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Market and Trade Impacts of Food Loss and Waste Reduction

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Comments are welcome and may be sent to tad.contact@oecd.org.

Abstract

MARKET AND TRADE IMPACTS OF FOOD LOSS AND WASTE REDUCTION

by

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This report provides a forward looking analysis of the market and trade impacts of food loss and waste reduction, based on the latest projections for world and national agricultural markets provided by the Aglink-Cosimo model for the ten-year period 2014-23. The study applies FAO estimates of producer loss and consumer waste, which are reduced by 20% over ten years, on the assumption that those reductions can be achieved without cost. In global terms, greater impacts on international markets come from contractions in demand via reduced waste than from the stimulus to supply from lower losses. Savings to consumers total more than USD 2.5 trillion over ten years. Reduced crop losses in developing countries lead to higher crop supply in these countries, with reduced prices from efficiency gains benefiting both developing and developed countries.

Keywords: food waste, Aglink-Cosimo model, agricultural commodity market

JEL Classification: Q11, Q10, Q17

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Abbrievations

CGE	Computable general equilibrium
DDG	Distiller's Dried Grains
DEFRA	Department for Environment, Food & Rural Affairs, United Kingdom
ERS-USDA	Economic Research Service, U.S. Department of Agriculture
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
LAFA	Loss Adjusted Food Availability
LDC	Least developed country
OECD	Organisation for Economic Co-operation and Development
PE	Partial equilibrium
USD	United States Dollar
WRAP	Waste and Resources Action Programme, United Kingdom

Executive Summary

This report provides a forward looking analysis of the market and trade impacts of food loss and waste reduction, based on the latest set of quantitative medium-term projections for world and national agricultural markets provided by the OECD-FAO Aglink-Cosimo model for the ten-year period, 2014-23.

The study applies FAO estimates of loss and waste to examine four different scenarios. The first scenario consists of reductions in producer losses and consumer waste for all countries and commodities covered by Aglink-Cosimo. The remaining three scenarios focus on the most important sources of loss and waste, as captured by the FAO data and corroborated by other sources. These are: reduced food waste from cereal consumption in North America, Europe and North Africa; reduced food waste in consumption of meat and dairy products in developed countries; and reduced food losses from crop production in developing countries. In each case the scenario reduces gradually the existing level of loss or waste so that the reduction rate becomes 20% in ten years, on the assumption that this can be achieved without cost.

Reductions in consumer waste are modelled as a negative demand shock, which reduces domestic prices and quantities, and lowers international prices via cumulative impacts that depend on countries' integration with world markets. Reductions in food losses during production are modelled as a positive supply shock, which raises domestic supplies and lowers domestic prices, again leading to lower international prices. At the country level, the final impacts correspond to changed volumes of production, consumption and net trade at new (lower) domestic and international prices.

In global terms, Scenario 1 suggests that the biggest impacts on international markets would come from demand reductions rather than supply impacts. The study compares the value of each market in US dollars between baseline and scenario, and calculates savings made by consumers. The total consumer saving throughout commodities and regions in 2023 amounts to USD 458 billion, and the accumulated total from 2014 to 2023 is USD 2.52 trillion. The total consumer savings in 2023 are decomposed across commodities and regions, where pigmeat, beef and wheat show high consumer savings, and the regions with the greatest benefits are the European Union, China and the United States. When the savings are further decomposed to each commodity in a region, the largest consumer savings come in the following sectors: pigmeat in China and the European Union, rice in China, wheat in the European Union, beef in the United States and fresh dairy products in India.

Reduced food waste in cereal consumption (Scenario 2) suggests larger gains for consumers of wheat and coarse grains than for rice, reflecting the large food use of wheat in developed countries. Under this scenario, the international price of wheat drops by 3.1% in 2023. Livestock production and exports in developed countries increase with the reduction in feed cost from lower coarse grain prices.

Reduced food waste of meat and dairy products in developed countries (Scenario 3) leads to relatively larger impacts on international trade, with substantial increases in pigmeat exports from developed countries (7%) and larger imports by developing countries (8%) as a result of lower prices. Dairy exports from the United States increase, whereas exports from

the European Union and New Zealand decline, reflecting their considerable exports to developed countries where demand is reduced in the scenario.

Reduced crop losses in developing countries (Scenario 4) lead to higher crop supply in these countries, where reduced prices from efficiency gains benefit both developing and developed countries. While this scenario targets developing countries, they are not the only beneficiaries as crop supplies increase feed available in both developing and developed countries and livestock and dairy producers benefit from lower feed costs. Exports increase for some developing countries, while others import more at lower prices. Global rice production increases by 5.5 Mt with the international price decreasing by nearly 10%. Increase in both exports and imports of rice by developing countries under Scenario 4 boost rice trade between developing countries. Comparison between four scenarios indicates that the demand side policies in developed countries can have larger market impacts and consumer savings.

The study provides indicative estimates of the market and trade impacts of loss and waste reduction. The rudimentary underlying data mean that these estimates should be treated with caution. At the same time, the analysis does not include important sources of food loss and waste, including the fruit and vegetable sector, as well as in the processing industry. The Aglink-Cosimo model captures direct economic impacts across countries and commodities, but it would be necessary to link these impacts to general equilibrium models in order to trace economy-wide impacts and the overall implications for countries' and citizens' economic welfare. Finally, the study assumes that these reductions can be achieved without cost. Yet some degree of food waste may reflect rational choices on the part of consumers, while producer losses may also be rational given wider constraints, such as lack of transport and storage facilities. A fuller link to the underlying economics of loss and waste would make it possible to examine the implications of alternative policy approaches.

1. Introduction

In 2010, OECD Ministers of Agriculture requested the Secretariat to explore ways to reduce food loss and waste in the food chain and in 2011 the OECD Green Growth Strategy identified reducing food waste as a means to increase the available food supply and to reduce pressures on resources and the climate. Many other organisations are also undertaking activities related to food loss and waste. The FAO has launched in 2011 the "SAVE FOOD: Global Initiative on Food Loss and Waste Reduction" and in 2013, together with UNEP, the "Think.Eat.Save - Reduce your Foodprint Campaign" that celebrated on 5 June 2013 the World Environment Day, highlighting the magnitude of the food waste issue and its humanitarian, economic and environmental implications. The European Commission has designated the year 2014 as the European Year Against Food Waste (European Commission, 2013). Reducing food waste is potentially one of the "low hanging fruits" to target in the quest for greening the food chain, improve its efficiency and to increase food availability. Reducing food loss and waste could relieve part of the pressures on agricultural production in future years and enhance food security, especially of the poor and vulnerable sections of society.

While there have been discussions to harmonize definitions of food loss and waste, there is yet to be consensus. According to FAO (2014), food losses refer to the decrease in edible food mass available for human consumption throughout the different segments of the supply chain. On the other hand, food waste refers to food losses resulting from decisions to discard food, which is most often associated with the behaviour of retailers, the food service sector and consumers.

Food loss and waste occur in each stage of the food supply chain and reasons for their occurrence vary. Nonetheless, it is often recognized that some of it is inevitable and

economically rational. Buzby et al. (2014a) list four factors that influence how much food loss can be realistically prevented, reduced, or recovered for human consumption: 1) technical factors (e.g. the perishable nature of most foods, food safety, storage, and temperature considerations); 2) temporal and spatial factors (e.g. the time needed to deliver food to a new destination, and the dispersion of food loss among millions of households, food processing plants, and foodservice locations); 3) individual consumers' tastes, preferences, and food habits (e.g. throwing out milk left over in a bowl of cereal); and 4) economic factors (e.g. costs to recover and redirect uneaten food to another use).

However, questions about the amount and causes of food loss and waste still remain, and a wide range of approaches to reduce them are in use. Lipinski et al. (2013) suggested a subset of approaches that are particularly practical and cost-effective. Some interventions, such as evaporative coolers for storage, directly affect food, whereas others, such as consumer education campaigns, indirectly affect food by influencing people's consumptive behaviour.

Against this background, the objective of this study is to assess the market and trade consequences of reducing food loss and waste. Specifically, the study examines the likely effects on commodity market prices, quantities supplied and consumed, and international trade flows in comparison with the medium-term baseline projection of the *OECD-FAO Agricultural Outlook*.

This research complements recent studies that have estimated the amount of food loss and waste nationally throughout the food chain from farm to fork (Kantor et al., 1997, WRAP, 2009). At the global level, a study compiling global and regional food loss and waste estimates has been published by the FAO (FAO, 2011). The FAO's estimates on food loss and waste by commodity, region and the different stages of the food chain now make it possible to go to the next step of making a global market impact analysis with the aid of the Aglink-Cosimo model. This quantitative analysis on the impacts of food loss and waste reduction is seen as building on earlier work in other organisations and as a precursor to assessing food waste policy options.

2. Definitions and data

Definition of food loss and waste

One of the problems in assembling data for a quantitative analysis is the lack of harmonization on definitions and methodologies for assessing food loss and waste. For example, preparatory study on food waste by the European Commission (2010) found that methodologies for collecting and calculating the food waste data submitted to EUROSTAT differs between member states, which are free to choose their own methodology, and limitations in the reliability of EUROSTAT data, due to a lack of clarity on the definition and methodology, may be significant.

While progress towards a harmonized definition is important as it affects policies and monitoring, the current study is simply based on the latest definition of food loss and waste by the FAO (FAO, 2014), because the quantitative study relies heavily on the loss and waste coefficient estimates utilised by the FAO for their global analysis (FAO, 2011, FAO, 2013a).[1]

1. In the study to quantify the environmental impact, FAO has used the definition of "food wastage" as a combination of food waste and loss (FAO, 2013a). However, the 2014 FAO global voluntary definitional framework provides definitional guidance for food losses (with food waste as a sub-component).

- **Food losses** refer to the decrease in edible food mass available for human consumption throughout the different segments of the supply chain. In addition to quantitative losses, food products can also face a deterioration of quality, leading to a loss of economic and nutritional value.
- **Food waste** refers to food losses resulting from decisions to discard food that still has value. Food waste is most often associated with the behaviour of retailers, the food service sector and consumers, but food waste and losses take place all along food supply chains. (FAO, 2014).

FAO's food loss and waste estimates

In 2011 FAO, despite the dearth of information at national level, conducted a thorough literature review and expert consultations in order to estimate food loss and waste along the international food supply chains. This FAO study includes estimates of how much is lost and wasted at different stages in the food supply chain, regions, and by commodities. Although the authors had to estimate loss and waste percentages in regions where first hand data are not available, the data has since been widely utilised by a number studies (Kummu et al., 2012, Rutten et al., 2013) as it is comparable in a few dimensions. FAO for example (2013a) has estimated direct cost of food loss and waste of agriculture products (excluding fish and seafood) based on the calculation of estimated food loss and waste on the change in producer prices, and indicated that it could amount to about USD 750 billion in current values.

Table 1. Estimated/assumed loss and waste percentages for each commodity group in each step of the food supply chain for Europe including Russian Federation

	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket retail	Consumption
Cereals	2%	4%	0.5%, 10%	2%	25%
Roots and tubers	20%	9%	15%	7%	17%
Oilseeds and pulses	10%	1%	5%	1%	4%
Fruit and vegetables	20%	5%	2%	10%	19%
Meat	3.1%	0.7%	5%	4%	11%
Fish and seafood	9.4%	0.5%	6%	9%	11%
Dairy products	3.5%	0.5%	1.2%	0.5%	7%

Source: FAO (2011).

Table 1 presents the food loss and waste estimates compiled by the FAO (2011) for the different food commodity groups and stages of the food chain. Table 2 shows the commodity, regional disaggregation and stages of the food chain represented in the FAO data. In subsequent sections, the current study utilises these coefficients to adjust supply and demand equations in the Aglink-Cosimo model for the different commodities/countries/regions represented in order to examine the implications of food loss and waste reduction for global commodity markets, cross commodity impacts, inter-temporal adjustments, world prices and regions.

Table 2. Dimensions of FAO food loss and waste data

Commodity groups	Stages in the food supply chain	Regions
Cereals	Agricultural production	Europe including Russia
Roots and tubers	Postharvest handling and storage	North America and Oceania
Oilseeds and pulses	Processing and packaging	Industrialised Asia
Fruit and vegetables	Distribution	Sub-Saharan Africa
Meat	Consumption	North Africa, West and Central Asia
Fish and seafood		South and Southeast Asia
Dairy products		Latin America

Source: FAO (2011).

Country level information

Monitoring and target setting on food loss and waste appearing in a number of countries can provide a useful benchmark for scenarios analysis. For this purpose, country level information is collected from delegations and secondary sources for OECD countries. The country level information is primarily concerned with the following.

- Quantification of food loss and waste in different commodity groups and at various stages within the food chain.
- National goal or target setting for food loss and waste reduction and achievements realised.

Table 3 shows the levels of food loss and waste reduction either observed in official statistics or expressed as national targets within a certain timeframe. Some of the figures are shown as a yearly growth (reduction) rates. It appears that a number of OECD countries are engaged in target setting and activity monitoring, especially for the stages of the food chain that are concerned with distribution (supermarket, retail) and final consumption, a reflection of the growing interest in issues related to food loss and waste.

Table 3. Targets and statistics about food loss and waste reduction

Target / Statistics	Region	Commodity	Stages of FSC concerned	Timeframe	Reduction level
Proposed Target	European Union	All	Consumption	2010-2020	10%, 20%, 50%
Proposed Target	European Union	All	Processing and packaging-Consumption	-2025	30%
Target	France	All	Consumption	-2025	50%
Target	Netherlands	All	Consumption	-2015	20%
Target	United Kingdom[1]	All	Consumption	2012-2015	5%
Target	United Kingdom	All	Distribution	2012-2015	3%
Target	United Kingdom	All	Consumption	2009-2012	4%
Target	United Kingdom	All	Distribution	2009-2012	5%
Proposed Target	Sweden	All	Postharvest handling and storage-consumption	2014-2020	20%
Target	Austria	All	Consumption	-2016	20%

Table 3. Targets and statistics about food loss and waste reduction (*cont*.)

Target	**All**[2]	**All**	**Agricultural Production-Consumption**	**1978-1985**	**50%**
Target	All[3]	All	Agricultural Production-Consumption	-2025	50%
Statistics	United States[4]	Cereals	Distribution-Consumption	2002-2011	0.2%/year
Statistics	United States	Meat, fish, eggs and nuts	Distribution-Consumption	2002-2011	0.0%/year
Statistics	United States	Dairy products	Distribution-Consumption	2002-2011	0.0%/year
Statistics	United States	Fats	Distribution-Consumption	2002-2011	3.5%/year
Statistics	United States	Vegetables	Distribution-Consumption	2002-2011	-0.2%/year
Statistics	United States	Fruits	Distribution-Consumption	2002-2011	0.2%/year
Statistics	United States	Sweeteners	Distribution-Consumption	2002-2011	0.0%/year
Statistics	United Kingdom	All	Distribution	2010-2012	7.4%
Statistics	United kingdom[5]	All	Consumption	2007-2012	15%
Statistics	Japan	All	Processing and packaging-Distribution	2008-2011	5.1%/year
Statistics	Japan	All	Consumption	2003-2009	3.8%/year

Source: 1. WRAP (2013).
2. Parfitt et al. (2010).
3. Lundqvist et al. (2008).
4. ERS-USDA (2014)
5. Quested et al. (2013).

The scenario analysis is complemented by detailed country case studies of the United Kingdom and Japan to reinforce the analysis and provide concrete examples of policy practices (OECD, 2015). These two countries are well advanced in addressing food loss and waste reduction and can offer useful lessons regarding data collection, reduction targets and initial achievements or outcomes.

