicators, such as ‘Animal food production in tons’ indicator. FAO projects an increase in global meat production from 229 million tons in 1999/2001 to 465 million tons in 2050 (FAO, 2006). The difference between the T21 base run and FAO projection can be attributed to different assumptions regarding the mix of meats considered. In addition, large regional variations linked to the stage of development of individual countries, especially developing countries (FAO, 2011a), can also introduce differences in the projections.

Table 3 lacks a value from FAO for 2050 but the value of the T21 base run is in line with current FAO projection for loss and waste. According to FAO (2009), roughly one-third of food produced for human consumption is lost or wasted globally which equals to 1.3 billion tons per year. This amount is about 15.5% of total food production. From the T21 base run, this share increase slightly to 16.5% in 2050 as a result of increasing PC waste at households’ level.

Indicator	T21 Base Run	FAO projection
Total population¹	9.31E+09	9.31E+09
Total harvested area	1.31E+09	NA
Total crops production in tons	11.2E+09	10.5E+09
Animal food production in tons (meat)	573E+06	465E+06
Total food waste and losses (Tons)	2.1+09	NA
Calories per person per day	3130	3130
Total daily pc calories animal food (kcal/day/person)²	621	620
Total daily pc calories vegetal food (kcal/day/ person)	2509	2500
Proportion of population undernourished	0.0368	0.0311

Table 3: comparison of T21 simulation and FAO projection by 2050, selected indicators

5. Quantitative specification of the Scenarios

For the sake of simulation by way of the T21 model, the scenarios qualitatively described in the previous sections are to be quantitatively characterized. Such process implies assigning specific values to selected indicators that are representative of the qualitative scenario description provided above. Table 4 provides an overview of tentative values for quantitative

¹ Also in line with the United Nations Population Division’s projections

² As nations become more affluent in the coming decades through development, per capita calorific intake from meat consumption is set to rise 40% by mid-century (IME, 2013)

characterization of the scenarios. The following paragraphs provide further insight about how such quantification has been determined, and its interpretation.



Type of Diet 	Meat rich diet	Low animal food diet
Proportion of Food Loss and Waste 		
High proportion of Food Loss and Waste	Scenario 1: 34% of food waste and food loss as share of total food production 620 daily pc calories animal food	Scenario 3: 34% food waste and food loss as share of total production 500 daily pc calories animal food
Low proportion of Food Loss and Waste	Scenario 2: 30% of food waste and losses as share of total production 620 daily pc calories animal food	Scenario 4: 30% food waste and losses as share of total production 500 daily pc calories animal food

Table 4: quantitative characterization of the scenarios

Scenario 1: Business-As-Usual

As illustrated above, our business as usual scenario replicates quite closely FAO’s projections for 2050. Daily pc calories from animal food are expected to increase by approximately 24% with respect to today’s values, to reach on average about 620 Kcal/person/day in 2050. In addition, the BAU scenario considers an increase in the proportion of food production being lost and wasted from the current 32% to approximately 34% by 2050.

Scenario 2

In this scenario, we assume total daily pc calories animal food and total daily pc calories vegetal food to increase by the same rates as described in the BAU scenario. In addition, this scenario considers a decrease in the proportion of food production being lost and wasted from the current 32% to approximately 30% by 2050. This is based on the assumption of a global convergence of food loss and waste levels towards a level of about 200Kg per capita per year. This allows for some slight increase in the PC food waste and loss in absolute levels in low-income countries, since in such countries the total amount of food production and consumption is expected to increase substantially. On the other hand, food waste and loss is set to decrease gradually in mid income countries, and more drastically in high income countries, as illustrated in table 5. Currently, in low-income countries households waste is a relatively small component of total food waste and loss (about 10%), while industrialized countries households waste represents a more relevant component of total food waste and loss (about one third). This we envision that in high-income countries major gains will be obtained from reduction of households waste.

Projected food waste and loss for 2050, Low waste and loss scenario					
Region	Current (2009) PC food waste & loss (kg/person/year)	Projected (2050) PC food waste & loss (kg/person/year)	Relative change compared to BAU 2009	Population (2050)	Total food waste & loss (ton/yr)
World (TOTAL)				9.31E+06	1.86E+09
Africa	180	200	11%	2.19E+06	4.38E+08
South America	225	200	-11%	4.88E+05	9.76E+07
Central America	225	200	-11%	2.16E+05	4.31E+07
Caribbean	225	200	-11%	4.73E+04	9.46E+06
Asia	160	200	25%	5.14E+06	1.03E+09
Oceania	295	200	-32%	5.52E+04	1.10E+07
Europe	280	200	-29%	7.19E+05	1.44E+08
North America	295	200	-32%	4.47E+05	8.94E+07

Table 5: Low Food Waste and Loss Scenarios

Scenario 3

This scenario takes into account a global convergence towards a low animal food diet. As presented in Table 6 this implies keeping, on a world average, the daily pc calories from animal food constant at about today’s level. It is important to note that it is possible to achieve such goal while allowing an increase in daily pc calories from animal food in low-income countries in Africa, the Caribbean and Asia. Such increase would be compensated by a reduction in daily pc calories from animal food in high-income countries in Europe, North America and Oceania by 30% to 35%. In addition, this scenario considers an increase in the proportion of food production being lost and wasted in line with the BAU scenario.

Projected PC calorie intake from animal food for 2050, Low animal food diet scenario					
Region	Current (2009) animal food supply (kcal/person/day)	Projected (2050) animal food supply (kcal/person/day)	Relative change (compared to BAU 2009)	Share of total population (2050)	Weighted animal food supply (kcal/person/day)
World	501				501.40
Africa	207	414	100%	0.24	97.50
South America	655	589.5	-10%	0.05	30.92
Central America	575	546.25	-5%	0.02	12.65
Caribbean	379	492.7	30%	0.01	2.50
Asia	429	493.35	15%	0.55	272.61
Oceania	946	662.2	-30%	0.01	3.93
Europe	925	647.5	-30%	0.08	50.04
North America	1001	650.65	-35%	0.05	31.24

Table 6: Low Animal Food Diet Scenarios

Scenario 4

This scenario assumes a decrease in the proportion of food production being lost and wasted from the current 32% to approximately 30% by 2050, jointly with a low-animal food diet as indicated in scenario 2.

