Assessing the potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction

Prepared for the Global Food Cold Chain Council with Support from Carrier

Document information

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Executive summary

According to the Food and Agriculture Organization of the United Nations (FAO), 30 to 40% of food produced for human consumption is lost before it can even make it to market in the developing world, namely due to spoilage. Such level of inefficiency has serious economic, social and environmental consequences. The carbon footprint alone of food produced and not eaten is estimated to be 3.3 Gtonnes of CO_2 equivalent – in other words, food loss and waste would rank as the third top GHG emitter after USA and China if it were a country.

The development of cold chain technologies is one opportunity to close the gap on food loss and carbon emissions, since spoilage could be avoided if proper refrigeration infrastructure were in place. Understanding that the expansion of cold chains does not come without its own environmental consequences, the Global Food Cold Chain Council with support from Carrier commissioned modelling analysis to answer the question "Is there a net benefit, in terms of greenhouse (GHG) emissions, from expanding the cold chains in the developed world to the developing world?". In all modelling scenarios, the decrease of food loss and waste (FLW) carbon footprint from cold chain expansion clearly outbalances the newly created emissions, by a factor ten approximately.

Methodology

The study was carried out in three steps: first, three prospective scenarios of cold chain expansion were defined, second, the GHG emissions savings through food waste reduction were estimated, and then on a third step, the additional GHG emissions from the additional cold storage and transport were estimated. The difference of the values from step one and two provided a view on the net effect of cold chain expansion in terms of GHG emissions.

The three scenarios assessed represent different hypothetical levels of cold chain development and corresponding reduction in food loss and waste in developing countries. The scenario for the 'highest potential for cold chain development' was based on the current cold chain penetration rates in developed countries, and the current amount of food loss and waste in these countries. Desk-based research were carried out to gather information on the cold chain penetration rates and the food losses due to a lack of cold chains, for each region and for each product category. Whenever information was not available, proxies or assumptions were used. Model input data were complemented with FAO Food Balance Sheets (2011) for estimations of food production as well as food emission factors adapted from the FAO (2013) Food wastage footprint study. In a second step, GHG emission savings through food waste reduction for the three scenarios could be calculated based on these datasets.

As a third step, the average transportation distances for products in different regions, in both refrigerated and non-refrigerated trucks were estimated. This information was based on a literature review, and provides a key point in the study – that distances for perishable foods increase once transported in a cold chain. Emission factors for refrigerated trucks and non-refrigerated trucks, as well as emission factor for refrigerated storage facilities were also estimated. With this information, GHG emissions related to transport and storage of perishable food for the current situation and for the three scenarios could be estimated; and from these estimates, the additional GHG emissions for the three scenarios were determined.

Results

According to the model, the total amount of food wastage in 2011 has generated about 1 Gtonnes of CO_2 equivalent, an amount comparable to the total GHG emissions of road transportation in the EU (0.9 Gt). Moreover, in all prospective scenarios, the decrease of FLW carbon footprint from cold chain expansion clearly outbalances the newly created emissions, by a factor ten approximately.

In scenario 1, which considers a limited cold chain expansion in developing countries (i.e. 1/3 of the current penetration rate of developed countries), the net GHG 'savings' would represent circa 180 Mtonnes of CO_2 eq. In scenario 3, which considers that cold chains have reached their full potential in developing countries, the net 'savings' would represent circa 550 Mtonnes of CO_2 eq. As an illustration of the magnitude of these results, they can be compared to the total emissions of France – i.e. circa 450 Mtonnes of CO_2 eq. in 2012.

The simplified model includes the key aspects of the development of cold chain transportation of perishable food – i.e. the increased of transport distances, the increased emission factors for refrigerated trucks (including refrigerant leakage), the reduction of food waste and related GHG emissions savings. The model does not consider potential increased GHG emissions from rebound effects, such as the possible evolution of consumer behaviour, the additional infrastructures (roads, buildings, etc.) needed for the development of cold chains, or potential increase of exportation.

Content

1. Introduction

1.1 Context

A significant share of food grown is ultimately not eaten, especially in developing countries. According to the Food and Agriculture Organization of the United Nations (FAO) **30 to 40% of food produced for human consumption is lost before it can even make it to market** in the developing world, namely due to spoilage[1].