The European Commission's Roadmap to a Resource Efficient Europe (European Commission, 2011) states that the "disposal of edible food waste should (be) halved" in the household, retail and catering sectors. A recent report in relation to potentially setting a target for food waste reduction within the European Union (BIO Intelligence Service, 2013) takes into account target setting to date among member states and proposes three levels of reduction targets, 10%, 20% and 50%, according to low, medium and high levels of ambition. Recent communication from the European Commission (2014) revises this goal and proposes that member states develop national food-waste prevention strategies and endeavour to ensure that food waste in the manufacturing, retail/distribution, food service/hospitality sectors and households is reduced by at least 30 % by 2025

ERS-USDA has established the longest and most comprehensive time series data on food loss in the retail, food service and consumer sectors (Buzby and Hyman, 2012). Table 3 shows major food groups covered by ERS-USDA and the recent trend of food loss levels; this data, which is regularly updated, can be traced back to 1970 and disaggregated into over 200 agricultural commodities. However, the ERS data currently do not capture most of these changes in food loss because for most commodity- and food-loss-level pairings, the same loss assumption is applied throughout the span of the data in the Loss Adjusted Food Availability (LAFA) data series (e.g. the retail level loss estimate for fresh apples is the same 8.6% over 1970-2011). The exception is that the retail-level loss estimates for beef account for greater trimming of fat over time (Buzby et al., 2014a).

What can be surmised from the country level information? It is often argued that elimination of all food loss and waste is not only unrealistic but also economically inefficient given the costs associated to reduce loss and waste. Food loss is found to be economically efficient in some cases (Buzby et al., 2014a), and there is a practical limit to how much food loss the United States or any other country could realistically prevent or recover for human consumption given technical, cultural and economic factors. In view of differing statistics on food waste among countries, Smil (2000) over a decade ago suggested that food waste equivalent to 10-15% of total supply may be unavoidable.

On the other hand, the developments of policies and monitoring in particular countries during the last decade enable us to refer to more concrete examples on the ground. In Table 3 we see that targets have been set to reduce certain part of existing loss and waste. Though it is difficult to exactly assess different trends and targets from country level information, they show that it is reasonable to expect reduction levels starting with 0% and then moving to 20% during the medium-term of ten years. The 20% reduction from existing loss and waste will be used to represent "feasible" reduction goals for the scenario analyses as follows.

3. Scenario analysis methodology

The Aglink-Cosimo model is a recursive-dynamic, partial equilibrium, supply-demand model of global agriculture, developed by the OECD and FAO. It covers annual supply, demand and prices for nearly 50 of the principal agricultural commodities produced, consumed and traded globally. Model simulation is utilised to make projections for the coming ten years, which are included in an annual publication of the OECD-FAO Agricultural Outlook (OECD/FAO, 2014). The model focuses in particular on the potential influence of agricultural and trade policies on agricultural markets in the medium term. An important capacity or strength of this modelling framework is for scenario analysis - answering "what if" type questions of future market developments or possible policy changes.

Use of the Aglink Cosimo model to study the impacts of food loss and waste is new. With the existing dataset on food loss and waste discussed in the last section, several scenarios are constructed with resulting market outcomes compared against the most recent OECD-FAO Outlook baseline projections. While FAO data show existing levels of food loss and waste, an important question is how much of this existing waste can be avoided over time? What is the likely loss and waste reduction scenario in the mid-term, i.e. some ten years into the future in the case of Aglink-Cosimo baseline projections. This study applies 20% reduction from the existing level of food loss and waste, according to country level information.

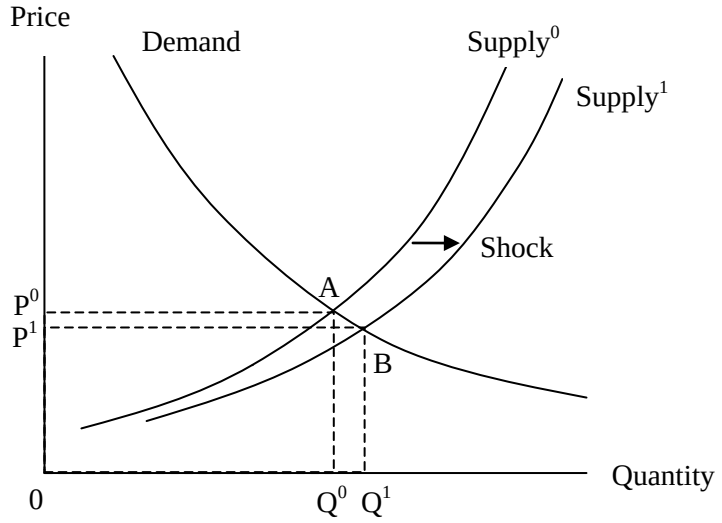
Since the FAO report in 2011, there have been other scenario analyses using CAPRI (Höjgård et al., 2013), MAGNET (Rutten et al., 2013), IMPACT and LEITAP (Stehfest et al., 2013) models to see environmental or economic impacts of food loss and waste. The focus of the current study using Aglink-Cosimo is to show global market and trade impacts, and to analyse regional and commodity differences appearing along the medium term baseline projections.

Shocks to Aglink-Cosimo model

It is useful to commence an investigation of the economic impacts of reducing food loss and waste with a discussion of the economic principles that underlie the interpretation of the outcomes of the empirical analysis based on an application of a complex partial equilibrium empirical model of global agriculture such as the Aglink-Cosimo model. This section provides a diagrammatic presentation of the economic impacts of reducing food loss in food supply and waste in food demand using standard economic theory of supply and demand.

This section utilises the partial equilibrium framework depicted by Rutten (2013) in order to outline the connection with the scenario analysis with the Aglink-Cosimo model. Figure 1 illustrates the reduction of food loss in the supply side. The scenario in Aglink-Cosimo considers the reduction of food loss as an improvement of technological efficiency in the mid-term, and replicates this effect as a shift of the supply curve towards the right at a certain rate.

Figure 1. Shift of supply curve



The rate of shift to the right is a key question in constructing a scenario analysis. To answer this question country level information has been collected about how much and what kind of food loss and waste could be avoided in a certain timeframe.

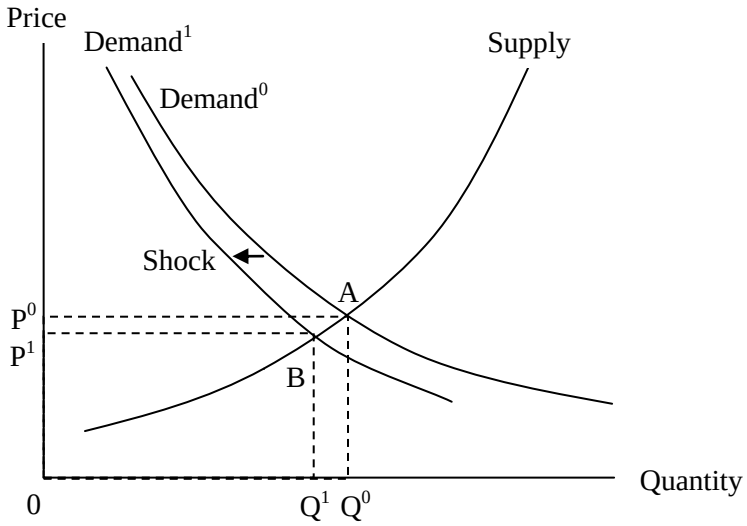
The shift of supply curve moves the equilibrium price and quantity from P^0 at Q^0 to P^1 at Q^1, as more quantity is available at lower prices. A crucial assumption is that this representation disregards the cost of achieving this technological improvement. If the cost is significant, a reverse shift of supply curve may occur resulting in lower production and higher price equilibrium, and this view may well be credible when consideration is given to issues of investment in improved transport and storage infrastructures associated with postharvest losses in developing countries. However, there are few studies which break down the different components to reduce food loss in agricultural production to indicate the cost associated with reducing food loss. The cost of reducing food loss is an important factor and one where further research is clearly needed in order to guide appropriate economic policy measures.

Demand side

Figure 2 shows the reduction of food waste on the demand side. Changes in demand may arise from the changes of preference towards the food concerned, the change of consumer income and the price change effect on other commodities. If consumers were better informed about the amount and value that they waste annually, including its share relative to their household's budget, they might waste less (Hodges et al., 2010) The current scenario study considers the reduction of food waste as the reduction of the perceived value of the food in the mid-term, and intends to replicate it within Aglink-Cosimo model as the shift of the demand curve towards the left. It is supposed that by eliminating waste in consuming their food, the consumer will consider that demand for the food in question can be satisfied by purchasing a smaller quantity.

In the case of the consumer demand analysis, the new equilibrium price P^1 and quantity Q^1 following food waste reduction are both below the initial equilibrium at P^0 and Q^0, resulting in consumers spending less (the area $P^0 \times Q^0 - P^1 \times Q^1$).

Figure 2. Shift of demand curve



Other modelling approaches

Saving theoretically enable the consumer to spend more on other commodities or buy more of the commodity concerned in this partial equilibrium (PE), in which case the demand curve will shift backwards to the right. In the case of Aglink-Cosimo, the income change has to be modelled as an exogenous variable which limits the scope to analyse the second-order income effect arising from a reduced level of food waste. Analysis employing a computable general equilibrium (CGE) model would be needed to examine overall income effect.

According to the report from integrated Modelling Platform for Agro-Economic Commodity and Policy Analysis (iMAP) by the European Commissions' Joint Research Centre, Institute for Prospective and Technological Studies (JRC-IPTS), the recommendation is to use both PE and CGE approaches (Tonini et al. (Eds.), 2013). PE models can be used to gather and process specialist information on particular parts of the economy. Results from PE analysis can then be passed to a GE model to work out economy-wide implications. It could be also the case that results from CGE analysis can be passed to a PE model to work out the sectorial implications or in order to disaggregate results further. This study does not proceed to such joint exercise with PE and CGE models; however, Annex D refers to the results generated by a CGE model to compare with Aglink-Cosimo model results.

On the other hand, the paper by Höjgård et al. predicts the effects on food waste from changes in parameters such as price, income and information, using the household model developed by Becker (1965), and compares them with existing observations in various food waste studies.

This scenario for food waste reduction in demand assumes no cost in reducing food waste. In order to minimise the amount of food waste due to over purchasing, one may need to shop more often than before or utilise expensive equipment such as a freezer. These considerations are important factors that may affect demand but are difficult to take into account in a quantitative study, except that the rate of reduction applied to the shock is based on country level information and set not to be too ambitious.

It is also argued that generation of food waste by consumers is rational behaviour in order to reduce the risk of missing the foods they require when they want to consume it. In this context one may look at how consumer food waste is being addressed by existing policy measures. While Korea is piloting a policy to charge fees on consumer food waste, a number of other countries are oriented towards public awareness campaigns and consumer education. In the example of Japan, the policies do not include economic incentive or deterrents, but place mandatory monitoring of food loss and waste generation, as well as providing forum to discuss ways to solve the problem among private sectors. This is partly because many causes of food loss and waste should be addressed by the public-private sector initiatives such as food labelling policies and implementation. On the other hand, these policies presume that a better understanding of the issue by consumers will lead to change in the trend of food waste, which in turn implies that filling the information gap may shift the demand curve without significant costs.

In the Aglink Cosimo model, the shock to the demand curve is introduced to the food-use demand equations for each commodity and region. The shock to the supply curve is introduced to the equations that estimate yield or production depending on the commodity. In each scenario, the equation specific residuals (R) is modified gradually throughout the projection period, in order to incorporate the target food loss and waste reduction, while at the same time, these endogenous variables are simulated to obtain global and national market balances. On the other hand, among 14 commodities and 56 regions, some commodities and regions are not represented by equations but given as exogenous variables. Those exogenous variables are directly shocked and do not change during the simulations. The full list of regions and commodities shocked in the study are given in Annex A, Table 18 and Table 19. The equations for food use, crop yield and meat production are given in Annex B.

Scenarios

This study examines four scenarios using the Aglink-Cosimo model.[2] The level of existing food loss and waste to be used as the base for the scenarios are the 2011 estimates provided by the FAO. The first scenario assesses the effects on all commodities at once to determine which have the largest market impact. Other scenarios are proposed to analyse specific commodities in certain regions. There is a difference between food waste at the consumption stage in developed countries and food loss at the production stage in developing countries, and these are usually analysed separately.[3]

In the case of the developing countries the available evidence suggests that food loss in supply rather than food waste in demand is likely to be of more importance. This is suggested by the available food loss/waste estimates which indicate a substantial difference with those of developed countries in general (FAO, 2011). In part this difference is due to the larger role of agriculture in these countries and stage of economic development with corresponding larger price and income elasticities as well as the policy/regulatory environment (Lundqvist et al., 2008).

The second to fourth scenarios are set up in order to reflect this and to compare the impacts of different targeted reductions. The four scenarios cover the following, and summarised in Table 4.

2. The underlying assumptions on economic growth and demographic trends are provided in *OECD-FAO Agricultural Outlook 2014-2023* (OECD/FAO, 2014).

3. This does not imply that no food loss occurs at the production stage for developed countries or at the consumption stage in developing countries.

1. Reduction of food loss and waste both in production and consumption for all commodities covered.
2. Reduction of food waste from cereal consumption in North America, Europe and North Africa.
3. Reduction of food waste from meats and dairy products consumption in developed countries.
4. Reduction of food loss from crop production in developing countries

Table 4. Food loss and waste reduction scenarios using Aglink-Cosimo

Region	Commodity	Stages of food supply chain concerned	Timeframe	Reduction level
All	All	All	2014-2023	20%
North America, Europe including Russia, Turkey, Iran, North Africa	Cereals	Distribution-Consumption	2014-2023	20%
Developed countries	Meat and dairy products	Distribution-Consumption	2014-2023	20%
Developing countries	Cereals and oilseeds	Agriculture production-Processing and packaging	2014-2023	20%

1. Reduction of food loss and waste both in production and consumption for all commodities covered

This scenario shocks the baseline projection from 2014 to 2023 for all commodities available in the Aglink-Cosimo model, both in production and consumption, in order to identify commodities and regions that show larger impacts from food loss and waste reduction. Results from this scenario could provide the basis for governments to decide priority commodities to focus on in their reduction efforts. The rate of reduction from the existing levels of food loss and waste is set at 20% at the end of the medium term of ten years, in view of the existing reduction levels and future ambitions summarised in the country level information.

In the model, the reduction of production loss shifts production (in the case of crops, through yield equations) so that production increases if the price remains the same. On the demand side, the reduction of food waste results in reduced demand at the same commodity price. If they occur at the same time, while lower prices are expected to balance the market, supply and demand will increase or decrease depending on the commodity. For example, a staple food with less elastic demand curve would have a larger impact on price given the same reduction in food waste.

While the first scenario includes shocks on demand and supply, the market and trade impacts from food loss and waste reduction from the interactions between substitute commodities and that of feed materials and livestock products are expected to be influenced largely by the degree of existing waste and loss in the FAO estimates and the elasticities within the model. For example, if a commodity in a certain region has a high level of existing food loss and waste and the commodity plays an important role in the international market, the impact of food loss and waste reduction would be expected to be significant. Even within the same commodity group in the FAO dataset, the market reactions of commodities will be different. For example, wheat and coarse grains are included in the same category in the FAO dataset and are shocked with the same percentages, but the structures of markets with different demand components and origins of supply produce scenario results which are particular to the commodities and regions.

- 14 commodities for which demands are shocked through the food use equation are: wheat, coarse grains, rice, oilseeds, vegetable oil, beef and veal, pig meat, poultry meat, sheep meat, butter, cheese, skim milk powder, whole milk powder and fresh dairy products.
- 6 commodities for which supplies are shocked through the yield equation are: wheat, coarse grains, rice, oilseeds, vegetable oil, and milk.
- 8 commodities for which supplies are shocked through the production equation are: beef and veal, pig meat, poultry meat, sheep meat, butter, cheese, skim milk powder, and whole milk powder.