6. Scenario results

This Section presents an overview of the results of the following scenarios for the period 1970-2050: Business-As-Usual (BAU) (scenario 1, grey line in the graphs), Low Food Loss and Waste (scenario 2, blue line in the graphs), Low Animal Food Diet (scenario 3, green line in the graphs), and Low Food Loss and Waste & Low Animal Food Diet (scenario 4, red line in the graphs). The simulation results are presented for the key indicators itemized in Table 3 in order to compare the four scenarios. The simulation results are summarized in Table 7.

6.1 Total population

As illustrated in Figure 1, all scenarios project a global population of 9.3 billion by 2050, which is in line with UN Population Division projection. There are no substantial differences among the four scenarios with respect to this indicator, since fertility and mortality are not substantially affected, on global average, by the policies introduced. Thus the four lines in Figure 1 are overlapping.

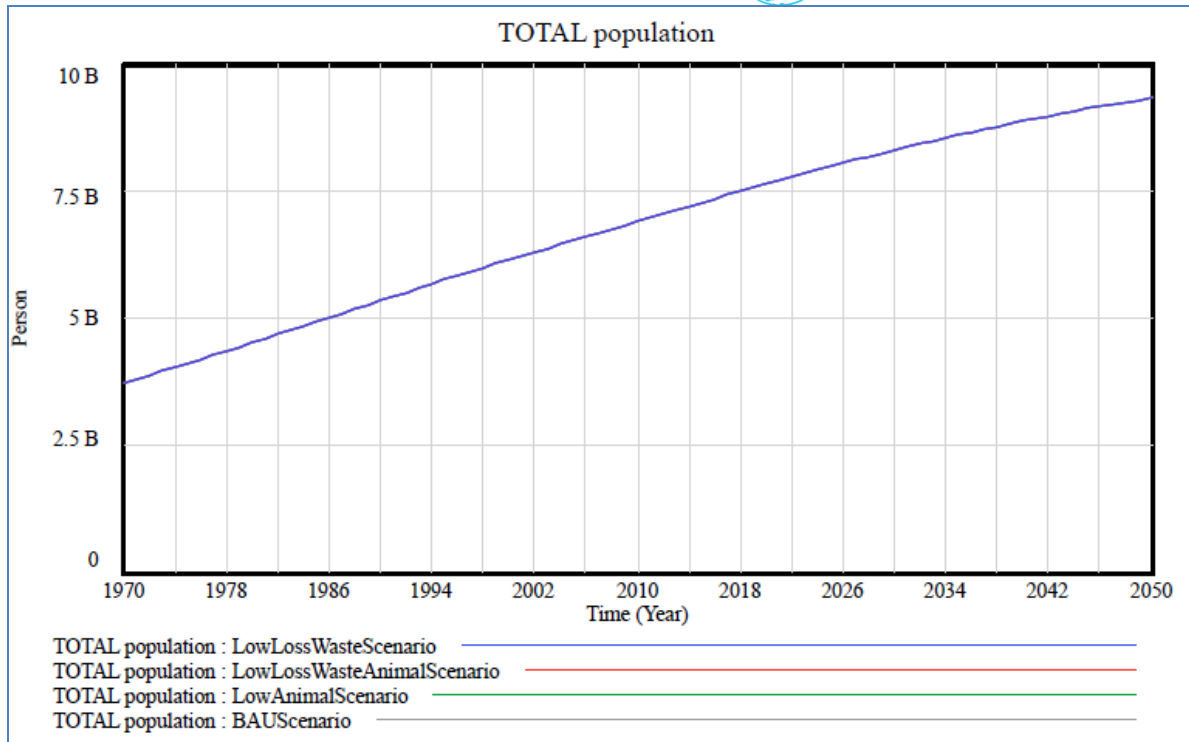


Figure 1: Population. Source: UNPOP data and T21 projections

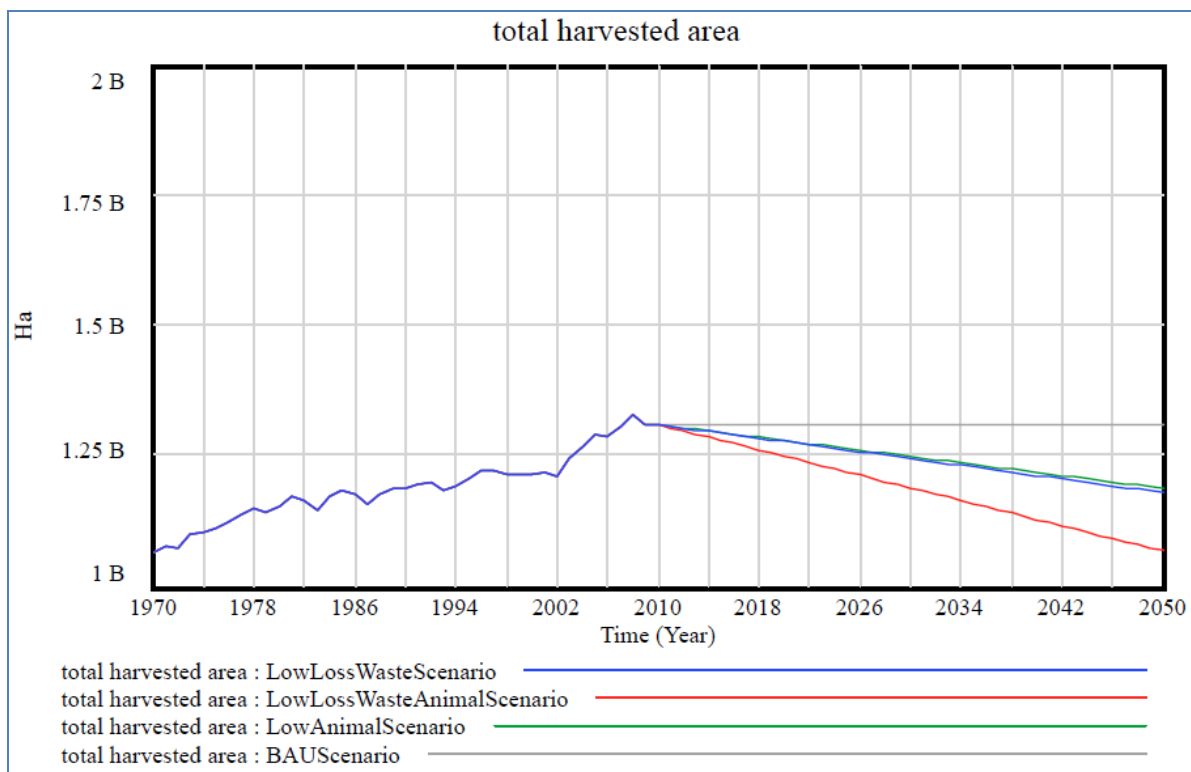
6.2 Total harvested area

In the BAU scenario, total harvested area is projected to remain stable around today’s level, at about 1.31 billion hectares (Figure 2). This is a conservative assumption, based on the observation that arable land and permanent crops areas have been growing at very slow rates over the last 20 years (FAOSTAT), and on the consideration that land conversion to agriculture will be increasingly regulated in the future. It is possible that a slower than expected growth in yield will increase demand for agriculture land, leading to a gradual increase in harvested area. Nevertheless, this would not substantially affect the relative difference observed in the results for the four scenarios.

In the Low Food Loss and Waste scenario, total harvested areas decreases to 1.178 Billion hectares by 2050. As a result of the important saving obtained from the reduction in processing, transportation, distribution losses as well as from the reduction in households waste, a larger proportion of the agriculture production reaches the consumers. This implies that a smaller amount of agriculture production is needed to provide consumers with the same amount of food. Consequently, production is reduced, and thus a smaller area needs to be cultivated in order to produce and deliver the same amount of total PC daily energy intake as in the BAU.