Such level of inefficiency has serious economic, social and environmental consequences. In monetary terms, the most recent global food loss estimate is a staggering $1 trillion in retail value, or about twice the gross domestic product of Norway [2], equivalent to the Gross Domestic Product of Switzerland. Further, such loss aggravates food insecurity and malnutrition in a context of growing population and increasing food demand[3]. And finally, this food wastage represents a missed opportunity to mitigate environmental impacts and use of resources from food chains. The carbon footprint of food produced and not eaten is estimated to be 3.3 Gtonnes of CO_2 equivalent: food loss and waste would rank as the third top GHG emitter after USA and China if it were a country. This amount is more than twice the total GHG emissions of all USA road transportation in 2010.[4]

As such, the development of cold chains has been increasingly discussed as an opportunity to close the gap on FLW and carbon emissions especially in developing world, highlighting the social and environmental benefits of doing so[5,6]. Ensuring adequate storage and transportation systems for perishable food reduces food loss, price variability of food, and more importantly in our context, **reduces wasted GHG emissions.**

However, cold chain development places a burden on the environment since refrigeration is energy-intensive and is a source of greenhouse gases. Keeping products cold throughout the mobile portion of the cold chain (such as trucks, trains and ships) account for 7% of global hydrofluorocarbons (HFC) consumption. This contributes to 4% of the total global warming impact of moving all freight (refrigerated or not).[7] Furthermore, diesel-powered transportation refrigeration units consume up to 21% more than a non-refrigerated diesel powered truck,[8] which has significant implications on climate change as the development of cold chains becomes more ubiquitous in developing countries.

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[1] FAO Cutting Food Waste to Feed the World, 2011.

[2] This figure is based on producer prices of agricultural commodities only and does not take into account fish and seafood.

[3] Global food production by 2050 will need to be 60% higher than in 2005/2007 to meet the increasing world population's demand. Source: Alexandratos, N. & Bruinsma, J. 2012. World Agriculture Towards 2030/2050: the 2012 Revision. ESA Working paper N°.12-03 FAO, Rome.

[4] FAO, 2014. Food Wastage Footprint – Full-cost accounting – Final report. Available at: http://www.fao.org/3/a-i3991e.pdf.

[5] Intergovernmental Organization for the Development of Refrigeration, 2009. *The Role of Refrigeration in Worldwide Nutrition*, 5th informatory Note on Refrigeration and Food

[6] Institution of Mechanical Engineers, 2014. A Tank of Cold: Cleantech Leapfrog to a More Secure World

[7] Greenbiz, October 18 2013. How Coke, UTC are cooling the cold chain's climate impact

[8] ADEME (French Agency) 2012, 'Comité de gouvernance de la base d'impacts ACV pour l'afficahge' presentation, Slide 20

The Global Food Cold Chain Council with support from Carrier commissioned modelling analysis to better understand the greenhouse gas impact of expanding the cold chain to reduce food waste in developing countries.

1.2 Objectives

The present study provides an assessment of the potential of cold chains expansion to reduce GHG emissions from food waste in developing countries as compared to the additional GHG emissions from these new cold chains.

The objective of the study is to establish the relationship between:

- Development of cold chains in emerging economies
- Reduction of food loss and waste carbon footprint through food waste reduction, balanced against additional emissions from increased energy consumption and use of refrigerants.

Ultimately, the goal is to answer the question "Is there a net benefit, in terms of GHG emissions, from expanding the cold chains in the developed world to the developing world?".

An approach that aligned with the timeline (July - August 2015) and the objectives of the study was followed, as further detailed in the Scope and Methodology sections hereafter.

1.3 Scope

This section details what was used to quantify the project. Considering the aim of the study, the scope was limited to perishable fresh food[9] and developing regions of the world[10]. The data collection was therefore limited to:

- 5 perishable fresh food commodities corresponding to 13 product groups
- 5 developing regions corresponding to 14 sub regions

The figure below graphically represents the scope of the project.

[9] Perishable food in this study includes product groups that are likely to spoil or decay quickly without temperature control, therefore excludes cereals, starchy roots, oilcrops and pulses.

[10] For the country classifications by world regions and sub-regions see: http://faostat.fao.org/site/371/default.aspx