2. Reduction of food waste from cereal consumption in North America, Europe and North Africa regions

The 2011 documentary film "Taste the Waste" depicts how a German bakery uses its unsold bread to heat its ovens. Since bread has a high calorific value similar to wood, the film suggests that around 4 tonnes of old bread could replace 900 litres of heating oil. A study in the United Kingdom indicates that bread is the most wasted food product of all because of its short shelf life; 23% of bread purchased by UK households is not consumed and thrown away when it could be eaten (Table 5). The Turkish Grain Board is conducting campaigns and surveys that target bread due to the magnitude of the waste problem and the importance of bread in overall food security (OECD/FAO, 2014).

Table 5. Avoidable food waste percentage by weight in the United Kingdom

Products	Waste percentage
Bakery	23%
Fresh vegetables	21%
Fresh fruit	14%
Meat and fish	11%
Dairy and eggs	7%
Drinks	7.5%
Food & drink total	11.7%

Source: WRAP (2014).

Loss and waste estimates by the FAO are categorised in seven commodity groups, seven regions and five stages of the food supply chain. Table 6 shows the highest figures among the 245 loss and waste coefficients. Many are commodities that cannot be included in the current study due to the commodity coverage of Aglink-Cosimo model. However, cereal consumption wastes in North America and European regions are among these commodities of highest loss and waste percentages. It is observed that food waste from bread, a major staple food in the region, is one aspect which may most affect the global market. In this connection, the study conducts a scenario about consumption waste of cereals in North America, Europe, and some Middle Eastern and North African countries, where per capita consumption of wheat are high, with the assumption that existing food waste will be reduced by 20% in the medium-term.

The exact list of countries or regions included in Scenario 2 is as follows: Algeria, Canada, Egypt, European Union, Islamic Republic of Iran, Norway, Other Eastern Europe, Other North Africa, Other Western Europe, Russian Federation, Switzerland, Turkey, Ukraine and United States.[4]

4. The different regional groupings correspond to Aglink-Cosimo regions, whose full list is given in Annex A.

Table 6. Highest loss and waste estimates among the FAO dataset

Region name	Commodity	Food supply chain phase	Loss/waste percentage
North America & Oceania	Fish & Seafood	Consumption	33%
North America & Oceania	Roots & Tubers	Consumption	30%
North America & Oceania	Fruit & Vegetables	Consumption	28%
North America & Oceania	Cereals	Consumption	27%
Europe incl. Russia	Cereals	Consumption	25%
Sub-Saharan Africa	Fruit & Vegetables	Processing and packaging	25%
South & Southeast Asia	Fruit & Vegetables	Processing and packaging	25%

Source: FAO (2011).

As shown in the country study by DEFRA and WRAP, analysis of the amounts (tonnage) of food and drink bought in the United Kingdom does show a significant reduction, at the household level, of around 4% between 2007 and 2012. This reduction is consistent with consumers buying less (as they waste less), but will of course also have been influenced by other initiatives such as those aimed at promoting healthy eating. However, population growth has meant there was a reduction of only 0.5% at the UK level, suggesting that an increase in population (of 4.4%) during the period has off-set most of the reduction due to less food being wasted.

It is hypothesised that reduced levels of food waste will lead to reduced levels of food demand, which would be partly compensated by growth in competing demand for feed and biofuels, and the growing demands from developing countries. It would be interesting to see how the shock to food consumption will impact the production of commodities and the income of producers. Stuart argues (2009) that the food saved from waste in industrialised countries would increase availability of food in developing countries, although the physical redistribution of saved food from industrialised countries would entail costs. This scenario would test these hypotheses.

A limitation of the demand side analysis is that the Aglink-Cosimo model does not capture the income effect of savings made by consumers purchasing at lower food prices in the context of food waste reduction. There is also a need to refer to other analyses that use the CGE framework to observe the effect of reducing food waste to other parts of the economy.

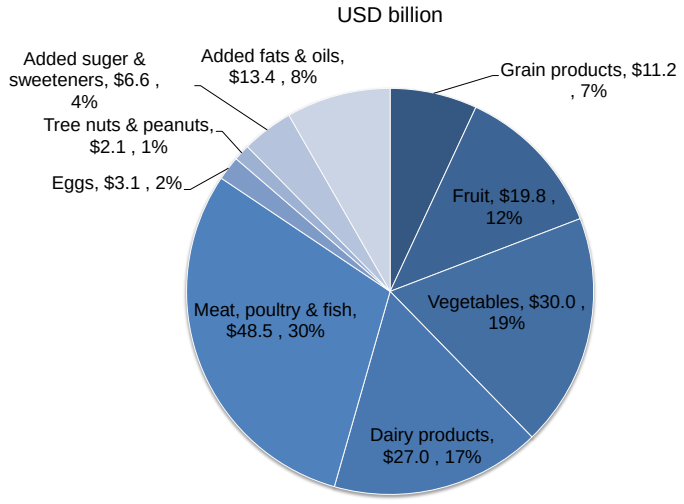
3. Reduction of food waste from meats and dairy products consumption in developed countries

Demand for meats and dairy products is expected to grow, especially in emerging economies and developing countries. Like the first scenario on cereals, this scenario is expected to shed light on the potential of reduced levels of food waste in developed countries to make available more food on the international market and how this will result in new international prices and quantities traded. How will the change in demand from developed countries impact market balances in developing countries through international trade? Contrary to the scenario on cereals, the reduction of food waste in meats and dairy products would make more cereals available as food, through reduced levels of feed demand.

Rutten (BIO Intelligence Service, 2013) argues that a reduction in food waste from meats, dairy products, fruit and vegetables at the consumer level is the most promising way to ease pressure on land use. An analysis in this regard would offer a good comparison against the cereals scenario. Figure 3 takes an example from the United States to show that losses of meats and dairy products make up the bulk of food waste losses by value (Buzby et al., 2014a).

Table 7 extracts the FAO loss and waste estimates for meats and dairy products in developed countries at the distribution and consumption levels. Meats and dairy products show lower percentages of food waste than is the case for cereals, but their high unit price may result in high values depicted in Figure 3, and have as large market impact as cereals. The scenario assumes the same reduction rate as the case of cereals, where 20% of existing levels of food waste will be reduced in ten years.

Figure 3. Estimated total value of food loss in the United States by food group, 2010



Source: Buzby et al. (2014a).

Table 7. Loss and waste estimates of meats and dairy products

Region name	Commodity	Food supply chain phase	Loss/waste percentage
Europe, including Russia	Meat	Distribution	4%
Europe, including Russia	Meat	Consumption	11%
Europe, including Russia	Milk	Distribution	1%
Europe, including Russia	Milk	Consumption	7%
North America & Oceania	Meat	Distribution	4%
North America & Oceania	Meat	Consumption	11%
North America & Oceania	Milk	Distribution	1%
North America & Oceania	Milk	Consumption	15%
Industrialised Asia	Meat	Distribution	6%
Industrialised Asia	Meat	Consumption	8%
Industrialised Asia	Milk	Distribution	1%
Industrialised Asia	Milk	Consumption	5%

Source: FAO (2011).

4. Reduction of food loss from crop production in developing countries

It is expected that crop production will increase in developing countries in the near future given the potential to increase both the area cropped and their yields (OECD/FAO, 2014). The changes in international prices due to reduced food loss in agricultural production could contribute to the food security in poor countries. In this study, the reduction of food loss in agricultural production is incorporated as an exogenous shock to the functions representing yield in the Aglink-Cosimo model. The commodities include cereals and oilseeds. On the other hand, coverage of roots and tubers in the model is not enough to represent the global market, and sugar crops are excluded from the analysis as their loss and waste estimates are not given in the FAO dataset.

It should be noted that this scenario again does not take into account the cost in reducing food loss. The problem of post-harvest losses in developing countries is often associated with poor storage and transport infrastructure, and investments are required to solve these problems. An important assumption of the current analysis is that an improvement in management and provision of information will alone reduce food loss at zero cost.

The reduction of food loss at the production stage implies that more is harvested with better quality and the amount of food for human consumption is increased. On the other hand, the amount for feed may possibly be reduced as less lower quality crops are harvested. This is another area which is interesting but cannot be captured by Aglink-Cosimo, as the model is not able to differentiate between the levels of quality supplied on the market.

As part of the current study, country level information is being collected in order to assess how much loss and waste can be reduced from the existing level. It is clear from the information gathered and literature reviewed that more information is available in developed countries, especially at the distribution and consumption stages, but that the quality of information from developing countries is relatively poor. The target set by the FAO's Special

Action Programme for the Prevention of Food Losses (1970s-1990s), was to reduce the level of food loss by 50% from the total 15% that was assumed to be present in 1970s (Parfitt et al, 2010), but this target is outdated to apply to this study. In view of this, the scenario applies a 20% reduction rate in ten years to evaluate market and trade impacts, and to be comparative with other scenarios.

4. Results and discussions

Scenario 1 Reduction of food loss and waste both in production and consumption for all commodities covered

This scenario gives shocks both to supply and demand at the same time for all commodities tied to FAO's loss and waste estimates, assuming that the existing loss and waste can be reduced by 20% by 2023. The impact depends on each market, particularly, its significance relative to the rest of the world, its level of loss and waste and behaviour of economic model given the shocks to supply and demand.

Table 8. Change of main variables for selected commodities in Scenario 1

% change in 2023

	Wheat	Rice	Oilseeds	Pigmeat	Poultry meat	Butter	Cheese	Whole milk powder
Production								
Developed	-1.9	-0.2	3.6	-3.2	-1.1	-1.0	-2.4	-2.0
Developing	0.1	-0.3	0.0	-0.5	-1.7	-2.5	-2.2	-0.4
World	-0.9	-0.3	1.5	-1.4	-1.5	-1.9	-2.3	-1.1
Food use								
Developed	-5.6	-1.6	-1.5	-3.5	-2.7	-1.1	-2.5	-1.3
Developing	-2.5	-1.4	-1.4	-0.4	-0.9	-2.4	-1.9	-1.1
World	-3.3	-1.4	-1.5	-1.4	-1.5	-2.0	-2.4	-1.1
Export								
Developed	-0.5	3.2	8.2	0.7	8.0	-0.2	0.3	-2.2
Developing	-10.0	-2.2	-7.4	0.7	-12.2	4.9	-1.4	0.8
World	-2.0	-1.6	0.5	0.7	-3.0	0.3	0.0	-1.5
Import								
Developed	-3.5	-2.5	-2.3	0.2	-3.0	0.3	0.9	-0.6
Developing	-1.7	-1.6	1.1	0.9	-3.0	0.2	-0.6	-1.5
World	-2.0	-1.7	0.5	0.7	-3.0	0.3	0.0	-1.5
Price								
World	-15.4	-13.8	-8.9		-13.5	-11.5	-10.6	-8.4
Atlantic				-16.2				
Pacific				-17.9				
Other				-17.9				

Table 8 shows the percentage changes in 2023 for major variables of demand and supply of selected commodities resulting from the first scenario. In the aggregated level, food use and production drops everywhere for almost every commodity, but with different degrees. International prices also fall according to the scenario. Beef shows the largest rates of reduction both in production and food use. The international prices of cereals, meats, butter and cheese show percentage changes larger than 10%, whereas oilseeds and other dairy

products show changes of less than 10%. The full results including other commodities are shown in Annex C, Table 20.

Production decreases across developing and developed countries and no major differences are observed between regions except oilseeds, the only commodity whose overall production increases driven by developed countries. Looking at food use, the rate of reduction is generally higher in developed countries than developing countries. Wheat in developed countries shows the highest reduction rate followed by meats in developed countries.

It is observed that in oilseeds, pigmeat and sheep meat, developed countries increase their exports while developing countries increase their imports. On the other hand, the opposite happens for butter and whole milk powder.

Next the market impacts are analysed with economic values. To provide the basis of analysis, it is useful to see which commodity in which region consumers value most. Thus, the food demand projected in 2023 is multiplied by the consumer price of the commodity in the region, in order to compare the market value in USD.

Figure 4. Top 30 commodity and region in 2023

Market value calculated by consumer price and food use amount

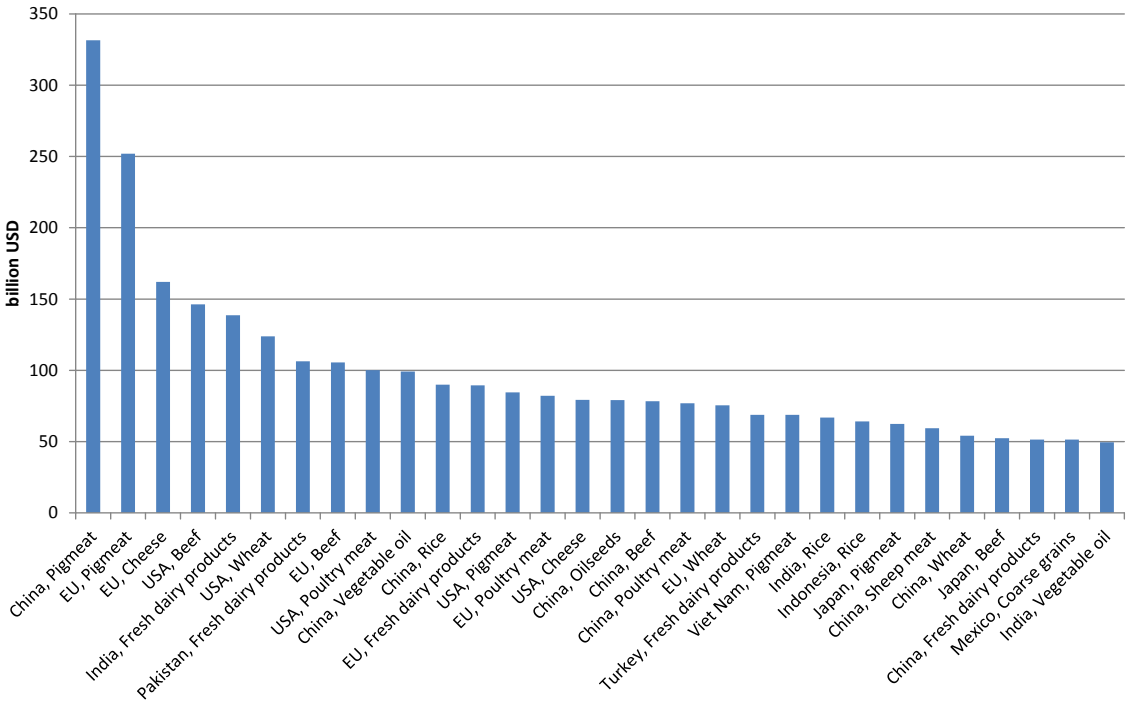


Figure 4 shows the 30 largest markets among 784 markets (14 commodities and 56 regions). The largest market is the pigmeat market in the People's Republic of China (hereafter 'China')[5], followed by pigmeat market in the European Union. It is generally observed that the large commodity markets are pigmeat, beef, wheat and rice in the European Union, the United States and China. Among other developing countries, fresh dairy product markets in India and Pakistan appear to be important.