In the Low Animal Food scenario, total harvested area decreases to 1.185 Billion hectares by 2050. Such important reduction is caused by the decrease in food requirements, in terms of daily per capita calories from animal food (from 620 in BAU to 500 in the Low Animal Food scenario). On average, the grain-meat conversion ratios vary from 2:1 for poultry to 7:1 for beef (FAO, 2006), implying that two Kg of cereals are needed to produce one Kg of poultry, and up to 7 to produce one kilogram of beef. Although meat calorie content can vary substantially depending on the type of meat, on average meat does not have higher calorie content than cereals. Therefore, in the Low Animal Food scenario, as less cereal crops are used to feed animals and more are used directly for human nutrition, we observe a large saving in terms of energy. As a consequence, less area needs to be cultivated to obtain the same amount of total PC daily energy intake as in the BAU.

Total harvested area is expected to further decrease in the combined scenario 4. The combined impacts result in a further decrease in the total harvested area to 1.065 billion hectares. Such reduction in harvested area (about 19% less than in the BAU) implies a lower pressure on natural resources, especially on conversion from other types of land, soil nutrients, and energy.



Fig

ure 2: Total harvested area. Source: FAO data and T21 projections

6.3 Total crop production in tons

As illustrated in Figure 3, the BAU scenario projects a 45% increase in total crop production for 2050 with regard to the current figure of 7.68 billion tons. Such increase is mainly driven by

increasing yields, and allows for an important global increase in PC calorie intake from vegetal food. For the period 2013-2050, both the Low Food Loss & Waste and Low Animal Food scenarios indicate a smaller increase in crop production (about 35.5%). In the former case, the lower amount of food loss and waste allows to meet the same level of PC calorie intake as in the BAU with a smaller production. In the latter case, the adoption of low animal food diets implies that a lower amount of crop production is used for animal feed, and a larger amount directly for human nutrition. Given the low energy efficiency of using crop production for human feed, the net amount of production necessary to meet the same level of PC calorie intake as in the BAU is smaller. The combined scenario projects a 26% increase in total crop production for 2050, as it combines the positive impacts of lower food loss and waste as well as the adoption of a low animal food diet on crop production.