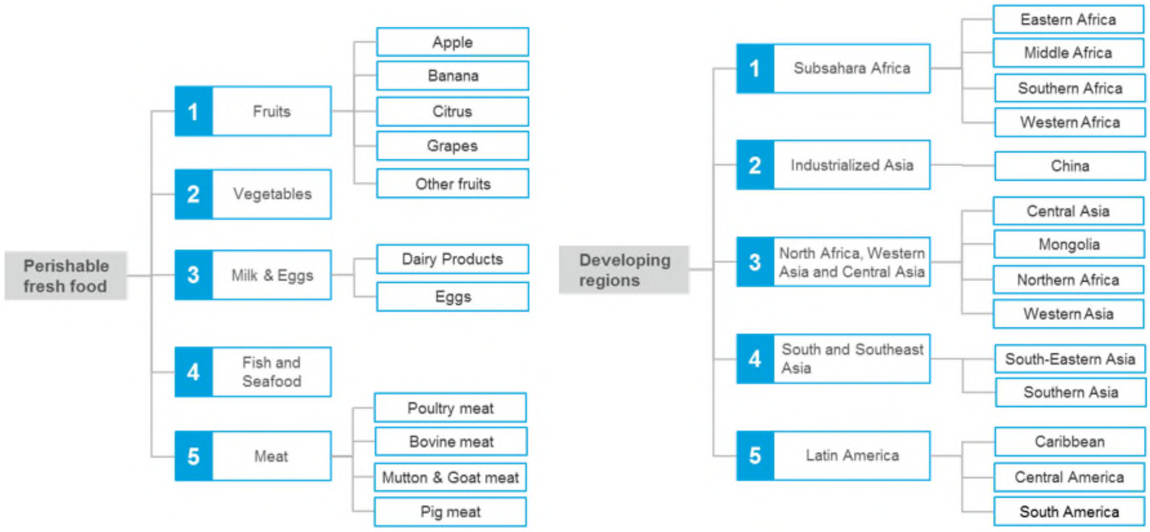

Figure 1 – Scope of the data collection

<u>Remark on vocabulary:</u>

About food loss & waste

The Food Loss & Waste Protocol[11] uses the phrase "food loss and waste" and the abbreviation 'FLW' as shorthand to refer to "food as well as associated inedible parts removed from the food supply chain." Therefore, the protocol does not make a distinction between 'loss' on one hand and 'waste' on the other hand. In the context of FLW quantification, both are considered.

On the one hand, in the scientific literature focusing on food loss and waste issues (e.g. FAO studies)[11], the term 'losses' generally refers to food being discarded (most of the time, involuntarily) because of inefficiencies in the food supply chain such as poor infrastructure and logistics, lack of technology, insufficient skills, knowledge and management capacity of supply chain actors, poor access to market, etc. This is usually the case in developing countries. On the other hand, the same literature generally defines food 'waste' as food appropriate for human consumption not being eaten, usually at the consumer level, an issue largely relating to behavioural aspects rather than inefficiencies in the food supply chain. However, food waste is not sharply defined, and is considered as a distinctive part of food loss[12]. Therefore, for this study, the team uses the inclusive terminology of 'food loss and waste'.

About GHG savings

In the following sections, **gross GHG 'savings'** refer to the decrease of GHG emissions due to the reduction of food loss and waste, whereas **net GHG 'savings'** is the sum of the gross GHG 'savings' and additional GHG emissions due to transport and storage.

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[11] FLW Protocol, 2015. FLW Protocol Accounting and Reporting Standard (FLW Standard) – DRAFT as of March 20, 2015 http://www.wri.org/our-work/project/global-food-loss-and-waste-measurement-protocol/documents-and-updates#project-tabs

[12] Definitional Framework of Food Loss Working Paper, FAO 2014

2. Description of methodology and data

The objective of this study is to estimate the potential GHG emissions savings from the reduction of food loss and waste through the development of cold chains in developing countries. The calculation was divided in three parts:

1. Definition of the baseline scenario and the three prospective scenarios;
2. Estimation of the gross GHG emissions 'savings' from food waste reduction;
3. Estimation of the additional GHG emissions from transport and storage.

2.1 Definition of the baseline scenario and the three prospective scenarios

2.1.1 Methodology used to define the scenarios

The definition of the scenarios is based on two sets of information (see Figure 2 below):

- The average rates (in percent of the total production) of perishable food lost/wasted due to the lack and/or inefficiency of cold chains, in developing countries and developed countries;
- The difference between the current average penetration rates of cold chains in developed and developing countries.

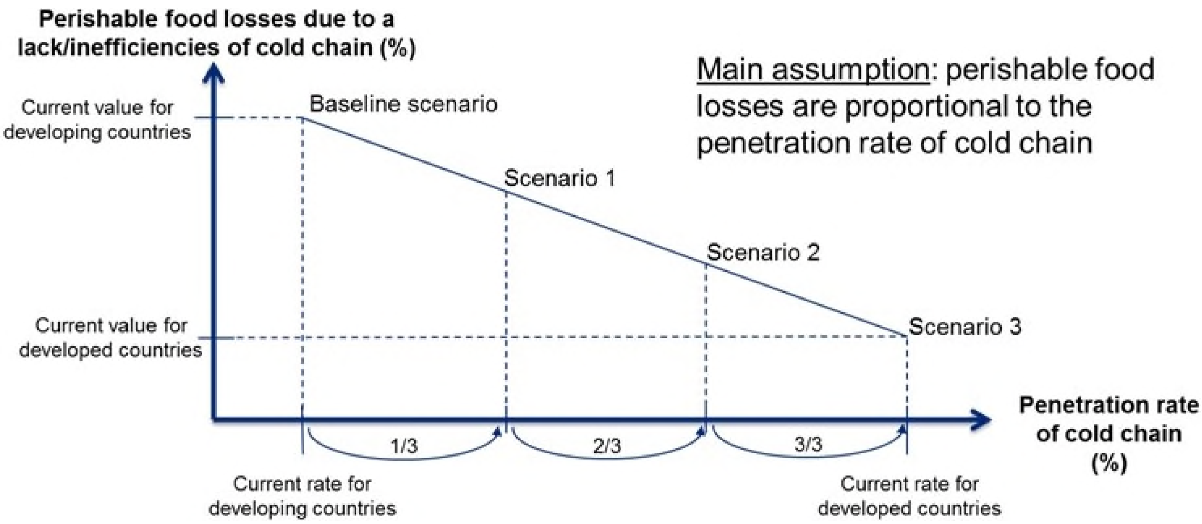

Figure 2 – Graphical representation of the prospective scenarios[13]

Baseline scenario – the current situation

The 'Baseline scenario' represents the current situation of market penetration rates *and* percentage of food losses due to a lack of cold chain in the developing world. The values are based on literature and statistics reviews, complemented with proxies and assumptions where information was unavailable.