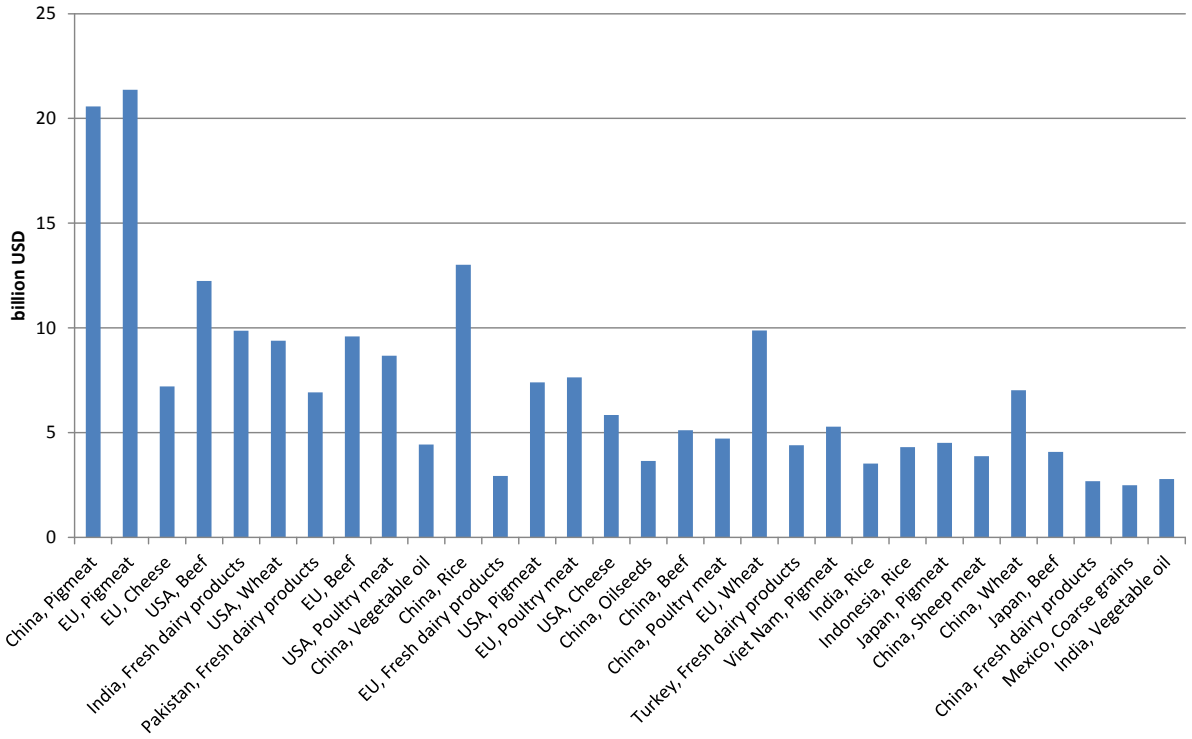
5. Refers to mainland only. The economies of Chinese Taipei, Hong Kong (China) and Macau (China) are included in the Other Asia Pacific aggregate throughout the study.

Comparison of market values between scenarios enables us to see how much the market is affected under each scenario and how large consumer savings are. This is the comparison between P^0AQ^00 and P^1BQ^10 in Figure 1 and Figure 2.

Figure 5 shows the levels of consumer saving for the same set of markets listed in Figure 4. The largest consumer savings come in the following sectors: pigmeat in the European Union and China, rice in China, beef in the United States, wheat in the European Union and fresh dairy products in India. The levels of consumer saving depend on the value of each market but are not exactly proportionate. Wheat and rice display larger saving than other commodities. The consumer saving made in the rice market in China is 14.5% of the baseline value. Such economic impact through price change is significant, as the initial shift of food demand in rice market in China is mere 5.1%. The total consumer saving throughout commodities and regions in 2023 amounted to USD 458 billion, and the accumulated total from 2014 to 2023 is USD 2.52 trillion.

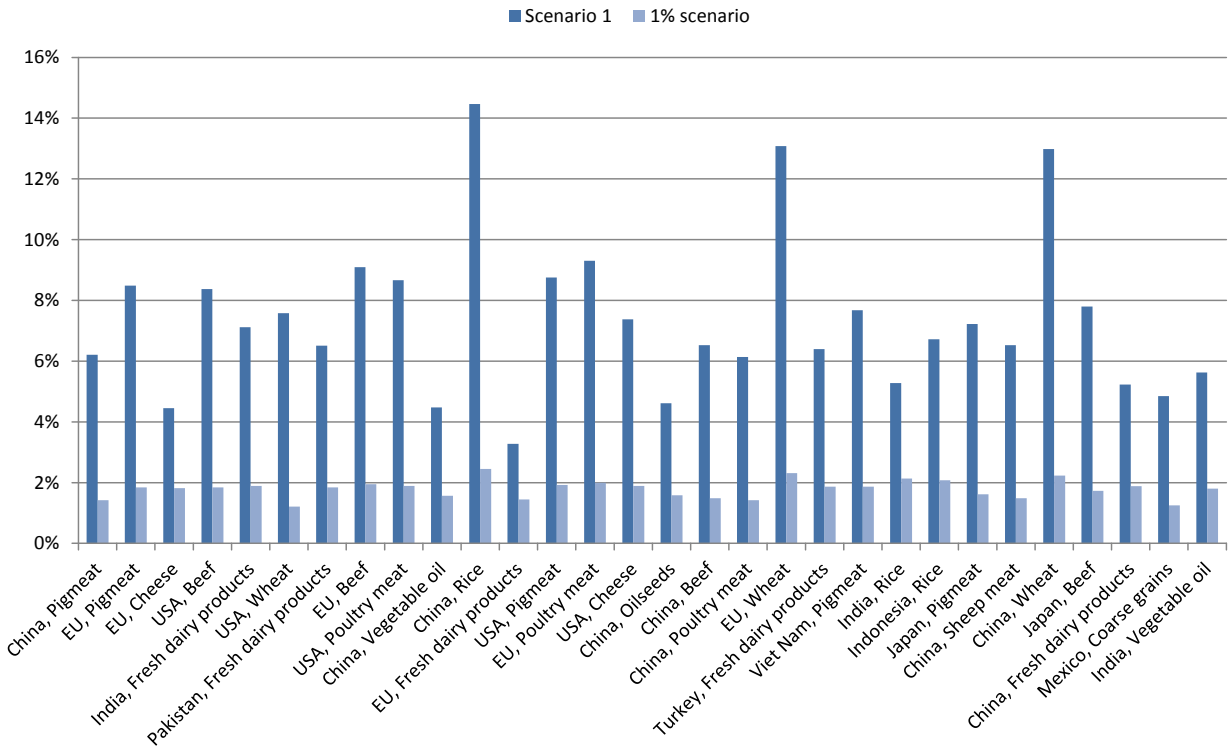
Figure 5. Consumer savings by food loss and waste reduction

Top 30 commodity and region in 2023



It is now interesting to question whether the variability observed in consumer saving are due to either the inherent characteristics of each market within the model, or the different degrees of food loss and waste estimates applied by the scenario. In order to assess this, the results of Scenario 1 are compared against a "sensitivity-analysis" scenario, where all food demands are shocked by 1% towards 2023 regardless of the level of food loss and waste. Figure 6 displays the results of Scenario 1 together with the results from the 1% reduction scenario. While the 1% scenario generally leads to consumer savings of 1% to 3%, the consumer saving based on Scenario 1 vary more with commodities and regions. Headed by rice and wheat in China and wheat in the European Union, cereals and meats generally show higher shares of consumer savings.

Figure 6. Share of consumer saving in the respective market value



In addition to looking at each market, the consumer savings can be decomposed either by commodities or by regions. Table 9 shows top five regions with large consumer savings in 2023. While China has the largest agricultural market of USD 973 billion, the European Union has the potential to achieve the largest consumer savings. The average rate of consumer savings is 7.2%, and most OECD countries, such as the European Union, United States, Japan, Australia and New Zealand shows the rate of savings above the world average.

Table 9. Top 5 regions with large consumer savings in 2023

Region	Market value (USD billion)	Consumer savings (USD billion)	Rate of saving
European Union	922	73	8.0%
China	973	70	7.2%
United States	637	51	8.1%
India	390	24	6.1%
Japan	239	21	8.7%

Table 10 shows six commodities with high consumer savings in 2023. Pigmeat, beef, wheat, rice and poultry meat show higher rates of savings than the average of 7.2%. Wheat and rice exceeds fresh dairy products and poultry meat, the commodities with higher market values than wheat and rice, respectively. According to the amount and rate of saving in Table 9 and Table 10, the European Union, China and the United States can make more savings than other regions, and pigmeat, beef and wheat can be identified as priority commodities.

Table 10. Commodities with large consumer savings in 2023

Commodity	Market value (USD billion)	Consumer saving (USD billion)	Rate of saving
Pigmeat	1 035	78	7.6%
Beef	897	68	7.5%
Wheat	717	59	8.2%
Fresh dairy products	893	54	6.0%
Rice	554	49	8.8%
Poultry meat	566	46	8.2%

When consumers save by reducing food waste, agricultural producers on the other hand will lose sales compared to the baseline, due to reduced price and quantity in the scenario. This loss to producers depends mainly on the size of each agriculture sector. Figure 7 shows the value of each agriculture sector, which is calculated by multiplying the production of a commodity in a region by the corresponding producer price. From the producers' perspective, the single largest agriculture sector is also pigmeat in China, but in comparison with Figure 4 that shows results from the consumers' side, the oilseeds and vegetable oil sectors in Brazil, Indonesia and Malaysia appear among the 30 largest sectors.

Figure 7. Top 30 producing regions in 2023

Value calculated by producer price and production amount

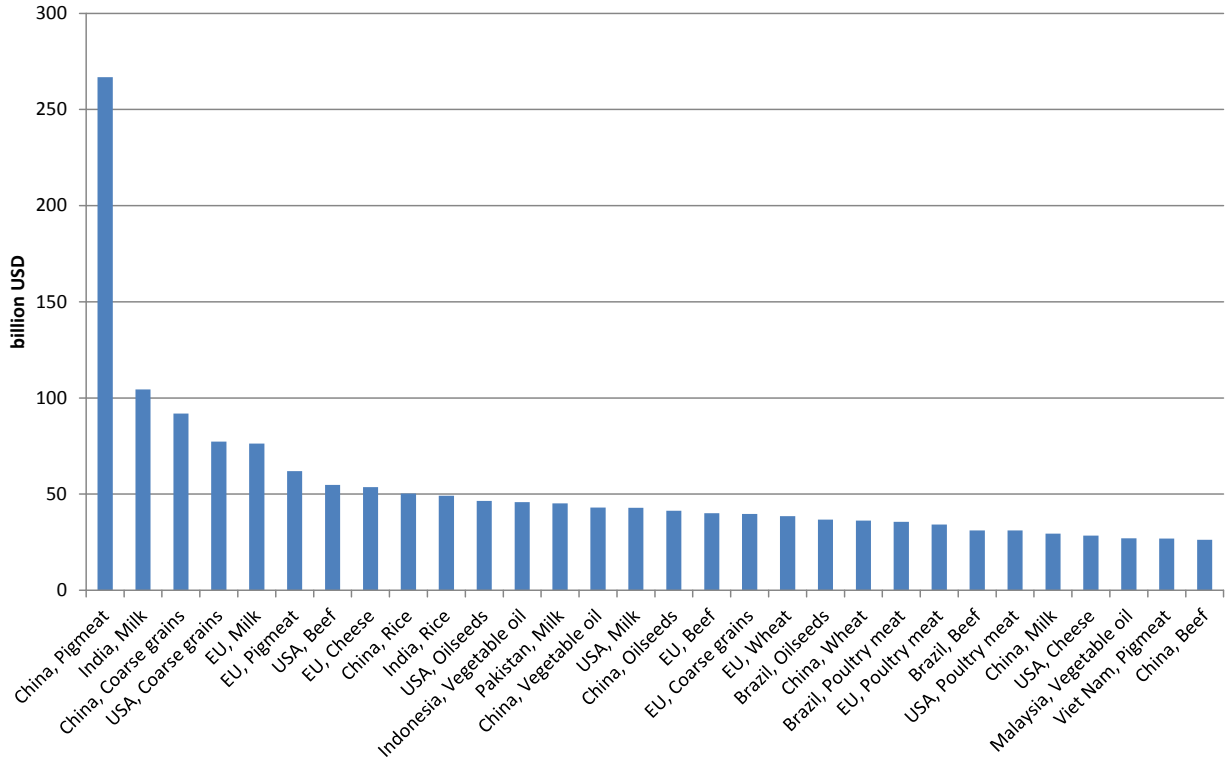


Figure 8 shows the producer losses corresponding to the 30 largest agricultural sectors listed in Figure 7. The pigmeat sector in China shows a particularly high figure compared with others, exceeding USD 40 billion in 2023. Other agriculture sectors with producer losses more than USD 10 billion are coarse grains in China and the United States, beef and pigmeat in the European Union, fresh dairy products in India and rice in China. Compared to the size

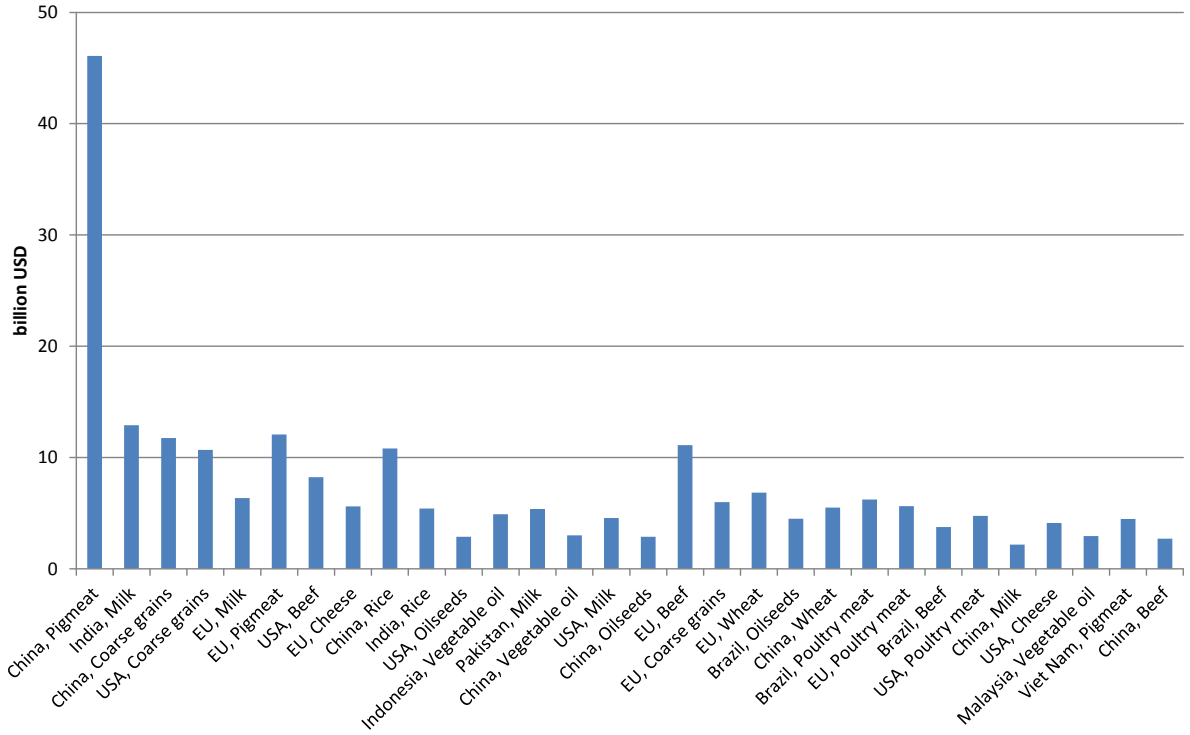
of sector, beef sector in the European Union experiences particularly high rate of producer loss, 28% of the initial production value. Total producer loss in 2023 amounts to USD 421 billion and the accumulated loss from 2014 to 2023 is USD 2.46 trillion.

The 2013 edition of Agricultural Outlook (OECD/FAO, 2013) presented a detailed scenario analysis of increased Chinese pork imports.[6] Historically China has been mostly self-sufficient in pork and coarse grains. While China's domestic production and consumption has been increasing over the past decade, net trade has oscillated significantly. Maintaining the self-sufficiency levels in pork and coarse grains over the ten-year period will be a challenge, and changes in production or consumption of pork in China from lower food loss will have significant implications for the international prices and trade balances. The current analysis of food loss and waste again indicates that the Chinese pork sector is one of the largest players in the international market.