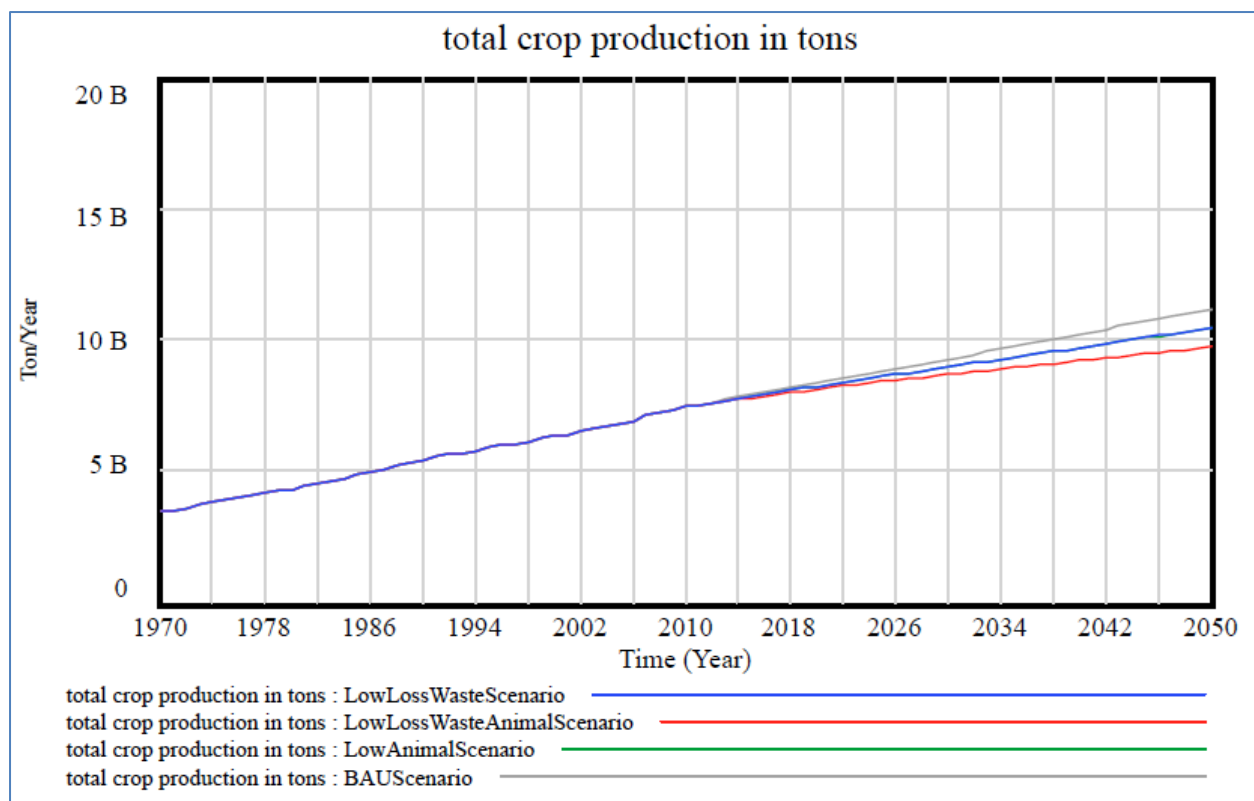


Figure 3: Total crop production in tons. Source: FAO data and T21 projections

6.4 Animal food production in tons

As illustrated in Figure 4, the BAU scenario (grey line) and the Low Food Loss & Waste scenario (blue line) indicate a continuous increase in global meat production from 229 million tons in 1999/2001 to 465 million tons in 2050, about a doubling of current production. For the same period, the Low Animal Food scenario and the combined scenario 4 indicate a slower growth in meat production, eventually reaching by 2050 a level about 90% lower than in BAU. Such

slower growth in global meat production is due to the global convergence towards a low animal food diet envisioned in these scenarios. Such slower growth in meat production (as well as in the production of other animal food products) results in a stabilization of daily per capita calorie intake from animal food at around today's level.

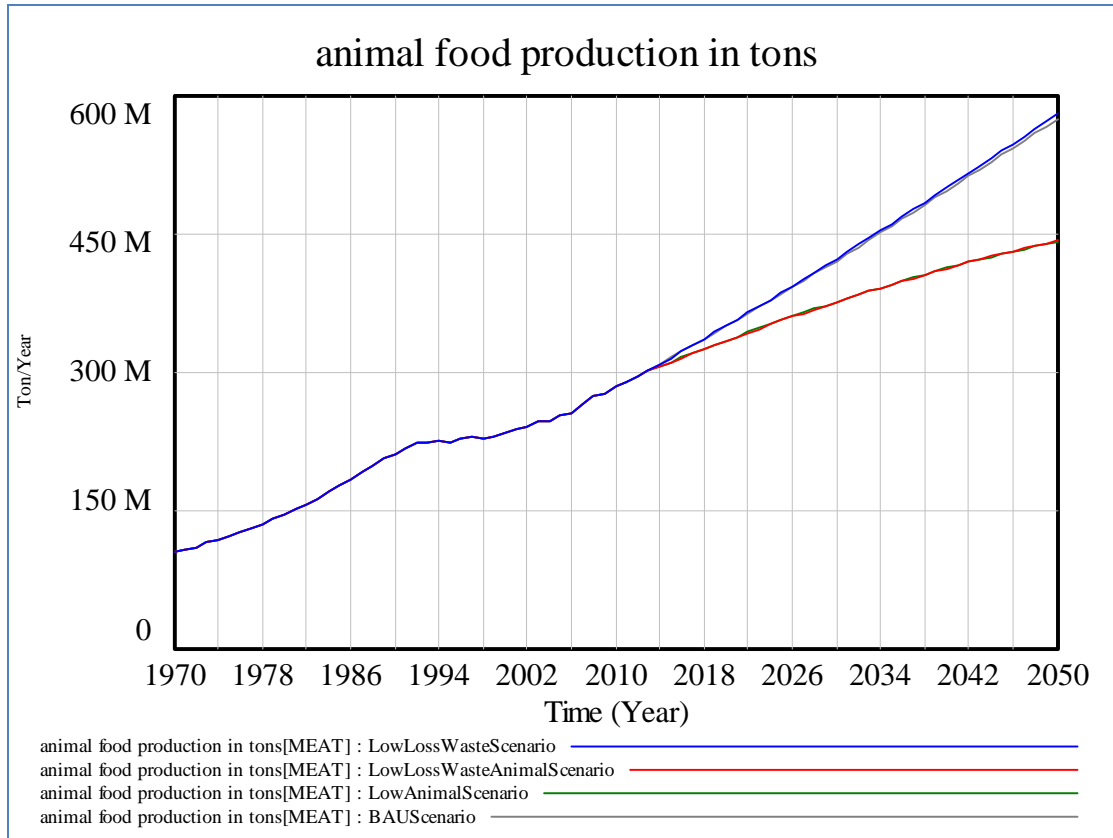


Figure 4: Meat production. Source: FAO data and T21 projections

6.5 Total food waste and losses (Tons)

In the BAU and Low Animal scenarios, total food waste and losses are projected to reach a level of about 2.1 Billion tons by 2050 (Figure 5). By comparison, the Low Food Loss & Waste scenario indicate a total food waste and loss of 1.85 Billion tons, as a consequence of more efficient processing, transportation, and distribution, as well as of more conscious food use at households level. We observe a slower growth in the amount of food loss and waste also in the Low Animal Food scenario (about 2 Billion tons in 2050): this is a consequence of the overall smaller amount of production necessary in this scenario to achieve the BAU's level of PC calorie intake: even at constant efficiency level, lower levels of production imply lower levels of loss and waste, in absolute terms. As a result of the combination of the assumptions of scenario 2 and 3, in scenario 4 we observe an even slower growth in the total amount of food loss and waste, which reaches about 1.75 Billion tons by 2050.