[13] Note: our primary assumption is that the relationship between cold chain development and perishable food losses is a *negative proportional linear relationship* in that 1/3 development of cold chain has a 1/3 decrease in food loss.

Scenario 3 – the highest potential of cold chain development

Scenario 3 illustrates a hypothetical situation where cold chains in developing countries reach their highest potential of cold chain penetration, and the lowest level of food loss due to lack of cold chains. The team defined the 'highest potential for penetration' as the penetration rates currently found in developed countries[14] so as not to overestimate the potential for cold chain development in developing countries.

Scenarios 1 and 2 – small and moderate development of the cold chain

Scenarios 1 and 2 (see Figure 2 above) illustrate a situation where the gap between the Baseline scenario and scenario 3 is reduced by 1/3 (scenario 1) and by 2/3 (scenario 2).

2.1.2 Data for perishable food and penetration rates

In order to collect and collate information on cold chain penetration rates as well as representative rates of food loss/waste attributable to the lack/inefficiencies of cold chains, the team assembled a desk-based research team dedicated to finding such information. Where information was not available, the team used proxies or assumptions based on internal discussions.

Data on perishable food losses due to inefficient cold chain

As a first rough estimate, the team used the global average of food losses for developed and developing countries (Table 1). Then, whenever available, the team looked for specific data by country and by product category, through a more in-depth literature review.

Global data on perishable food losses

The International Institute of Refrigeration (IIR) estimated that about one quarter of food production is lost due to a lack of or an incomplete cold chain in developing countries on average. In developed countries this number is about 9%.

Table 1 – Losses of perishable foods through lack of cold chain from IIR

	Global	Developed Countries	Developing Countries
Losses of perishable foodstuffs through a lack of refrigeration (% out of total production)	20%	9%	23%

Source: *International Institute of Refrigeration, 2009. The Role of Refrigeration in Worldwide Nutrition*

Specific data by country and by product category for perishable food losses

An extensive literature review was conducted to find data on food losses due to the lack of cold chain for each of the 14 sub-regions and each of the 12 product groups.

The team found that when the literature addressed the causes of food loss/waste, the lack of sufficient cold chain infrastructure was often identified as a 'major contributor' of FLW. However, relevant studies were scarce and quantitative data even less frequent. Therefore, whenever possible, the team made proxies based on qualitative information.

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[14] Developed countries used in this study are the following: Europe, Australia, Canada, New Zealand, USA, Japan and South Korea.

For example, for Near East and North Africa (NENA):

> "The lack of sufficient and efficient cold chain infrastructure is a **major contributor** to food losses and waste in NENA, estimated to be 55% of fruits and vegetables, 22% of meats, 30% of fish and seafood, and 20% of dairy" – FAO, 2011

Therefore, the team used these figures to estimate the losses of foods through a lack of cold chain, but applied a ratio of 80% -- the team interpreted 'major contributor' as meaning about 80% of food losses could be attributed to the lack of a cold chain, with 20% being for other reasons. Due to the lack of data, the team used proxies:

- for some regions: for example, the team used China's values for the region of South East Asia, given the geographical and developmental similarities;
- for some product groups: fruits and vegetables were commonly grouped in the literature and so we often used the same figures for both.

When no specific figures were found and proxies were irrelevant, the team resorted to the global IIR figures of 23% for developing countries (See the Annexes for more information).

Country example –China

Table 2 below illustrates China's values used for the three food loss reduction scenarios.

- The Baseline Situation in China of food loss due to a lack of cold chain, whereby 25% of fruits and vegetables, 10% of meats, 11% of fish and seafood and 28% of fish and eggs, comes from the literature review undertaken by the research team.
- Scenario 3 used the IIR data that estimates about 9% of food is lost due to inefficiencies in cold chains in the developed world.
- From there, the team calculated scenarios 1 and 2, where there is a one third and two third decrease in food losses, respectively, compared to the difference between the baseline scenario and scenario 3.

See the Annexes for the full list of sources.

Table 2 – China's Food Loss Reduction (%) scenarios

Scenarios	Fruits and Vegetables	Meats, other	Fish & Seafood	Milk and Egg
Baseline scenario	25	12	15	28
Scenario 1	20	11	13	22
Scenario 2	14	10	11	15
Scenario 3 (similar to developed countries)	9	9	9	9

Data on penetration rates of cold chains

Unlike the rate of food loss/waste, the team did not have global data on the current penetration rates of cold chains in developed and developing countries. Therefore, the team searched for penetration rates per country/region by product category. Detailed values are presented in Table 10 in Annex. When information was not available, the team used proxies and calculations. For this reason, some regions and product groups are consolidated. For example, the team found information for Peru, Argentina and Bolivia, therefore using this information as a proxy for the entire region of Latin America (including South, Central America and the Caribbean).