This scenario to shift demand downwards and supply upwards generally led to lower food demand and production. Thus the shock on the demand side appears to exert more impacts on international markets than the supply side. Main factors contributing to the reduction are the degree of the shock to the demand and supply, i.e. the existing levels of food loss and waste, and the elasticities in these functions.

Figure 8. Producer loss by food loss and waste reduction

Top 30 producing regions in 2023



6. Chapter 7 Meat, Box 7.2. Increased Chinese pork import implications for world markets

Scenario 2 Reduction of food waste from cereal consumption in North America, Europe and North Africa regions

Scenario 2 shifts the food demand of cereals (wheat, rice and coarse grains) in North America, Europe, and some Middle Eastern and North African countries. As a baseline, Figure 9 shows the projected amount of cereals used as food in 2023. While it is clear that most cereals are consumed in developing countries, a large amount of wheat is consumed in developed countries. It therefore makes sense for some industrialized countries to identify wheat or bread as a target commodity for food waste reduction.

Figure 9. Food use of cereals in 2023, baseline projection

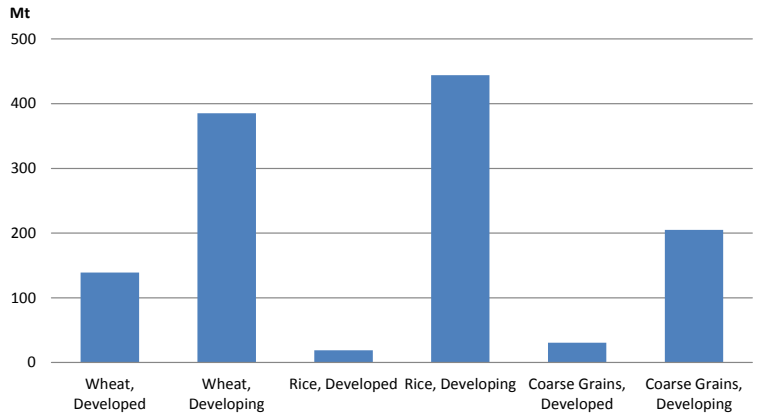


Table 11 shows main results of Scenario 2 for wheat, rice and coarse grains. While the rates of changes are smaller than Scenario 1, the changes in food demand in developed countries still affects production, trade and international prices.

In developed countries, food demand for cereals is reduced by 2% to 5%, with international prices falling. International price of wheat will drop by 3.1% in 2023. Exports by developed countries are boosted by the scenario, but food demand in developing countries declines, because the scenario includes developing countries that are major wheat consumers. The full results including other commodities are shown in Annex C, Table 21.

Total consumer saving calculated in the same manner as Scenario 1 amounts to USD 38 billion, where wheat accounts for USD 22 billion, and coarse grains and rice account for USD 6 billion and USD 4 billion respectively. The factors affecting the magnitude of the change among the three commodities are the large food use of wheat in developed countries and the significance of rice in developing countries, which is not the target of this scenario. In terms of regions, the greatest savings of around USD 11 billion are made in both the European Union and the United States, followed by Egypt (USD 2 billion).

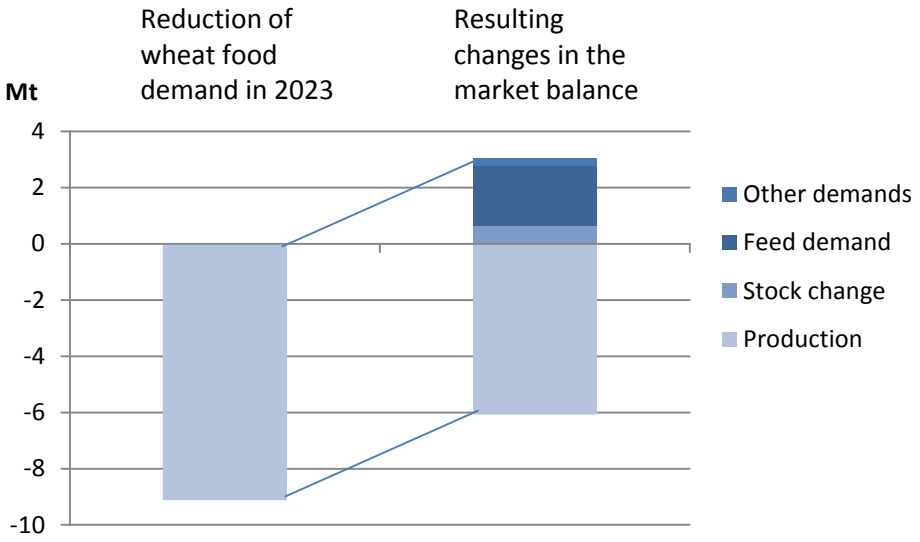
The rate of change for rice either exported or imported by developed countries is larger than other indicators, but they are from a small base as the bulk of rice is traded among developing countries. The large difference in rice consumption between developed and developing countries is shown in Figure 9. On the other hand, the significance of wheat in the regions covered in the scenario has led to larger reduction in the international price of wheat than rice or coarse grains. In this scenario, livestock production and exports in developed countries increase as feed cost fall and demand increases with lower prices. Figure 10 shows the changes in the global market balance of wheat in 2023. Lower waste of wheat for food reduces demand by 9 Mt and global production declines by 6 Mt, while the other amount is redistributed to feed demand, other demand and accumulation of stocks.

Table 11. Change of main variables for cereals in Scenario 2

% change in 2023

Region	Wheat	Rice	Coarse grains
Production			
Developed	-1.1	-0.5	0.0
Developing	-0.5	-0.1	-0.1
World	-0.8	-0.1	-0.1
Food use			
Developed	-5.0	-2.8	-5.2
Developing	-0.5	-0.1	-0.2
World	-1.7	-0.2	-0.8
Feed use			
Developed	1.8	0.4	0.0
Developing	0.5	0.0	0.1
World	1.4	0.0	0.1
Export			
Developed	0.4	5.7	0.5
Developing	-3.4	-0.8	-0.6
World	-0.2	-0.2	0.0
Import			
Developed	-0.9	-2.7	-1.3
Developing	0.0	0.2	0.4
World	-0.2	-0.2	0.0
Price			
World	-3.1	-1.1	-0.9

Figure 10. Change of wheat market balance in 2023



Scenario 3 Reduction of food waste from meats and dairy products consumption in developed countries

Scenario 3 shifts food demand for meats and dairy products in developed countries. While Scenario 2 shifts demand for cereals by the same 20%, the results of Scenario 3 show more impacts on international trade. For example in Table 12, pigmeat export from developed countries increases by 7% whereas imports by developing countries increases by 8%. Poultry meat shows similar changes in trade resulting in increased pigmeat and poultry meat consumption in developing countries. The reduction rates of international prices are also larger than Scenario 2, although it is not an exact comparison as the target countries are different.

Regarding consumer savings decomposed by commodities, pigmeat (USD 27 billion) and beef (USD 24 billion) show high figures followed by poultry meat (USD 16 billion) and cheese (USD 10 billion) within the total of USD 96 billion in 2023. In terms of regions, the largest consumer savings come in the European Union (USD 34 billion) and the United States (USD 23 billion) followed by Japan (USD 8 billion).

Changes of export volume from major producers vary. Regarding the impacts on international meat trade, the European Union and the United States increase their exports (Table 13) resulting from reduced domestic demands. On the other hand, exports from Brazil, a major producer of beef and poultry meat, fall.

Table 12. Changes of main variables for meats and dairy products in Scenario 3

% change in 2023

Region	Beef	Pigmeat	Poultry meat	Sheep meat	Butter	Cheese	Skim milk powder	Whole milk powder
Production								
Developed	-2.1	-2.1	-1.7	-1.1	-0.8	-1.9	-1.8	-0.5
Developing	-0.8	-0.4	-0.6	-0.2	-0.1	-1.0	-0.2	0.1
World	-1.3	-1.0	-1.0	-0.4	-0.4	-1.7	-1.7	-0.2
Food use								
Developed	-3.5	-3.7	-3.6	-3.4	-1.4	-2.4	-2.7	-1.8
Developing	0.1	0.3	0.4	0.2	0.1	0.2	-0.3	0.0
World	-1.3	-1.0	-1.1	-0.4	-0.4	-1.7	-1.3	-0.2
Export								
Developed	2.6	6.9	8.4	1.6	1.3	2.5	-0.4	-0.1
Developing	-3.3	-11.3	-6.0	-4.5	-2.9	-4.9	0.8	0.4
World	-0.9	3.7	0.6	0.2	0.9	1.5	-0.3	0.0
Import								
Developed	-5.6	-3.5	-5.8	-11.4	-2.4	-0.4	-0.5	-1.1
Developing	2.4	8.3	2.3	4.0	2.1	3.1	-0.2	0.0
World	-0.9	3.7	0.6	0.2	1.0	1.6	-0.3	0.0
Price								
World			-2.9	-3.1	-5.5	-2.9	0.2	-0.8
Atlantic	-1.7	-4.6						
Pacific	-4.4	-5.3						
Other	-1.0	-1.5						

Table 13. Growth of meat exports from major producing regions in Scenario 3

% change in 2023

Commodity	Australia	Brazil	Canada	European Union	India	New Zealand	United States
Beef	-0.2	-6.21			-1.02		5.4
Pigmeat			-2.53	14.94			4.73
Poultry meat		-8.24		13.3			7.71
Sheep meat	2.19					0.82	

As for dairy products, expansion of trade is projected in the baseline over the coming decade (OECD/FAO, 2014). The bulk of this growth will be satisfied by expanded exports from the United States, the European Union, New Zealand, Australia and Argentina. In contrast to concentrated exports, imports of dairy products are wide spread and the main destinations for dairy products are developing countries.

Table 14. Growth of dairy product exports from the European Union, New Zealand and the United States in Scenario 3

% change in 2023

Commodity	European Union	New Zealand	United States
Butter	-3.87	-2.29	20.74
Cheese	-1.6	-2.05	19.4
Skim milk powder	-2.31	-2.65	2.09
Whole milk powder	-0.81	-0.21	5.53

On the other hand in Scenario 3, while the United States extends the export of all dairy products, exports from the European Union and New Zealand contract (Table 14). The results imply that the United States is better positioned to respond to the negative demand shocks in developed countries. In the United States, the shares of butter and cheese exports among domestic production are relatively small compared with New Zealand and the European Union, and the shocks to its domestic demand are translated into higher exports. On the other hand, considerable share of exports from the European Union and New Zealand are destined to developed countries, where demand is reduced in the scenario. The full results of Scenario 3 including other commodities, e.g. fresh dairy product consumption and milk production, are shown in Annex C, Table 22.

Scenario 4. Reduction of food loss from crop production in developing countries

In Scenario 4 the 20% reduction in existing food loss is implemented by shifting crop production in developing countries by adjusting yields. The rate of reduction is the same as in the other three scenarios, but unlike the other three scenarios, this scenario does not involve reducing consumption. Table 15 shows the growth of crop production and expansion of food use in the world. In developing countries, production is stimulated not only in crops but also in pigmeat, poultry meat and sheep meat as part of the additional crop production in developing countries is used on local markets as feeds. The improved productivity and lower prices generally contributes to the increase of food consumption in developing countries with rice as a prime example.

Looking at the impacts on trade, it is not always that developing countries increase their exports and developed countries increase their imports. For example, exports by developed countries increase for beef, pigmeat and poultry meat. In another example, import and export by developing countries have both increased in rice, which signifies that the trade between developing countries has been promoted by the surplus production of 5.5 Mt. The full results including other commodities are shown in Annex C, Table 23.

Table 15. Changes of main variables for crops in Scenario 4

% change in 2023

Region	Wheat	Rice	Coarse grains	Oilseeds
Production				
Developed	-0.5	-1.1	-0.4	-0.2
Developing	2.2	1.1	1.5	1.2
World	0.8	1.0	0.6	0.7
Food use				
Developed	0.0	0.3	0.1	0.1
Developing	0.1	0.9	0.2	0.5
World	0.1	0.9	0.2	0.5
Feed use				
Developed	0.0	3.1	0.4	0.5
Developing	0.2	1.9	0.7	0.6
World	0.0	1.9	0.6	0.6
Export				
Developed	-1.4	-3.8	-4.8	-0.9
Developing	-0.7	1.8	3.7	0.6
World	-1.3	1.3	-1.4	-0.1
Import				
Developed	1.2	1.5	1.7	0.8
Developing	-1.9	1.3	-2.2	-0.3
World	-1.3	1.3	-1.4	-0.1
Price				
World	-3.7	-9.7	-4.4	-3.4

Regarding consumer savings decomposed by commodity, rice (USD 16 billion) shows the highest figure followed by wheat (USD 8 billion), pigmeat and beef within the total of USD 60 billion in 2023. In terms of regions, the largest consumer savings come in China (USD 10 billion), followed by the European Union (USD 6 billion), India and the United States. These results and Table 15 suggest that increased crop production in developing countries help provide more feeds in developed countries which increase their exports of meats at low price. The benefits of reducing crop production loss thus spread to livestock sectors especially in developed countries.

In this scenario, reduction of price generally results in reduced sales, however it does not necessarily lead to pessimistic conclusions for producers. Although they experience the reduction in sales, they have achieved in reduced production costs by reducing loss. Price decrease in meats and dairy products, which leads to producer loss in these commodities, is

largely due to the reduction of inputs costs i.e. feeds. Table 16 reports total consumer savings calculated for each scenario, together with rates of saving against the market value of target commodity and regions in each scenario. While demand side shock in Scenario 2 leads to high rate of saving, supply side shock in Scenario 4 leads to the smaller rate of consumer saving than other scenarios reflecting that prices are reduced but amounts of supply and demand have grown.

Table 16. Total consumer savings in four scenarios, in 2023

Scenario	Type of shock	Market value of target commodity and regions (USD billion)	Consumer saving (USD billion)	Rate of saving
1	Demand and supply	6 347	458	7.2%
2	Demand	459	38	8.3%
3	Demand	1 812	96	5.3%
4	Supply	1 226	60	4.9%

Limitations and future challenges

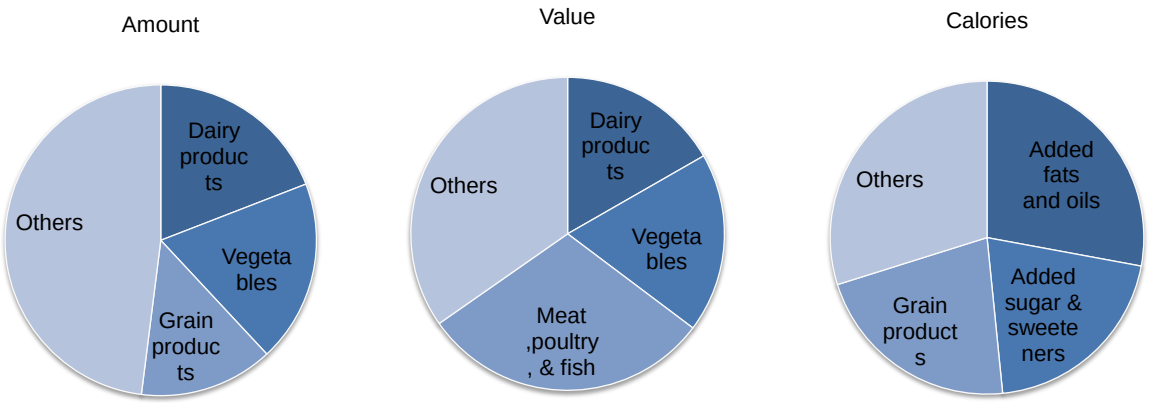
While the Aglink-Cosimo model with its detailed commodity representation and forward looking focus has a number of strengths for undertaking this food waste analysis, it also has some limitations to be borne in mind. Firstly, the scope to analyse the different phases or stages of the food chain is limited by the structure of the model with its rather aggregate representation of production and consumption. For example major policies in Japan concern prevention and reduction of food loss and waste in the food manufacturing, distribution and retail sectors, while the food waste at consumer level has shown no change in recent years. These differences are aggregated in the current analysis.