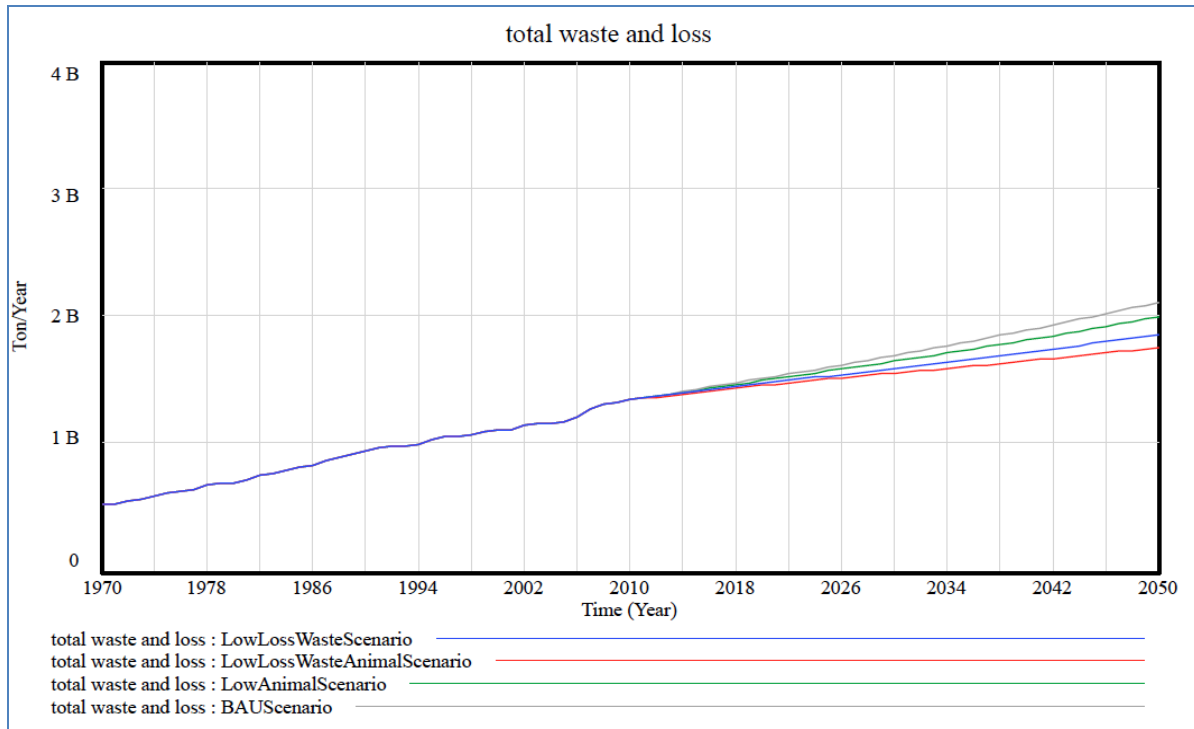


Figure 5: Total food waste and loss. Source: FAO data and T21 projections

6.6 Calories per person per day

As illustrated in Figure 6, all scenarios follow the FAO projection of a total of calories per person per day of 3130 by 2050. While the actual composition of such calorie intake, i.e. whether calories are obtained from animal food or vegetal food, and the efficiency of the processing, transportation and distribution are modified in the four scenarios analyzed, the total pc calorie intake is held constant to allow comparison on the other dimensions.

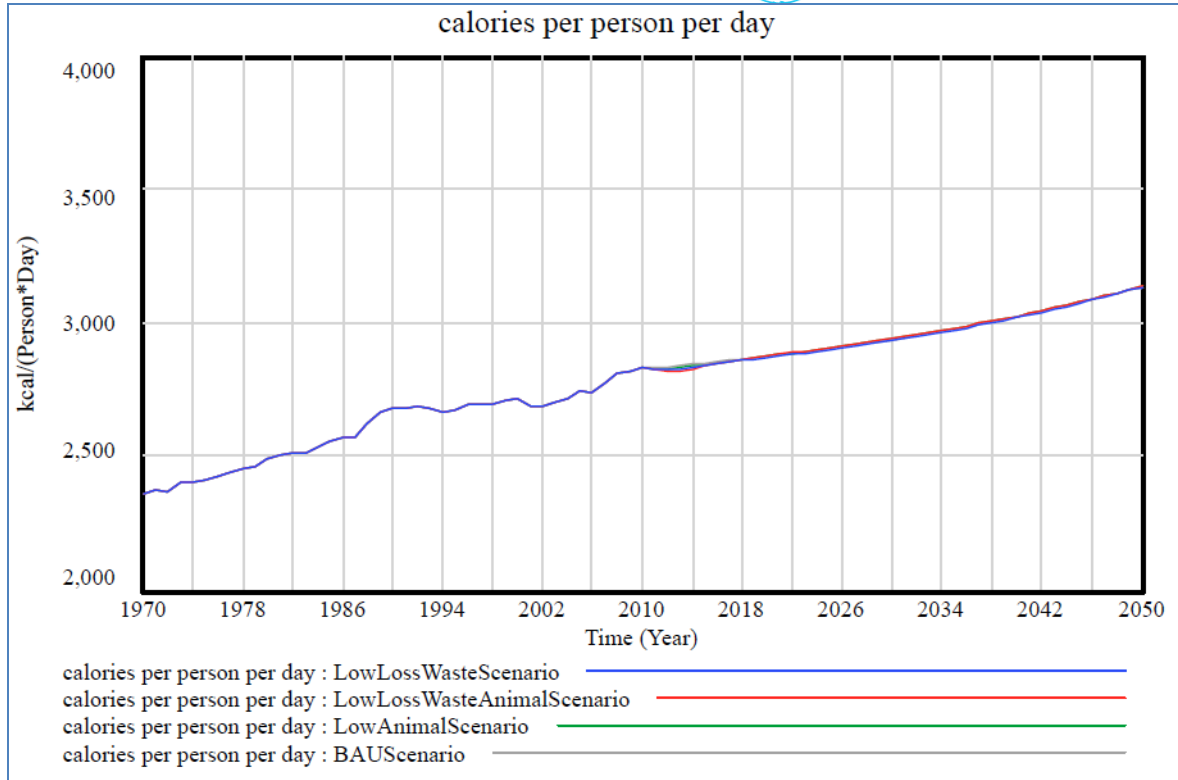


Figure 6: Calories per person per day: Source: FAO data and T21 projections

6.7 Total daily pc calories animal food (kcal/day/person)

In the BAU and Low Food Loss & Waste scenarios, daily pc calories from animal food are expected to increase by approximately 24% with respect to today’s values, to reach on average about 620 Kcal/person/day in 2050 (Figure 7). By comparison, in the Low Animal Food and the combined scenario 4, daily per capita calories from animal food are expected to reach about 500 Kcal/person/day by 2050. In such scenarios, the lower average daily per capita calories from animal food can be realized by compensating an increase in daily pc calories from animal food in low-income countries with a reduction in daily pc calories from animal food in high-income countries.