Country example –China

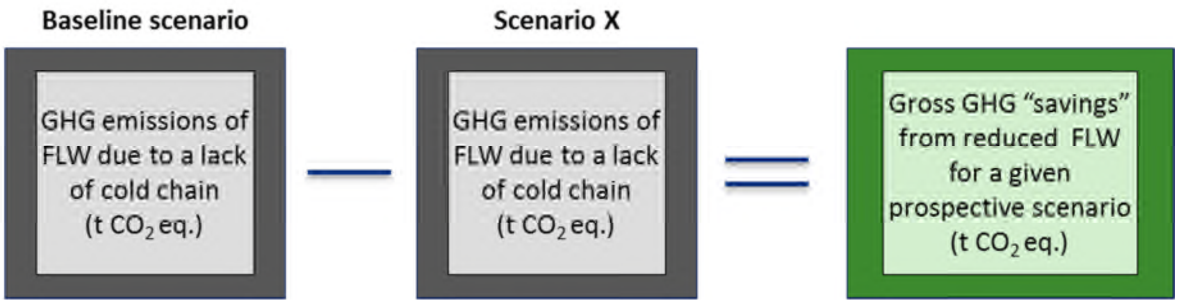
Table 3 illustrates China's cold chain penetration rates (%) per food category and for each scenario. Currently, China's cold chain penetration rate is very low, with only about 5% of fruits/vegetables and a quarter of seafood being transported through a cold chain. Meanwhile, for almost all fresh food product categories in developed countries, penetration rates range between 95 and 100%. The penetration rate also depends on consumer behaviour. For instance in Europe, about half the population prefers UHT milk, therefore the cold chain penetration for milk is about 50%; meanwhile Europe's egg production does not use a cold chain whereas the United States does. Taking into account these differences of consumer behaviour per regions, the team set the rate at 75% for scenario 3 for eggs and milk.

Table 3 China's cold chain penetration rates (%) per food category and for each scenario

	Fruits and Vegetables	Pig Meat	Meats, other	Fish & Seafood	Milk	Egg
Baseline scenario	5	10	15	23	13	13
Scenario 1	30	30	30	30	30	30
Scenario 2	60	60	60	60	41	41
Scenario 3 (similar to developed countries)	95	100	100	100	75	75

2.2 Estimation of gross GHG emissions 'savings' from food waste reduction

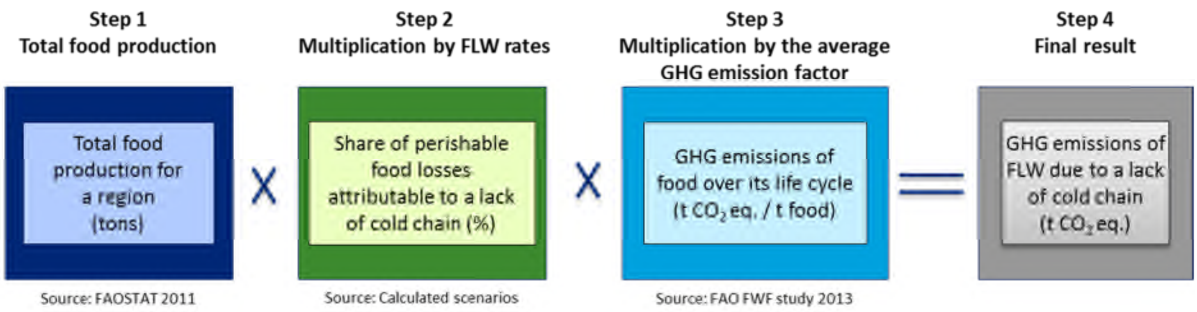
The gross GHG 'savings' from FLW for a given prospective scenario is the difference between the GHG emissions of the baseline scenario and the GHG emissions of the prospective scenario (see Equation 1).



Equation 1 – Estimation of gross GHG emissions 'savings' from reduced food loss and waste for a scenario

Before being able to calculate the gross GHG 'savings', the team first had to estimate the GHG emissions of FLW due to the lack of cold chain for individual scenarios. This calculation was done for each product group and each region studied, then these GHG emissions were added to get the total GHG emissions for individual scenarios.

The methodology used to estimate the GHG emissions of FWL for each product group and each region is presented in Equation 2.