Commodity coverage

Also the commodity representation in Aglink-Cosimo differs somewhat from the FAO dataset. For instance, the model does not include roots and tubers and fruit and vegetables, which are important in terms of food loss and waste. Given these constraints it may be more interesting to focus scenarios around commodity group and regional differences, e.g. between crops and livestock products, and between developed and developing countries in addition to assessing world price and commodity market impacts.

In future, inclusion of these and other commodities would allow interesting analyses in other angles, namely, expenditure values and calories. For example in Figure 11, the food groups with the highest share of food loss vary with the type of measurement, in the United States (Buzby et al., 2014b). Three food groups (dairy products, vegetables, and grain products) made up almost half of the food loss at the retail and consumer levels in terms of weight. On a total value basis, the meat, poultry, and fish group comprises almost a third (30%) of the total (versus 12% by weight) because foods in this group tend to cost more per pound than many other foods. Vegetables and dairy products come in second and third in terms of share of total value. The top three food groups in terms of shares of total calories uneaten are noticeably different - shares for added fats and oils, added sugars and sweeteners, and grains are much higher in terms of calories, reflecting these foods' caloric density per pound.

Figure 11. The top three food groups in the United States in terms of annual food loss at the retail and consumer levels vary depending on if measured by amount, value or calories



Source: Buzby et al. (2014b).

No-cost assumption and data availability

The exclusion of costs to reduce food loss and waste is an important assumption. The study has set a 20% reduction rate from existing levels of loss and waste, on the premise that this level of reduction can be achieved without significant costs in view of current efforts and targets set by countries. It is a subject of future studies to assess the feasibility to reduce loss and waste with associated costs and benefits. A thorough reflection on the economic mechanisms that are behind the phenomenon of losses and waste would be needed in order to validate the scale of reductions that are achievable with a net economic gain, and to calibrate the associated shifts in supply and demand curves.

FAO member countries are working on food losses and food waste with the Regional FAO Offices and with the FAO Statistics Division to improve and disaggregate their food loss and waste estimates in 2011 (FAO, 2013b). If detailed data become available, estimates for regions and commodities could be seen as panel data, and be used to model and estimate food loss and waste as a function of consumer price, per capita consumption, income, and commodity groups, for example. Then analysis of the interaction between consumer price and degree of loss and waste may be possible. Another approach could be a microeconomic study of actual price (or charges) and the amount of food waste using the information from existing policies such as in Korea.

Different causes of food loss and waste exist along the food supply chain (Buzby et al., 2014a; Gunders, 2012; Rutten et al., 2013). Costs to reduce food loss and waste are the other side of coin, and given the variety of causes and measures, there could be different degrees of efficiencies in reducing these costs. Table 17 shows the type of costs that could be incurred to reduce waste along the food supply chain. These include infrastructure and technology, but also changes to individuals' behaviours and time allocation.

Table 17. Costs to reduce food loss and waste

Category	Agricultural production	Postharvest handling and storage	Processing and packaging	Distribution: Supermarket retail	Consumption
Infrastructure and hardware	Agriculture machinery	Postharvest infrastructure and storage, e.g. silos	Processing and packaging equipment	Roads, ports, stockyards, etc. Electricity for refrigerator	Better storage facilities
Technology	Prevention and treatment to avoid loss	Introduction of better postharvest treatment	Reuse of by-products for food	Improvement of distribution, e.g. distance, temperature, pests Provision of small/varied portions	New materials to prevent waste Redistribution of foods Provision of small/varied portions
Information	Market information on demand and supply Opportunity costs to gain market information	Extension of knowledge to farmers Opportunity costs to gain new technology	Extension of knowledge and technology to other industry participants	Arrangements for smooth information flow between buyers and sellers	Extension of knowledge Opportunity costs to plan the purchase exactly and timely

Recycling of by-products in the feed market

While the reduction of food loss and waste throughout the food supply chain has been prioritized in view of food security and efficiency concerns, recycling of food loss is also actively promoted in a number of countries. For example in Japan the promotion of food loss recycling is considered to contribute to the improvement of feed self-sufficiency.

With a growing demand for animal protein and biofuels, food loss during agricultural production and distribution is an important source of by-products such as feeds and fertilizers (OECD/FAO, 2014). The market has experienced, for example, a sizable entry of Dried Distillers Grains (DDG), a cereal by-product of the distillation process especially from ethanol plants to feeds market since 2000s.

However, the developments have not been uniform in regions and there remain opportunities for countries to take a lead. It may therefore be useful to review what policies can be in place and if any existing policies e.g. safety regulations on feed and fertilizer may affect the development negatively.

5. Conclusion

In the study, reductions in consumer waste are modelled as a negative demand shock, which reduces domestic prices and quantities, and lowers international prices via cumulative impacts that depend on countries' integration with world markets. Reductions in food losses during production are modelled as a positive supply shock, which raises domestic supplies and lowers domestic prices, again leading to lower international prices. At the country level, the final impacts correspond to changed volumes of production, consumption and net trade at new (lower) domestic and international prices.

In global terms, Scenario 1 suggests that the biggest impacts on international markets would come from demand reductions rather than supply impacts. The study compares the value of each market in US dollars between baseline and scenario, and calculates savings made by consumers. The total consumer saving throughout commodities and regions in 2023 amounts to USD 458 billion, and the accumulated total from 2014 to 2023 is USD 2.52 trillion. The total consumer savings in 2023 are decomposed across commodities and regions, where pigmeat, beef and wheat show high consumer savings, and the regions with the greatest benefits are the European Union, China and the United States. When the savings are further decomposed to each commodity in a region, the largest consumer savings come in the following sectors: pigmeat in China and the European Union, rice in China, wheat in the European Union, beef in the United States and fresh dairy products in India.

Reduced food waste in cereal consumption (Scenario 2) suggests larger gains for consumers of wheat and coarse grains than for rice, reflecting the large food use of wheat in developed countries. Under this scenario, the international price of wheat drops by 3.1% in 2023. Livestock production and exports in developed countries increase with the reduction in feed cost from lower coarse grain prices.

Reduced food waste of meat and dairy products in developed countries (Scenario 3) leads to relatively larger impacts on international trade, with substantial increases in pigmeat exports from developed countries and larger imports by developing countries as a result of lower prices. Dairy exports from the United States increase, whereas exports from the European Union and New Zealand decline, reflecting their considerable exports to developed countries where demand is reduced in the scenario.

Reduced crop losses in developing countries (Scenario 4) lead to higher crop supply in these countries, where reduced prices from efficiency gains benefit consumers in both developing and developed countries. While this scenario targets developing countries, they are not the only beneficiaries as crop supplies increase feed available in both developing and developed countries and livestock and dairy producers benefit from lower feed costs. Exports increase for some developing countries, while others import more at lower prices. Global rice production increases by 5.5 Mt with the international price decreasing by nearly 10%. Increase in both exports and imports of rice by developing countries under Scenario 4 boost rice trade between developing countries. Comparison between the four scenarios indicates that the demand side policies in developed countries can have larger market impacts and consumer savings.

The study provides indicative estimates of the market and trade impacts of loss and waste reduction. The rudimentary underlying data mean that these estimates should be treated with caution. At the same time, the analysis does not include important sources of food loss and waste, including the fruit and vegetable sector, as well as in the processing industry. The Aglink-Cosimo model captures direct economic impacts across countries and commodities, but it would be necessary to link these impacts to general equilibrium models in order to trace economy-wide impacts and the overall implications for countries' and citizens' economic welfare. Finally, the study assumes that these reductions can be achieved without cost. Yet

some degree of food waste may reflect rational choices on the part of consumers, while producer losses may also be rational given wider constraints, such as lack of transport and storage facilities. A fuller link to the underlying economics of loss and waste would make it possible to examine the implications of alternative policy approaches.

References

Becker, G.S. (1965), A theory of the allocation of time, *The Economic Journal*, Vol. 75: 493-517.

BIO Intelligence Service (2013), Modelling of Milestones for achieving Resource Efficiency, Turning Milestones into Quantified Objectives: Food Waste, European Commission DG Environmenthttp://ec.europa.eu/environment/enveco/resource_efficiency/pdf/Task1_report.pdf (accessed 18 December 2013)

Buzby, J.C. and J. Hyman (2012), "Total and per capita value of food loss in the United States", *Food Policy*, Vol. 37, Issue 5, pp. 561-570.

Buzby, J.C., H.F. Wells, and J. Hyman (2014a), *The Estimated Amount, Value, and Calories of Postharvest Food Losses at the Retail and Consumer Levels in the United States*, EIB-121, U.S. Department of Agriculture, Economic Research Service, http://www.ers.usda.gov/publications/eib-economic-information-bulletin/eib121.aspx (accessed 23 June 2014)

Buzby, J.C., H.F. Wells and J. Aulakh (2014b), *Food Loss – Questions About the Amount and Causes Still Remain, Amber Waves*, June 2014, U.S. Department of Agriculture, Economic Research Service, http://ers.usda.gov/amber-waves/2014-june/food-loss—questions-about-the-amount-and-causes-still-remain.aspx (accessed 01 September 2014)

Economic Research Service (ERS) (2014), *Loss-Adjusted Food Availability Data in the Food Availability* (Per Capita) Data System, U.S. Department of Agriculture, http://www.ers.usda.gov/data-products/food-availability-(per-capita)-data-system.aspx (accessed 23 June 2014)

European Commission (2014), *Towards a circular economy: A zero waste programme for Europe*, COM(2014) 398 final, Brussels http://ec.europa.eu/environment/circular-economy/pdf/circular-economy-communication.pdf (accessed 10 July 2014)

European Commission (2011), *Roadmap to a Resource Efficient Europe*, COM (2011) 571 final, http://ec.europa.eu/environment/resource_efficiency/pdf/com2011_571.pdf (accessed 10 July 2014)

European Commission (2013), European Parliament website http://www.europarl.europa.eu/sides/getAllAnswers.do?reference=P-2013-006319&language=EN(last updated 3 July 2013, accessed 5 September 2013)

European Commission (2010), *Final Report – Preparatory Study on Food Waste across EU 27*, Technical Report – 2010 – 054, DG ENV - Directorate C, http://ec.europa.eu/environment/eussd/pdf/bio_foodwaste_report.pdf (accessed 2 September 2014)

FAO (2014), *Definitional framework of food loss*, FAO website, http://www.fao.org/fileadmin/user_upload/save-food/PDF/FLW_Definition_and_Scope_2014.pdf (accessed 23 September 2014)

FAO (2013a), *Food wastage footprint Impacts on natural resources – Summary Report*, FAO website, http://www.fao.org/docrep/018/i3347e/i3347e.pdf (accessed 11 September 2013)

FAO (2013b), "Global Initiative of Food Losses and Food Waste", presentation at FourthOECD Food Chain Network Analysis Meeting, 20-21 June 2013, OECD Food Chain Network

website, http://www.oecd.org/site/agrfcn/Introductory%20Session_Yahia_Bucatariu.pdf(accessed 10 July 2014)

FAO (2011), *Global Food Losses and Food Waste: Extent, Causes and Prevention*. Study conducted for the International Congress SAVE FOOD! at Interpack 2011, Düsseldorf, Germany.

Gunders, D. (2012), *Wasted: How America is Losing Up to 40 Percent of Its Food from Farm to Fork to Landfill*, NRDC Issue Paper 12-06-B. Natural Resources Defense Council, Washington DC, http://www.nrdc.org/food/files/wasted-food-ip.pdf (accessed 9 September 2014)

Gustavsson, J., C. Cederberg, U. Sonesson and A. Emanuelsson (2013), *The methodology of the FAO study: "Global Food Losses and Food Waste - extent, causes and prevention FAO, 2011*", SIK report No. 857, The Swedish Institute for Food and Biotechnology, http://www.sik.se/archive/pdf-filer-katalog/SR857.pdf (accessed 10 July 2014)

Hodges, R.J., J.C. Buzby and B. Bennett (2010), "Postharvest Losses and Waste in Developed and Less Developed Countries: Opportunities to Improve Resource Use." *Journal of Agricultural Science*, doi:10.1017/S0021859610000936.

Höjgård, S., T. Jansson and E. Rabinowicz (2013), Food waste among Swedish households - much ado about nothing?, *AgriFood Economics Centre Working Paper* 2013:8, http://www.agrifood.se/Files/AgriFood_WP20138.pdf (accessed 1 July 2014)

Kantor, L.S., K. Lipton, A. Manchester and V. Oliveira (1997) "Estimating and Addressing America's Food Losses" *Food Review*, January-April 1997, pp. 2-12 http://webarchives.cdlib.org/wayback.public/UERS_ag_1/20110903004334/http://ers.usda.gov/Publications/FoodReview/Jan1997/Jan97a.pdf (accessed 1 July 2014)

Kummu, M., H. de Moel, M. Porkka, S. Siebert, O. Varis and P.J. Ward (2012), "Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use", *Science of the Total Environment*, Vol. 438, pp. 477-489.

Lipinski, B., C. Hanson, J. Lomax, L. Kitinoja, R. Waite and T. Searchinger (2013), "Reducing Food Loss and Waste", *World Resource Institute Working Paper, Instalment 2 of Creating a Sustainable Food Future*, Washington, DC., http://www.wri.org/sites/default/files/reducing_food_loss_and_waste.pdf (accessed 16 October 2013)

Lundqvist, J., C. de Fraiture, D. Molden (2008) *Saving Water: From Field to Fork – Curbing Losses and Wastage in the Food Chain*, SIWI Policy Brief, Stockholm International Water Institute (SIWI), Stockholm, Sweden. http://www.siwi.org/documents/Resources/Policy_Briefs/PB_From_Filed_to_Fork_2008.pdf (accessed 5 September 2013)

OECD/FAO (2013), *OECD-FAO Agricultural Outlook 2013-2022*, OECD Publishing, Paris, http://dx.doi.org/10.1787/agr_outlook-2013-en

OECD/FAO (2014), *OECD-FAO Agricultural Outlook 2014-2023*, OECD Publishing, Paris, http://dx.doi.org/10.1787/agr_outlook-2014-en

OECD (2015), "Preventing Food Waste: Case Studies of Japan and the United Kingdom", *OECD Food, Agriculture and Fisheries Paper*, N°76, OECD Publications, Paris.

Parfitt, J., M. Barthel and S. MacNaughton (2010), Food waste within food supply chains: qualification and potential for change to 2050. *Philosophical transactions of the Royal Society B*, 365, pp. 3065-3081

Quested, T., R. Ingle and A. Parry (2013), *Household Food and Drink Waste in the United Kingdom 2012*, WRAP, http://www.wrap.org.uk/content/household-food-and-drink-waste-uk-2012 (accessed 11 September 2014).

Rutten, M., P. Nowicki, M.J. Bogaardt and L. Aramyan (2013) *Reducing food waste by households and in retail in the EU – A prioritisation using economic, land use and food security impacts*, LEI Report 2013-035, LEI Wageningen UR, The Hague. https://www.wageningenur.nl/upload_mm/b/c/8/27078547-595c-48c2-a016-d9ad8b8b3164_2013-035%20Rutten_DEF_WEB%205-11_Totaal.pdf (accessed 10 February 2014)

Smil, V. (2000), *Feeding the World: A Challenge for the Twenty-First Century*. MIT Press, Cambridge, MA.