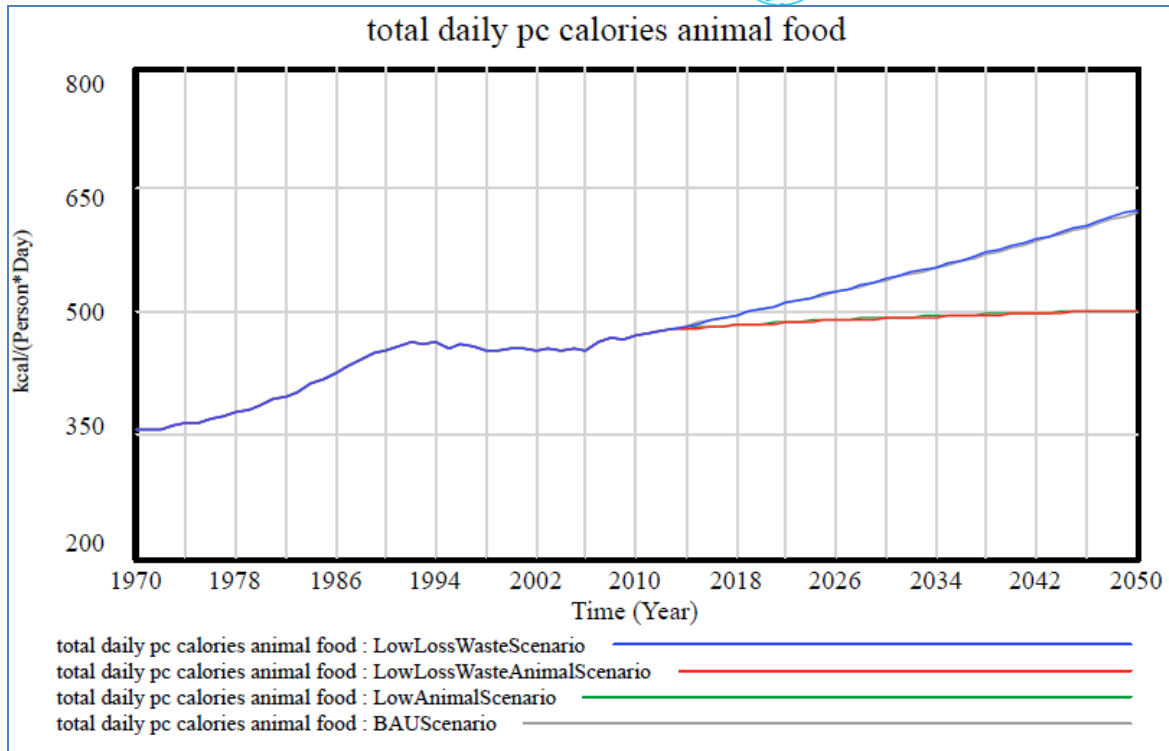


Figure 7: Total daily per capita calories animal food. Source: FAO data and T21 projections

6.8 Total daily pc calories vegetal food kcal/day/ person)

In the BAU and Low Food Loss & Waste scenarios, daily pc calories from vegetal food are projected to reach about 2509 Kcal/person/day by 2050 (Figure 8). By comparison, in the Low Animal Food and the combined scenario 4, daily per capita calories from animal food are projected to reach about 2630 Kcal/person/day by 2050. As discussed above, in such scenarios the higher average daily per capita calories from vegetal food is the reflection of the reduction in the daily pc calories from animal food to about 500 Kcal/person/day by 2050.

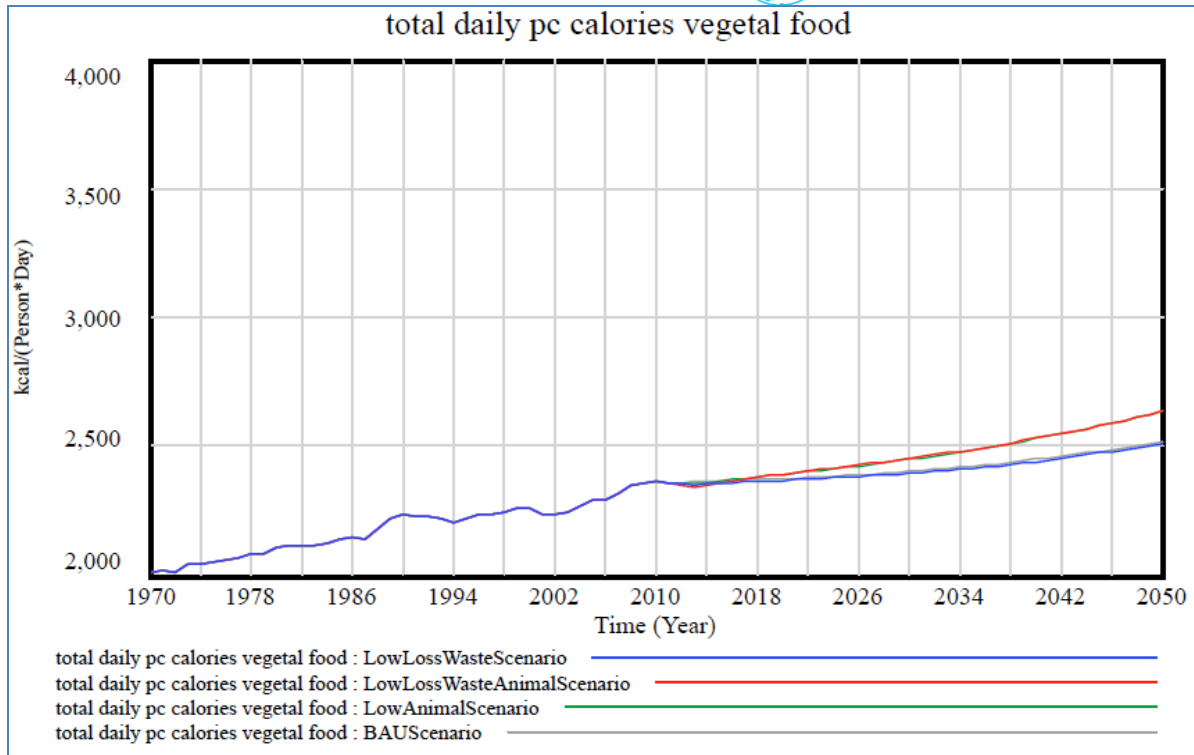


Figure 8: Total daily per capita calories vegetal food. Source: FAO data and T21 projections

6.9 Proportion of population undernourished

In all scenarios, the average proportion of population undernourished decreases gradually from the current 13.5% to 3.6% by 2050 (Figure 9). The difference in the proportion of population undernourished in the four scenarios is relatively small, since eventually in all scenarios the projections for PC calorie daily intake reach a level of about 3130.