Equation 2 – Calculation for the GHG emissions of food waste and loss due to a lack of cold chain for a specific product group in a specific region

In order to perform this calculation, the team used three sets of information:

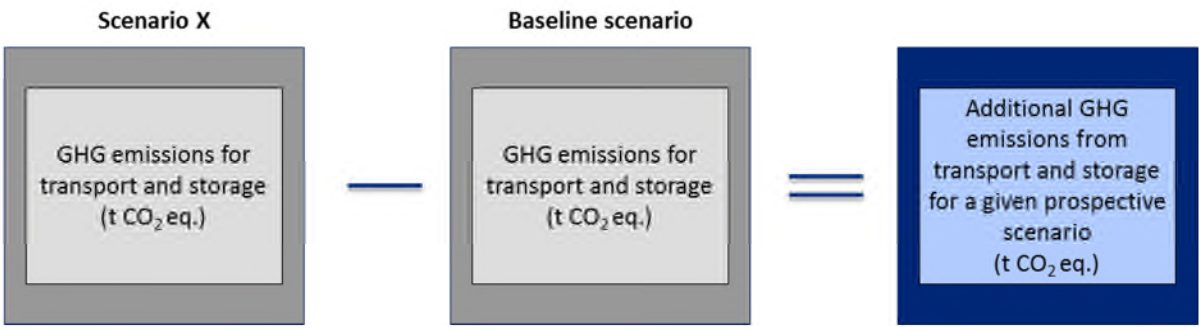
- Total food production (see Table 6 in Annex)
- Share of perishable food losses and waste attributed to a lack of cold chain
- GHG emissions of wasted food over its lifecycle : specific average values for each region and each product category (see Table 7 in Annex)

The values used in step 1 were extracted from FAOSTAT 2011 Food Balance Sheets database (most recent year available). Values used in step 2 come from the calculated scenarios of perishable food losses (see Table 2 for an example). Values used in step 3 were adapted from the dataset used in the model of the FAO Food Wastage Footprint study[4].

By multiplying values from steps 1, 2 and 3, the GHG emissions of FLW due to a lack of cold chain for a specific product group in a specific region are obtained. The total GHG emissions of FLW for a scenario are the sum of GHG emissions for all product groups and all regions.

2.3 Estimation of additional GHG emissions from transport and storage

The additional GHG emissions from transport and storage are defined as the difference between GHG emissions from transport and storage for a prospective scenario and GHG emissions from transport and storage for the baseline scenario. The equation below shows this calculation.



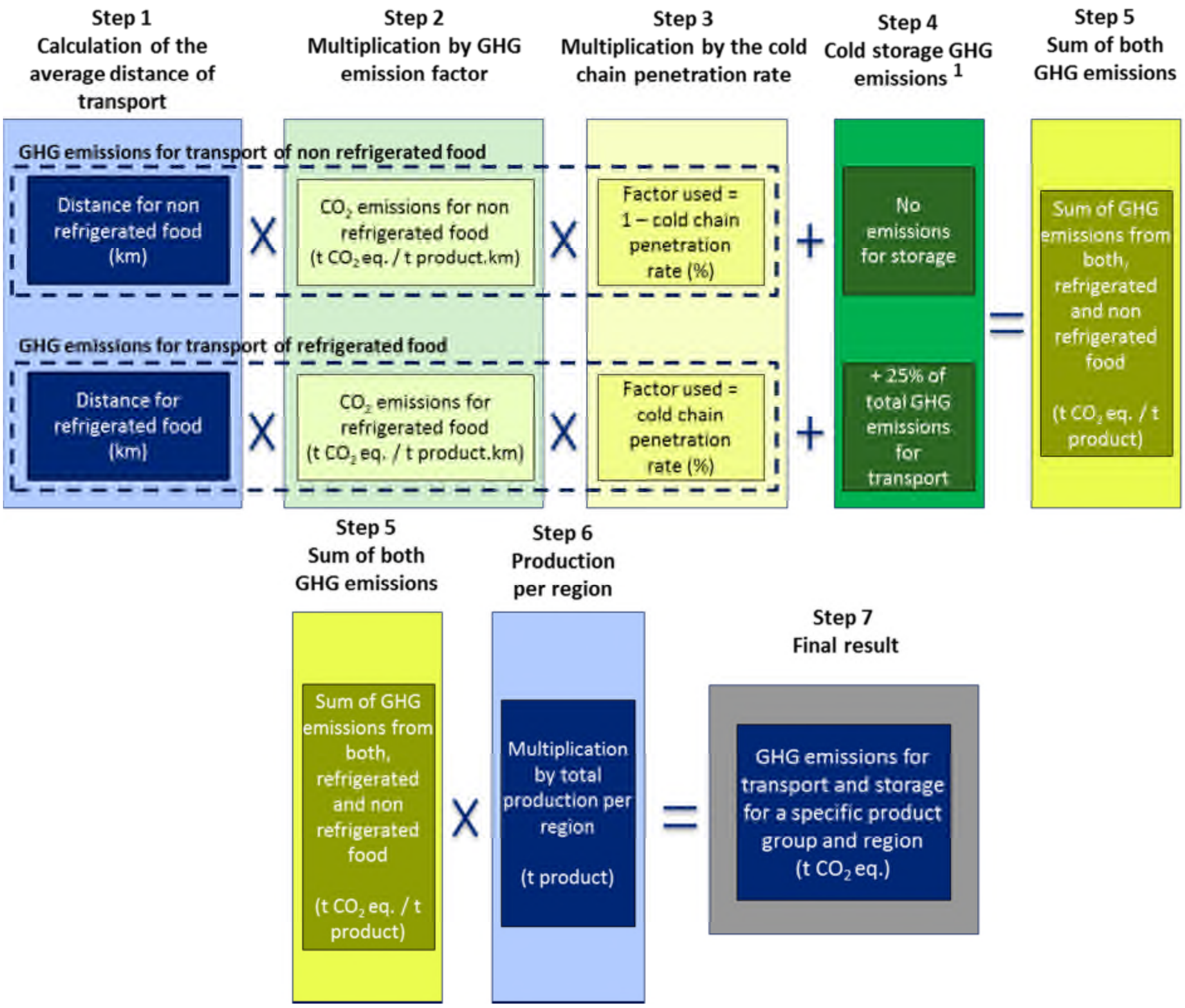
Equation 3 – Estimation of additional GHG emissions from transport and storage for a scenario