Stehfest, E., M. van den Berg, G. Woltjer, S. Msangi and H. Westhoek (2013), Options to reduce the environmental effects of livestock production – Comparison of two economic models, *Agricultural Systems*, vol. 114, issue C, pages 38-53

Stuart, T. (2009) *Waste: Uncovering the Global Food Scandal*. Penguin, London.

Tonini, A., J. Michalek, T. Fellmann, R. M'barek, J. Delincé and G. Philippidis (Eds.) (2013), *Simulating long-term effects of policies in the agri-food sector: requirements, challenges and recommendations*, EUR Number: 26253 EN, Publications Office of the European Union, DOI: 10.2791/32906, http://ftp.jrc.es/EURdoc/JRC84850.pdf (accessed 1 July 2014)

WRAP (2014), *Household Food & Drink Waste – A Product Focus*, WRAP website, http://www.wrap.org.uk/sites/files/wrap/Product-focused%20report%20v5_3.pdf *(*accessed 11 September 2014)

WRAP (2013), *Information Sheet, The Courtauld Commitment*, WRAP website, http://www.wrap.org.uk/sites/files/wrap/Courtauld%20information%20sheet.pdf (accessed 11 September 2014)

WRAP (2009), *Household Food and Drink Waste in the UK*, WRAP website, http://www.wrap.org.uk/sites/files/wrap/Household%20food%20and%20drink%20waste%20in%20the%20UK%20-%20report.pdf (accessed 11 September 2014).

Annex A.

List of regions and commodities included in the scenario

Table 18. List of Aglink-Cosimo regions and commodities where food use function is shocked

"exo" signs represent the exogenous variables. "exoQC" signs represent exogenous consumption variables (only applicable for rice in New Zealand)

	Butter	Beef	Coarse Grains	Cheese	Fresh dairy products	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
LDC Sub-Saharan Africa	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other North Africa	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Sub-Saharan Africa	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Argentina	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Other Asia Developing	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Asia Developed	X	X	X	X	X	X	X	X	X	X	X	X	X	X
LDC Asia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Australia	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Bangladesh	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Brazil	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Canada	X	X	X	X	X	exo	X	No	X	X	X	X	exo	X
Switzerland	exo	exo	exo	exo	exo	No	exo	exo	exo	exo	exo	exo	exo	exo
Chile	X	X	X	X	X	X	X	X	X	X	X	X	X	X
China	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Colombia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Algeria	X	X	X	X	X	X	No	X	X	X	X	X	X	X
European Union new member states	X	X	X	X	X	No	X	X	X	X	X	X	X	X
European	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Butter	Beef	Coarse Grains	Cheese	Fresh dairy products	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
Union 15														
Egypt	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ethiopia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Eastern Europe	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Other Western Europe	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo
Ghana	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Haiti	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo
Indonesia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
India	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Iran, Islamic Republic of	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Israel	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo
Japan	X	X	X	X	X	X	X	X	X	X	X	X	exo	X
Kazakhstan	X	X	X	X	X	X	X	X	X	X	X	X	X	X
South Korea	exo	X	X	X	X	X	X	X	X	X	exo	X	exo	X
Mexico	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Other Middle East	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mozambique	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Malaysia	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Nigeria	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Norway	exo	exo	exo	exo	exo	No	exo	exo	exo	exo	exo	exo	exo	exo
New Zealand	X	X	X	X	X	exo	X	X	exoQC	X	X	exo	X	X
Other Oceania	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo
LDC Oceania	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo	exo
Pakistan	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Peru	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Philippines	X	X	X	X	X	X	X	X	X	X	X	X	X	X

	Butter	Beef	Coarse Grains	Cheese	Fresh dairy products	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
Paraguay	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Russian Federation	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Other South America and Caribbean	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Saudi Arabia	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Sudan	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Thailand	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Turkey	X	X	X	X	X	X	No	X	X	X	X	X	X	X
Tanzania, United Republic of	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ukraine	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Uruguay	X	X	X	X	X	X	X	X	X	X	X	X	X	X
United States	X	X	X	X	X	exo	X	X	X	X	X	X	X	X
Viet Nam	X	X	X	X	X	X	X	X	X	X	X	X	X	X
South Africa	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Zambia	X	X	X	X	X	X	X	X	X	X	X	X	X	X

1. Pigmeat food use in Bangladesh, Algeria, Islamic Republic of Iran, Pakistan, Saudi Arabia, Sudan and Turkey are shocked through the changes of beef food use functions

2. Poultry meat food use in Canada is shocked through the changes of food use functions of Chicken and other poultry.

3. Oilseeds food use in European Union new member states is calculated endogenously but not feasible to include the shock.

4. Oilseeds food use in Switzerland and Norway are not included in the model, even as exogenous variables.

Table 19. List of Aglink-Cosimo regions and commodities where yield function or production function are shocked

"QP", "YLD" and "CR" represent production function, yield function and crushed oilseed function respectively

"exoYLD" and "exoQP" signs represent the exogenous variables to be shocked

	Butter	Beef	Coarse Grains	Cheese	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
LDC Sub-Saharan Africa	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Other North Africa	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Other Sub-Saharan Africa	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Argentina	QP	QP	No	QP	YLD	No	QP	No	YLD	QP	QP	CR	QP	YLD
Other Asia Developing	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Other Asia Developed	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
LDC Asia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Australia	QP	QP	No	QP	YLD	No	QP	No	YLD	QP	QP	CR	QP	YLD
Bangladesh	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Brazil	QP	QP	No	QP	YLD	No	QP	No	YLD	exo	QP	CR	QP	YLD
Canada	No	QP	No	No	No	No	QP	No	exo	QP	QP	CR	exo	exo
Switzerland	exo	exo	exo	exo	exo	exo	exo	No	exo	exo	exo	exo	exo	exo
Chile	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
China	QP	QP	No	QP	YLD	No	QP	QP	YLD	QP	QP	CR	QP	YLD
Colombia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Algeria	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
European Union new member states	QP	QP	No	No	YLD	No	QP	No	YLD	QP	QP	No	QP	No
European Union 15	QP	QP	No	No	YLD	No	QP	No	YLD	QP	QP	No	QP	No
Egypt	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Ethiopia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Other Eastern Europe	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Other Western Europe	exo	exo	exoQP	exo	exoQP	exoQP	exo	exo	exoQP	exo	exo	exoQP	exo	exoQP

	Butter	Beef	Coarse Grains	Cheese	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
Ghana	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Haiti	exo	exo	exoQP	exo	exoQP	exoQP	exo	exo	exoQP	exo	exo	exoQP	exo	exoQP
Indonesia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
India	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Iran, Islamic Republic of	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Israel	exo	exo	exoQP	exo	exoQP	exoQP	exo	exo	exoQP	exo	exo	exoQP	exo	exoQP
Japan	QP	QP	YLD	QP	YLD	YLD	QP	No	YLD	exo	QP	CR	exo	YLD
Kazakhstan	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
South Korea	No	QP	exo	exo	YLD	exo	QP	No	YLD	exo	No	CR	No	exo
Mexico	QP	QP	No	QP	YLD	No	QP	No	YLD	QP	QP	CR	QP	YLD
Other Middle East	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Mozambique	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Malaysia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Nigeria	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Norway	exo	exo	exo	exo	exo	exo	exo	No	exo	exo	exo	exoQP	exo	exo
New Zealand	QP	QP	YLD	QP	YLD	exo	QP	No	No	No	QP	exo	QP	YLD
Other Oceania	exo	exo	exoQP	exo	exoQP	exoQP	exo	exo	exoQP	exo	exo	exoQP	exo	exoQP
LDC Oceania	exo	exo	exoQP	exo	exoQP	exoQP	exo	exo	exoQP	exo	exo	exoQP	exo	exoQP
Pakistan	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Peru	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Philippines	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Paraguay	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Russian Federation	QP	QP	No	QP	YLD	No	QP	No	YLD	QP	QP	CR	QP	YLD
Other South America and Caribbean	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Saudi Arabia	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Sudan	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Thailand	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD

	Butter	Beef	Coarse Grains	Cheese	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oils	Whole milk powder	Wheat
Turkey	QP	QP	YLD	QP	YLD	YLD	No	QP	YLD	QP	QP	CR	QP	YLD
Tanzania, United Republic of	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Ukraine	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Uruguay	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
United States	QP	QP	No	QP	YLD	No	QP	No	YLD	QP	QP	CR	QP	YLD
Viet Nam	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
South Africa	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD
Zambia	QP	QP	YLD	QP	YLD	YLD	QP	QP	YLD	QP	QP	CR	QP	YLD

1. Coarse grains yield in Argentina, Australia, Brazil, Canada, China, European Union new member states, European Union 15, Mexico, Russian Federation and the United States are shocked separately through yield functions of Barley, Maize, Oats, Sorghum, Rye and Other cereals.

2. Oilseeds yield in Argentina, Australia, Brazil, Canada, China, European Union new member states, European Union 15, Mexico, Russian Federation and the United States are shocked separately through yield functions of Groundnut, Rapeseed, Soybean and Sunflower seed.

3. Wheat yield in European Union new member states and European Union 15 are shocked separately through yield functions of Durum wheat and Soft wheat.

4. Milk yield in Canada is shocked through production function of milk for processing.

4. Crushed oilseeds functions are shocked in order to represent the shocks to vegetable oil production. Vegetable oil production in European Union new member states and European Union 15 are shocked separately through crushed oilseeds functions of Rapeseed, Soybean and Sunflower seed.

5. Vegetable oil production in Switzerland, Other Western Europe, Haiti, Israel, Norway, Other Oceania and LDC Oceania are shocked through exogenous production (QP) variables. Vegetable oil production in New Zealand is shocked through exogenous Oilseed crush variable.

6. Butter and Cheese production in Canada, and Butter, Skim milk powder and Whole milk powder production in South Korea are not feasible to include the shock.

7. Pigmeat production in Bangladesh, Algeria, Islamic Republic of Iran, Pakistan, Saudi Arabia, Sudan and Turkey are not feasible to include the shock.

8. Poultry meat production in Argentina, Australia, Brazil, Canada, China, Switzerland, European Union new member states, European Union 15, Japan, South Korea, Mexico, Norway, New Zealand, Russian Federation and the United States are shocked separately through production functions of Chicken and Other poultry.

9. Cheese production in European Union new member states and European Union 15 are shocked separately through production functions from pure cow's milk and other milk.

Annex B.

Equations for food use, crop yield and meat production

The equation for food demand incorporates relationship between all food items. In the equation, the subscript refers to the regional, commodity and time dimension in the following order: 'r', 'c' and 't' are placeholders if multiple dimensions are possible.

$$\log(FO_{r,c,t}) = \alpha + \sum_{c1(food)} \beta_{c1} * \log\left(\frac{CP_{r,c1,t}}{CPI_{r,t}}\right) + \beta_1 * \log\left(\frac{GDPI_{r,t}}{POP_{r,t}/POP_{r,2005}}\right) + \log(POP_{r,t}) + \beta_2 * TRD + \log(R)$$

Where:

FO = food demand

CP = consumer price

CPI = consumer price index

GDPI = index of the gross domestic product

POP = population

TRD = yearly trend variable

R = equation specific residual

α = equation specific constant

β = parameter

c1(food) = commodities with food use

βc1 = cross- and own-price elasticities

For annual crops yield is calculated along the same equation.

$$log(YLD_{r,c,t}) = \alpha + \beta_1 * \log\left(\frac{PP_{r,c,(t-1)} + EPY_{r,c,(t-1)}}{\gamma_c * CPCI_{r,c,(t-1)} + (1-\gamma_c) * CPCI_{r,c,t}}\right) + \beta_2 * TRD + \log(R)$$

Where:

YLD = annual crop yield

EPY = policy variable affecting yield (in LCU per ton)

CPCI = cost of production index (2008 = 1)

γ_c = share of production cost occurring in the previous marketing year

Production equation of meats and dairy products vary with commodities and regions, for example in the use of time lags. The example below is the beef production in Korea.

$$log(QP_{r,c,t}) = \alpha + \sum_{t=-2}^{0} \beta_1 * \log\left(\frac{PP_{r,c,t} + EPQ_{r,c,t}}{CPCI_{r,c,t}}\right) + \sum_{t=-2}^{-1} \beta_2 * \log\left(\frac{FECI_{r,c,t}}{CPCI_{r,c,t}}\right) + \sum_{t=-2}^{-1} \beta_3 * \log(CI_{r,bv,t} + CI_{r,mk,t}) + \beta_4 * log(QP_{r,c,t-1}) + \beta_5 * TRD + \log(R)$$

Where:

YLD = annual production

EPQ = policy variable affecting production (in LCU per ton)

CPCI = cost of production index (2008 = 1)

FECI = feed expenditure for ruminant production

CI = Cow inventory, beef (*bv*) and milk (*mk*)

Annex C.

Result tables from Scenario 1 to Scenario 4

Table 20. Scenario 1 results

% change in 2023

Region	Butter	Beef	Coarse grains	Cheese	Fresh dairy products	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oil	Whole milk powder	Wheat
Production	**Top 10 items highlighted**														
Developed	-1.0	-2.6	-0.5	-2.4	-	-1.6	3.6	-3.2	-1.1	-0.2	-0.1	-3.5	0.8	-2.0	-1.9
Developing	-2.5	-4.3	-0.5	-2.2	-	-2.2	0.0	-0.5	-1.7	-0.3	-0.9	4.2	-0.9	-0.4	0.1
World	-1.9	-3.6	-0.5	-2.3	-	-1.9	1.5	-1.4	-1.5	-0.3	-0.7	-2.6	-0.5	-1.1	-0.9
Food use	**Bottom 10 items highlighted**														
Developed	-1.1	-4.0	-5.3	-2.5	-2.4	-	-1.5	-3.5	-2.7	-1.6	-2.8	-1.8	-2.1	-1.3	-5.6
Developing	-2.4	-3.4	-2.2	-1.9	-2.6	-	-1.4	-0.4	-0.9	-1.4	-0.3	-1.9	-1.6	-1.1	-2.5
World	-2.0	-3.7	-2.6	-2.4	-2.5	-	-1.5	-1.4	-1.5	-1.4	-0.8	-1.9	-1.7	-1.1	-3.3
Export	**Top 10 items highlighted**														
Developed	-0.2	2.0	-2.9	0.3	-	-	8.2	0.7	8.0	3.2	5.0	-3.2	-1.2	-2.2	-0.5
Developing	4.9	-6.1	-0.2	-1.4	-	-	-7.4	0.7	-12.2	-2.2	-8.2	10.1	-2.6	0.8	-10.0
World	0.3	-2.8	-1.8	0.0	-	-	0.5	0.7	-3.0	-1.6	1.8	-2.1	-2.4	-1.5	-2.0
Import	**Top 10 items highlighted**														
Developed	0.3	-6.4	-6.9	0.9	-	-	-2.3	0.2	-3.0	-2.5	-6.3	-0.3	0.1	-0.6	-3.5
Developing	0.2	-0.4	-0.6	-0.6	-	-	1.1	0.9	-3.0	-1.6	4.6	-2.3	-3.1	-1.5	-1.7
World	0.3	-2.9	-1.9	0.0	-	-	0.5	0.7	-3.0	-1.7	1.9	-2.1	-2.4	-1.5	-2.0
Price	**Bottom 10 items highlighted**														
World	-11.5		-13.3	-10.6	-	-	-8.9		-13.5	-13.8	-15.9	-7.9	-8.2	-8.4	-15.4
Atlantic		-7.5						-16.2							
Pacific		-11.9						-17.9							
Other		-10.6						-17.9							

1. Top 10 items are highlighted for production, export and import.
2. Bottom 10 items are highlighted for food use and international price.