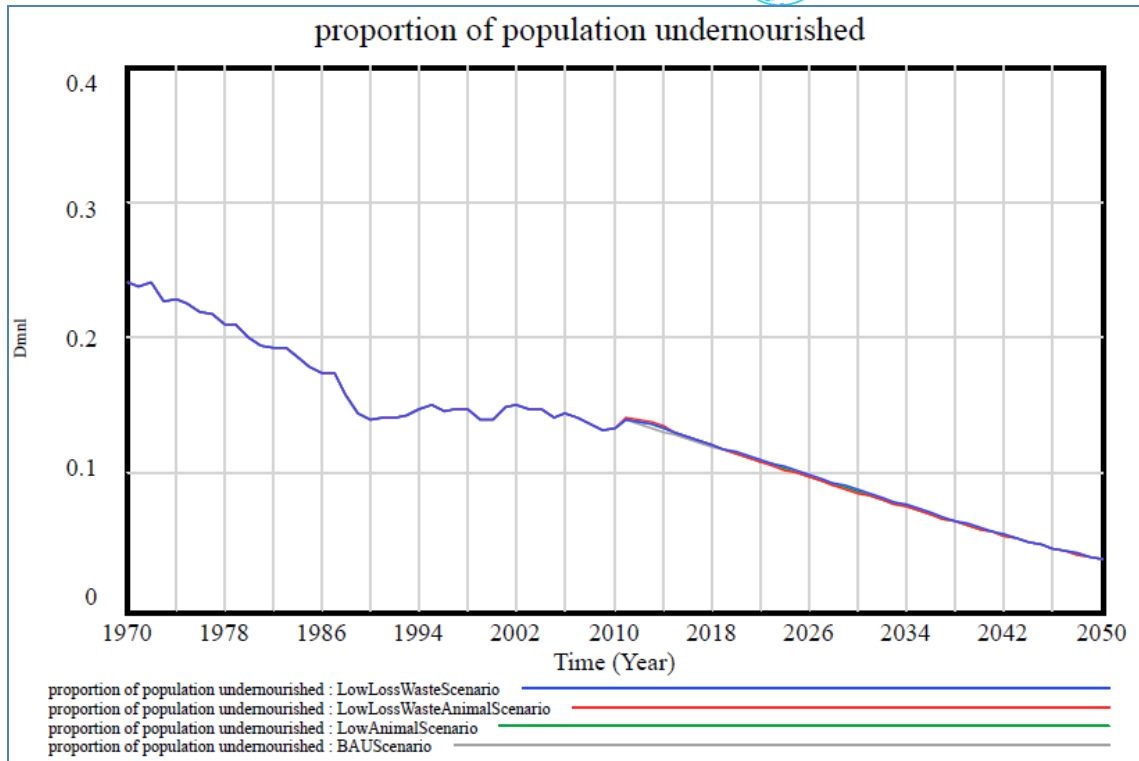


Figure 9: Proportion of population undernourished. Source: WHO data and T21 projections

6.10 Summary table

Indicator	BAU	Scenario 2	Scenario 3	Scenario 4
Total population	9.31E+09	9.31E+09	9.31E+09	9.31E+09
Total harvested area (Ha)	1.31E+09	1.178E+09	1.185E+09	1.065E+09
Total crops production in tons	11.17E+09	10.43E+09	10.41E+09	9.70E+09
Animal food production in tons (meat)	573E+06	579E+06	444E+06	442E+06
Total food waste and losses (Tons)	2.1E+09	1.85E+09	1.99E+09	1.75E+09
Calories per person per day	3130	3130	3131	3132
Total daily pc calories animal food (kcal/day/person)	621	624	501	501
Total daily pc calories vegetal food kcal/day/person)	2509	2506	2630	2630
Proportion of population undernourished	0.0368	0.0366	0.0365	0.0364

Table 7: Summary table

7. Policy interventions

7.1 Sustainable diets

In order to meet the dietary and nutritional needs of a world that becomes more affluent, more urbanized, and with a growing population, people's dietary habits will have to undergo radical transformations (Wirsenius et al., 2010). At the same time, such transformation requires consumers to become aware of the limited availability of planet's natural resources and that current dietary habits cannot be sustained over the long term (MEA, 2005; IME, 2013). The following paragraphs present three fundamental areas for policy intervention that can facilitate such transformation process.

Food taxes on unhealthy dietary habits

The adoption of price leverage or food taxes on unhealthy dietary habits in a balanced and appropriate way may help to discourage the use of junk food and encourage purchases of healthy food (BCFN, 2012a). The use of price leverage on certain foods may thus likely significantly impact behaviors, if interventions are put in place to encourage the choice of healthier alternatives and made them actually accessible to the consumer.

Education programs on promotion of healthy dietary habits

As the health of human beings cannot be separated from the health of ecosystems, it necessary to promote the adoption of healthy lifestyles and diets favoring the consumption of foods that have a lower impact on the planet's ecosystem (Wirsenius et al., 2010; IME, 2013). To that end, the dissemination of accurate information and dietary education needs to be supported in order to promote the adoption of proper dietary and life attitudes, so that individuals may achieve greater awareness of the importance of dietary choices and more complete knowledge on the topic (BCFN, 2012b). This may help people choose and implement a proper dietary style.