Before being able to perform this calculation, the team first had to estimate the GHG emissions in transport and storage for individual scenarios (see Equation 4).

2.3.1 General methodology for a given scenario

For each product category and each region, GHG emissions due to transport and storage were estimated using five pieces of information (see Equation 4):

- Average distance of transport (in km) for refrigerated and non-refrigerated goods (Step 1)
- GHG emission factors (in tons of CO_2 eq. per ton.km of products) for refrigerated and non-refrigerated goods (Step 2)
- Cold chain penetration rates (in %) (Step 3)
- Cold storage GHG emissions (tons of CO_2 eq.) (Step 4)
- Total production in the region (tons of food) (Step 6)



Equation 4 – Estimation of GHG emissions in transport and storage for a specific product category and region

There is only one variable in this equation which changes for each scenario – i.e. step 3: the cold chain penetration rate (see Table 3 for an example).

At step 5, GHG emissions from refrigerated and non-refrigerated food for a specific product category is summed up. During step 6, the result of step 5 is multiplied by the total production of the specific product to get the GHG emissions from transport and storage for a specific developing region. The team carried out this calculation for each food category in each region.

The total GHG emissions for a scenario is the sum of GHG emissions for all food categories in all regions.

In the following sections, the approaches used in steps 1, 2 and 4 are presented. Data used in step 3 are presented in Section 2.1.2, and data used in step 6 were extracted from the 2011 Food Balance Sheet available in the FAOSTAT database.

2.3.2 Step 1: Transport distances

Distinct average transport distances were calculated for refrigerated and non-refrigerated food because cold chain enables to transport food products further and access new markets. However, in both cases, in order to simplify the model, it was considered that all transports were done by trucks (i.e. refrigerated or conventional trucks, respectively).

Considering the lack of available data on average transport distances per food product category and per region, these data were estimated based on the best information available and using the following methodology:

- A maximum distance and/or time of travel for each food product was estimated
- In order to determine average transport distances, the maximum travel distance was then weighted according to the urbanisation rate and coastal population of the region. This takes into account the heterogeneity and development of regions by making the assumption that urban areas need to be supplied by the countryside and therefore have higher transport distances, whereas rural areas consume mainly local products and therefore have lower transport distances. As a simplification, the maximum transport distance for urban areas and 0 transport distance for rural areas were used in the calculation, knowing that the reality is in-between for both cases. For the average transport distance of fish and seafood products, the urban rate was replaced in the calculation by the percentage of population living on the coastal area.
- The calculated average transport distances were then compared with the few data available in order to adjust certain values when necessary.

Table 13 in Annex presents the average distances travelled with and without cold chains for the different region and product groups.

2.3.3 Step 2: GHG emission factors for refrigerated and non-refrigerated transport

For non-refrigerated food, considering the variety of means of transportation used in developed countries, is was not possible to use specific GHG emission factors for each of them. Therefore, a unique GHG emission factor was used, representative of a lorry with 16 tonnes of load. The emission factor for this transport is **1.03 kg CO_2 eq. / km**[15].

For the calculation of refrigerated food, a new emission factor was calculated based on the average lorry of 16 tonnes, the additional emissions due to overconsumption of diesel (for the refrigeration system) is considered to an additional 21% compared to non-refrigerated goods, based on available information[16]. The additional GHG emissions due to refrigerants production and leakage[17] were also

[15] Data from EcoInvent database v2.2

[16] ADEME (French Environnent and Energy Agency), 2012. Présentation au Comité de gouvernance de la base d'impacts ACV pour l'affichage (slide 20)

taken into consideration. The refrigerant used for calculation was R404A, with an average leakage of 14% a year. The calculated emission factor for refrigerated transport was therefore: **1.29 kg CO_2 eq. / km**.