Table 21. Scenario 2 results

% change in 2023

Region	Butter	Beef	Coarse grains	Cheese	Fresh dairy products	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oil	Whole milk powder	Wheat
Production	**Top 10 items highlighted**														
Developed	0.0	0.1	0.0	0.0	-	0.0	0.3	0.0	0.2	-0.5	0.0	0.0	0.1	0.1	-1.1
Developing	0.0	-0.1	-0.1	-0.1	-	0.0	-0.1	0.0	0.0	-0.1	0.1	-0.1	0.0	0.0	-0.5
World	0.0	0.0	-0.1	0.0	-	0.0	0.0	0.0	0.1	-0.1	0.0	0.0	0.0	0.0	-0.8
Food use	**Bottom 10 items highlighted**														
Developed	0.0	0.0	-5.2	0.0	0.0	-	0.0	0.0	0.1	-2.8	0.0	0.0	0.0	0.0	-5.0
Developing	0.0	0.0	-0.2	0.0	0.0	-	0.1	0.0	0.1	-0.1	0.1	0.0	0.0	0.0	-0.5
World	0.0	0.0	-0.8	0.0	0.0	-	0.1	0.0	0.1	-0.2	0.0	0.0	0.0	0.0	-1.7
Export	**Top 10 items highlighted**														
Developed	0.1	0.2	0.5	0.0	-	-	0.5	0.0	0.6	5.7	0.0	0.0	0.1	0.1	0.4
Developing	0.1	-0.3	-0.6	-0.1	-	-	-0.6	-0.4	-0.5	-0.8	-0.3	-0.1	0.0	-0.1	-3.4
World	0.1	-0.1	0.0	0.0	-	-	-0.1	-0.1	0.0	-0.2	0.0	0.0	0.0	0.0	-0.2
Import	**Top 10 items highlighted**														
Developed	0.1	-0.3	-1.3	-0.2	-	-	-0.6	-0.6	-0.4	-2.7	-0.1	-0.1	-0.1	-0.3	-0.9
Developing	0.1	0.0	0.4	0.1	-	-	0.1	0.3	0.1	0.2	0.0	0.0	0.0	0.1	0.0
World	0.1	-0.1	0.0	0.0	-	-	-0.1	-0.1	0.0	-0.2	0.0	0.0	0.0	0.0	-0.2
Price	**Bottom 10 items highlighted**														
World	-0.3		-0.9	-0.3	-	-	-0.5		-0.5	-1.1	-0.4	-0.3	-0.1	-0.3	-3.1
Atlantic		-0.2						-0.6							
Pacific		-0.3						-0.5							
Other		-0.2						-0.3							

1. Top 10 items are highlighted for production, export and import.

2. Bottom 10 items are highlighted for food use and international price.

Table 22. Scenario 3 results

% change in 2023

Region	Butter	Beef	Coarse grains	Cheese	Fresh dairy products	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oil	Whole milk powder	Wheat
Production	**Top 10 items highlighted**														
Developed	-0.8	-2.1	-0.3	-1.9	-	-0.8	0.1	-2.1	-1.7	0.0	-1.1	-1.8	-0.3	-0.5	-0.1
Developing	-0.1	-0.8	-0.5	-1.0	-	-0.1	-0.6	-0.4	-0.6	0.0	-0.2	-0.2	-0.2	0.1	-0.2
World	-0.4	-1.3	-0.4	-1.7	-	-0.4	-0.3	-1.0	-1.0	0.0	-0.4	-1.7	-0.2	-0.2	-0.2
Food use	**Bottom 10 items highlighted**														
Developed	-1.4	-3.5	0.1	-2.4	-0.2	-	0.0	-3.7	-3.6	0.0	-3.4	-2.7	-0.6	-1.8	0.0
Developing	0.1	0.1	0.1	0.2	-0.1	-	0.2	0.3	0.4	0.0	0.2	-0.3	-0.2	0.0	0.0
World	-0.4	-1.3	0.1	-1.7	-0.1		0.2	-1.0	-1.1	0.0	-0.4	-1.3	-0.3	-0.2	0.0
Export	**Top 10 items highlighted**														
Developed	1.3	2.6	1.3	2.5	-	-	1.2	6.9	8.4	0.5	1.6	-0.4	-0.3	-0.1	0.8
Developing	-2.9	-3.3	-1.0	-4.9	-	-	-1.7	-11.3	-6.0	0.0	-4.5	0.8	-0.1	0.4	-2.4
World	0.9	-0.9	0.4	1.5	-	-	-0.2	3.7	0.6	0.0	0.2	-0.3	-0.1	0.0	0.3
Import	**Top 10 items highlighted**														
Developed	-2.4	-5.6	-2.0	-0.4	-	-	-0.5	-3.5	-5.8	-0.1	-11.4	-0.5	-0.3	-1.1	-0.7
Developing	2.1	2.4	1.0	3.1	-	-	-0.2	8.3	2.3	0.1	4.0	-0.2	-0.1	0.0	0.6
World	1.0	-0.9	0.4	1.6	-	-	-0.2	3.7	0.6	0.0	0.2	-0.3	-0.1	0.0	0.3
Price	**Bottom 10 items highlighted**														
World	-5.5		-2.3	-2.9	-	-	-1.4		-2.9	-0.6	-3.1	0.2	-0.3	-0.8	-2.0
Atlantic		-1.7						-4.6							
Pacific		-4.4						-5.3							
Other		-1.0						-1.5							

1. Top 10 items are highlighted for production, export and import.

2. Bottom 10 items are highlighted for food use and international price.

Table 23. Scenario 4 results

% change in 2023

Region	Butter	Beef	Coarse grains	Cheese	Fresh dairy products	Milk	Oilseeds	Pigmeat	Poultry meat	Rice	Sheep meat	Skim milk powder	Vegetable oil	Whole milk powder	Wheat
Production	Top 10 items highlighted														
Developed	0.0	0.0	-0.4	-0.1	-	0.0	-0.2	-0.2	0.3	-1.0	-0.1	-0.2	0.2	-0.2	-0.5
Developing	-0.2	-0.3	1.5	-0.1	-	-0.1	1.2	0.5	0.4	1.1	0.3	0.8	0.1	0.1	2.2
World	-0.1	-0.2	0.6	-0.1	-	-0.1	0.7	0.3	0.4	1.0	0.2	-0.1	0.1	0.0	0.8
Food use	Bottom 10 items highlighted														
Developed	0.1	-0.1	0.1	0.0	0.0	-	0.1	0.0	0.3	0.2	-0.1	0.1	0.0	0.1	0.0
Developing	-0.2	-0.2	0.2	-0.1	-0.1	-	0.5	0.4	0.4	0.9	0.3	0.0	0.1	0.0	0.1
World	-0.1	-0.2	0.2	-0.1	-0.1	-	0.5	0.3	0.4	0.8	0.2	0.0	0.1	0.0	0.1
Export	Top 10 items highlighted														
Developed	0.0	0.2	-4.8	-0.1	-	-	-0.9	-0.9	0.9	-3.8	0.1	-0.2	0.0	-0.3	-1.4
Developing	0.5	-0.7	3.7	-0.2	-	-	0.6	1.3	-0.6	1.8	-1.1	1.6	-0.3	-0.4	-0.7
World	0.1	-0.3	-1.4	-0.1	-	-	-0.1	-0.5	0.1	1.3	-0.2	-0.1	-0.3	-0.3	-1.3
Import	Top 10 items highlighted														
Developed	0.5	-0.7	1.7	0.0	-	-	0.8	-0.1	1.6	1.5	0.7	0.2	0.3	0.1	1.2
Developing	-0.1	-0.1	-2.2	-0.2	-	-	-0.3	-0.8	-0.3	1.3	-0.5	-0.1	-0.4	-0.3	-1.9
World	0.1	-0.3	-1.4	-0.1	-	-	-0.1	-0.5	0.1	1.3	-0.2	-0.1	-0.3	-0.3	-1.3
Price	Bottom 10 items highlighted														
World	-1.0	-1.1	-4.4	-1.2	-	-	-3.4	-2.4	-2.6	-9.7	-1.8	-1.3	-1.2	-1.2	-3.7
Atlantic		-1.1						-2.4							
Pacific		-1.7						-2.6							
Other		-1.6						-2.4							

1. Top 10 items are highlighted for production, export and import.

2. Bottom 10 items are highlighted for food use and international price.

Annex D.

Comparison with the CGE modelling framework

As noted in the section summarizing scenarios, the International Policy Department of LEI-Wageningen UR has conducted the scenario analysis on food loss and waste based in the European Union (Rutten et al., 2013). The LEI study applies FAO's loss and waste estimates at the consumer stage to a computable general equilibrium model, MAGNET, to project impacts of reducing food waste in the European Union against a business as usual scenario, for the medium term from 2012 to 2020. The levels of food waste reduction were set to 50% (ambitious), 40% (realistic) and 30% (modest), and the results were analysed with a number of indicators about demand, supply, GDP among others.

The current study with Aglink-Cosimo employs similar methodology to apply FAO's loss and waste estimates in order to project different scenarios in mid-term future, and it is interesting to observe the simulation results based on an exactly same scenario. The intention is to provide with additional reference information to interpret the results generated Aglink-Cosimo, or vice versa.

The scenario adopted from LEI's study is about red-meat consumption, which is described first as A.1. FW_rmt scenario in the report, and which allows direct comparison with Aglink-Cosimo. As the waste percentage of meats in Europe including Russian Federation is 11% in the FAO database, the ambitious scenario assumes to reduce it by 50%, and the red-meat consumption in the European Union in 2020 will be 94.5% of its business-as-usual scenario. Table 24 summarises the two simulation results, where the consumption of beef and sheep meat in the European Union are also shocked in Aglink-Cosimo model by the same percentage to 94.5% in 2023.

Table 24. Comparison of scenario results - 50% reduction of food loss and waste in consumption of red meat in the European Union

Item	Subcategory	OECD study (in 2023)	LEI study (in 2020)
Per capita consumption	Red meat	-4.2	-5.44
Production	Red meat	-2.53	-4.31
Producer price	Beef	-16.04	-0.137
	Cattle		
Consumer price	Beef	-3.44	
	Red meat		-0.058
Exports	Red meat	15.35	
	Red meat products		0.201
Imports	Red meat	-18.43	
	Red meat products		-4.36

Source: Rutten et al. (2013), OECD Secretariat.

Per capita consumption in the LEI study shows almost exact reduction of 5.5% in 2020, and that of OECD shows reduction of 4.2% after the new market equilibrium. The smaller reduction in production than in consumption implies that the reduction in consumption has led more to the decrease of imports and the increase of exports,. It is projected that the consumer and producer prices are both dropping, but with different degrees between the two models by more than ten times, which means that supply response to price in Aglink-Cosimo is rather inelastic than MAGNET. The orientations towards more exports and less imports are common in the two studies, but again the degrees of trade impacts are observed much larger in the OECD study.

Annex E.

Application of FAO estimates of food loss and waste

This section deals with detailed incorporation of FAO estimates of food loss and waste, originally published in 2011 (FAO, 2011, Gustavsson et al., 2013) and subsequently used in a number of studies in this field. The dataset was compiled in an environment characterised by a deficiency of national information on food loss and waste, and acknowledges that room for improvement exists in the estimates. However, the data does permit a global analysis by commodities, regions and stages of the food chain. The proposed methodology to incorporate these estimates in the Aglink-Cosimo model are explained below and how to shock supply and demand.

The loss and waste estimates are categorised into five stages of food chain: 1) Agricultural Production, 2) Postharvest handling and storage, 3) Processing and packaging, 4) Distribution (Supermarket, Retail) and 5) Consumption. The aggregation of estimates across these stages is not straightforward or as simple to just sum up. To see this let us call these loss and waste coefficients *r1*, *r2*, *r3*, *r4* and *r5* respectively. In the stage of agricultural production, the loss coefficient (*r1*) is given as the rate of loss against "potential production" and not the quantity produced (or supplied) usually reported in the food balance sheets. In order to calculate backward the potential production, it is required to apply the formula 1/(1-*r1*) to the reported production amount. After the stage of postharvest handling and storage, the amount of loss and waste are calculated simply using the coefficients, but as the stage advances, it is required to apply the coefficient against the amount that removes losses in the preceding stages. Thus for example, the calculation for an aggregated loss coefficient (*R*) throughout the five stages, which can be used together with the reported production amount, is shown below[7]. The changes implied by aggregation to the original coefficients are generally small, but may be significant depending on the region and commodity. In the case of fruit and vegetables in Latin America, a simple addition of the loss and waste coefficients amounts to 72%, whereas the calculation below will result in a slightly lower estimate of 68%.

$$1.\ R = {}^{r1}/_{(1-r1)} + r2 + (1-r2) \times r3$$

$$2.\qquad + (1-r2-(1-r2) \times r3) \times r4$$

$$3.\qquad + (1-r2-(1-r2) \times r3-(1-r2-(1-r2) \times r3) \times r4) \times r5$$

7. In this calculation it is assumed that the amount produced is the amount consumed, or food available for human consumption.

In our analysis, *r1* and *r2* are aggregated (*R'*) and used to shift the supply functions, and *r3, r4* and *r5* are aggregated (*R''*) and used to shift the demand functions assuming that the data of quantity consumed in the model does not take into account the loss at include the postharvest handling and storage stage.

$$4.R' = {}^{r1}/_{(1-r1)} + r2$$

$$5.R" = r3 + (1-r3) \times r4 + (1-r3-(1-r3) \times r4) \times r5$$

Table 25 shows aggregated loss and waste coefficients corresponding to Table 1 for Europe including Russian Federation. The table includes the one fifth of these figures, in order to give idea on how much demand or supply will be shifted in 2023 according to the 20% reduction scenario.

Table 25. Estimated/assumed loss and waste percentages for each commodity groups in each step of the food supply chain for Europe including Russian Federation

	Aggregated loss/waste in supply side *R'*	*R'* * 20%	Aggregated loss/waste in demand side *R''*	*R''* * 20%
Cereals	6.0%	1.2%	30%	6.1%
Roots and tubers	34%	6.8%	34%	6.9%
Oilseeds and pulses	12%	2.4%	10%	1.9%
Fruit and vegetables	30%	6.0%	29%	5.7%
Meat	3.9%	0.8%	19%	3.8%
Fish and seafood	11%	2.2%	24%	4.8%
Dairy product	4.1%	0.8%	8.6%	1.7%

Note: 5% is applied for processing and packaging stage of cereals, by taking rough average of 0.5% and 10% which appear in FAO database.

Source: FAO (2011).

While it would be desirable to analyse food loss and waste at each of the five stages of the food chain, the more aggregated commodity representation of the Aglink-Cosimo model does not permit us to advance in this direction. The scenario analysis will be more straightforward to interpret when it deals with either commodity demand or supply. In the current analysis, the shocks to supply will apply aggregated loss estimates of 1) agricultural production and 2) postharvest handling and storage, whereas the shocks to demand will apply aggregated loss estimates of 1) processing and packaging, 2) distribution and 3) consumption. This is in line with the FAO methodology to estimate global amount of food loss and waste, where the former is applied to the amount produced and the latter is applied to the amount of food available for human consumption in the food balance sheets.

In estimating the global amount of food loss and waste, FAO applied edible weight conversion factors to all waste figures, rendering the waste corresponding to the edible parts of the food. In the case of our study, the edible weight conversion factors will not be taken into account since interests are on commodities traded in the market which by nature include inedible parts of food products as well.

It should be noted with regard to regional analysis that the loss and waste estimates by the FAO are categorised into seven regions of the world, and the same estimates will be applied to several countries. For example, China, Japan and Korea are grouped as the "Industrialized Asia" region. Currently the FAO is engaged in the activity to disaggregate these estimates into sub-regions (FAO, 2013b), and the OECD Secretariat will seek to incorporate the new

estimates into future analyses. Although the Aglink-Cosimo framework makes possible a scenario analyses on a country basis, it is suitable to set up the scenarios in larger units than countries in view of the regional aggregation of loss and waste estimates.