Corporate social responsibility

Businesses in the food sector should be able to adapt food offerings to the good practices discussed above and, at the same time, be able to communicate them in an effective way (BCFN, 2012b). For this to happen, companies in the food sector should continue to develop new forms of convenience food featuring a high nutritional level and propose further innovations regarding format size in order to meet the growing personalization of food offerings (FAO, 2011c). This particular case includes single-serving packages, which are targeted at satisfying the needs of people living alone, as well as specific formats for large families.

7.2 Food waste and losses prevention

Food is wasted throughout the food supply chain, from initial agricultural production, postharvest handling and storage, processing, distribution down to final household consumption. According to FAO (2011), in medium- and high-income countries food is to a high

extent wasted, even though it is still suitable for human consumption. By comparison, in low-income countries food is mostly lost during the production-to-processing stages of the food supply chain. By introducing adequate measures, food waste and losses in the food supply chain can be reduced to the targeted per capita food waste and loss of 200 kg per person per year in both low- and high-income countries.

Production

Often in industrialized countries food gets lost when production exceeds demand, as argued by FAO (2011b). Farmers intend to produce larger quantities than they agreed to deliver in order to anticipate unpredictable bad weather conditions or pest attacks, even when conditions are “average”. In the case of surplus production, some surplus crops are sold to processors or as animal feed. This is considered less profitable given the lower prices in these sectors compared to those from retailers. More efficiency can result from improved communication and cooperation among farmers which could reduce the risk of overproduction by allowing surplus crops from one farm to compensate a shortage on another (Stuart, 2009).

In developing countries and, to some extent, developed countries, food may be lost due to premature harvesting. FAO (2011b) claims that poor farmers may harvest crops too early due to food deficiency or the desperate need for cash during the second half of the agricultural season. In this way, the food incurs a loss in nutritional and economic value, and may get wasted if it is not suitable for consumption. As a precautionary measure, Stuart (2009) suggests that small farmers need to organize themselves to better diversify and upscale their production and marketing. Small resource-poor farmers can be organized in groups to produce a variety of significant quantities of cash crops or animals. In this way they can receive credit from agricultural financial institutions or advance payments from clients.

Transportation and distribution

FAO (2011b) considers poor storage facilities and lack of infrastructure as the main cause for postharvest food losses in developing countries. Fresh products like fruits, vegetables, meat and fish straight from the farm or after being harvested can be lost in hot climates due to lack of infrastructure for transportation, storage, cooling and markets (Rolle, 2006; Stuart, 2009). To increase efficiency in food transportation, distribution, governments should invest infrastructure for roads, energy and markets. Subsequently, private sector investments can improve storage and cold chain facilities as well as transportation. In addition, selling farm crops closer to consumers without intervention of strict quality standards set up by supermarkets on weight, size and appearance would possibly reduce the amount of rejected crops. This could be achieved through, e.g., farmers markets and farm shops (Stuart, 2009).

End use

Food waste at households' level is especially relevant in high and mid-income countries. Targeted educational programs can be a primary level of intervention in order to help households to make the best use of the available food, prepare nutritious meals, and reduce waste. FAO has recently engaged in an agreement with Brazil's Serviço Social da Indústria (Industrial Social Services, SESI), to replicate in other countries SESI's successful targeted educational program (FAO, 2012).

According to FAO (2011b), the so-called "high appearance quality standards" from supermarkets for fresh products could lead to food waste reduction in the end use. This is due to the fact that some harvest is rejected by supermarkets at the farm gate due to rigorous quality standards for weight, size, shape and appearance of crops. This causes large portions of crops never to leave the farms. Even though some rejected crops are used as animal feed, the quality standards might drive food originally aimed for human consumption to other uses (Stuart, 2009).

Finally, consumer surveys carried out by supermarkets may be a tool to increase efficiency in the end use of food. As Stuart (2009) claims, supermarkets seem convinced that consumers will not buy food which has the 'wrong' weight, size or appearance. Surveys do however show that consumers are willing to buy heterogeneous produce as long as the taste is not affected. Consumers have the power to influence the quality standards. This could be done by questioning them and offering them a broader quality range of products in the retail stores.

8. Conclusions

The world population is estimated to grow to around 9 billion by 2050 (UN, 2010) imposing profound challenges in meeting future food requirements. Globally, diets are also changing rapidly, with a clear tendency towards an increasing consumption of meat. Another element of complexity and uncertainty regarding future projections for food availability is the level of food loss and waste (currently around 30% to 50% as estimated by FAO and the Institution of Mechanical Engineers (IME)). The present research addresses two fundamental issues:

- (1) How much would agriculture production need to increase to meet food requirements, assuming a general shift towards more sustainable diets?
- (2) How much would agriculture production need to increase to meet food requirements, assuming a reduction in food loss and waste?

Simulation results indicate that substantial benefits can be derived from a gradual shift to more sustainable diets and from more efficient food processing, transportation, distribution and use. By shifting towards more sustainable diets (i.e. diets based on a lower amount of calorie intake

from animal food) less crop production is used for animal feed, and more directly for human nutrition. Since using crop production for animal feed is little energy efficient, such shift implies that lesser agriculture production is needed to provide the same amount of PC calorie intake. A gradual convergence towards low animal food diets can be obtained at the global level by compensating the necessary increase in animal food consumption in low-income countries, with a corresponding reduction in animal food consumption in high-income countries.

Similarly, by increasing efficiency in food processing, transportation, distribution and use, food loss and waste can be relevantly decreased. Such improvement in efficiency would allow for a smaller overall agriculture production to eventually provide consumers with the same amount of food. Improvements in efficiency would focus primarily on processing, transportation, and distribution in low-income countries, where waste at households level accounts for only a small part of total food loss and waste. On the other hand, waste at households' level accounts for a large share of total food loss and waste in high-income countries, and thus important gains can be obtained at such level.

In summary, the combination of more sustainable diets with improvement in efficiency in food processing, transportation, distribution, and use, would allow for a slower growth in agriculture production and for a reduction in harvested area, while still meeting the dietary needs of the growing global population. In particular, under such conditions the total demand for harvested area would be 20% smaller than in the Business as Usual scenario, implying a substantially lower pressure on environmental resources, such as land, water, soil nutrients, and energy.

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