Table 4 – GHG emission factors between refrigerated and non-refrigerated transport vehicles

Non Refrigerated food GHG emission factor	Refrigerated food GHG emission factor
1.03 kg CO_2 eq. / km (0.068 kg CO_2 eq. / t.km)	1.29 kg CO_2 eq. / km (0.0856 kg CO_2 eq. / t.km)
(kg of CO_2 equivalent for 1 tonne transported on 1 km)	

2.3.4 Step 4: GHG emissions related to storage within cold chains

In order to accurately account for the increase in GHG emissions from the development of cold chains, not only 'mobile' aspects of the cold chain (the refrigerated lorries, etc.) must be considered, but also the refrigerated storage systems along the chain. It is assumed that there are no GHG emissions due to storage in case of non-refrigerated food chain. Moreover, due to the lack of information, the energy consumed by pre-cooling equipment in packhouse facilities was not taken into account.

According to a study carried out by the Food Refrigeration and Process Engineering Research Centre[18], the total energy consumed by UK cold storage for refrigeration represents 19% of the total energy used in refrigerated transport for UK[19]. To estimate the GHG emissions related to each activity GHG emission factors (EF) for electricity and diesel from the BioGrace project were used[20]. These EF were chosen because they represent an average situation for the whole Europe. Using these figures the calculated emissions related to energy used for cold storage represent about 27% of the emissions related to the energy used for refrigerated transport. For simplicity, the team rounded down to 25%. This ratio enabled the team to use the calculated emission factor for refrigerated transport (see paragraph above) as a basis for the emissions related to storage within cold chains. Therefore:

$$Refrigerated\ vehicle\ emissions\ factor \times Ratio\ of\ storage\ to\ vehicle\ emissions = Storage\ emissions$$

$$(0.0856\ kg\ CO2eq/t.km \times 25\% = 0.022\ kg\ CO2eq/t.km)$$

2.3.5 Total emission factors due to transport and storage (sum of steps 4 and 2)

Once the team had the values for the emission factor for refrigerated transport and the emission factor for refrigerated storage, the team summed the two values to obtain the final emission factor for cold chain *and* storage facilities, as shown in Table 5.

Table 5 – GHG emission factors (in kg CO2eq/t.km) for non-refrigerated and refrigerated transportation

[17] Data from MINES PARISTECH, 2009. "Inventory of emissions from refrigerants"

[18] Food Refrigeration and Process Engineering Research Centre (FRPERC), 2008. Energy use in food refrigeration - Calculations, assumptions and data sources.

[19] Energy use in cold storage = 900 GWh/year and energy use in refrigerated transport = 4822 GWh/year.

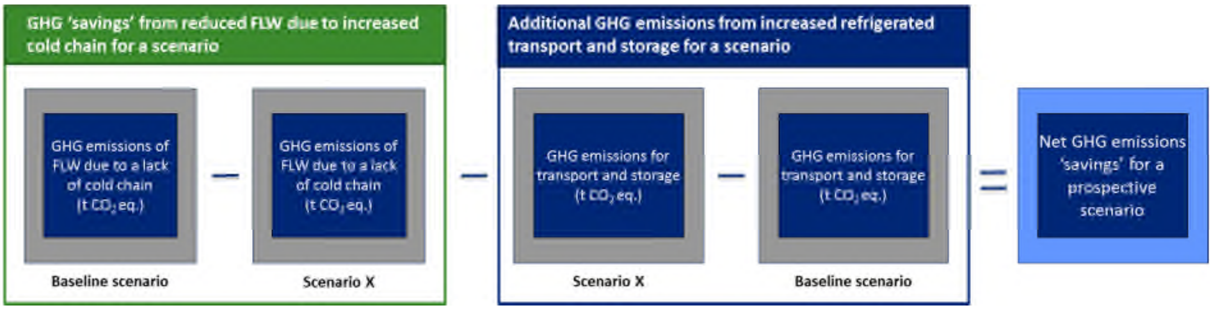
[20] Diesel = 87,638 gCO2-eq/MJ; Electricity European mix (medium voltage) = 127,65 gCO2-eq/MJ. Source : BioGrace project (www.biograce.net)

	Transport	Storage	Total Emission Factors
Emission Factors WITHOUT cold chains	0,068	0	0.068
Emission factors WITH cold chains	0.086	0.214	0.107

2.4 Calculation of the net GHG emissions 'savings' for a scenario

In order to calculate the net effect that the development of cold chains would have on GHG emissions, the team subtracted the additional emissions from cold chain development from the Total GHG 'Savings' through food waste.

Equation 5 – Calculation of total net effect of increased cold chain development on GHG emissions



(Section 2.2 of report) (Section 2.3 of report)

2.5 Discussion on the model

A simple but inclusive model was used for the project. The team used relevant data when available, but otherwise used proxies and assumptions. The team incorporated urbanisation rates and proximity to coastlines when estimating maximum transport time for food, and used assumptions to include refrigerant leakage in addition to diesel consumption to estimate emission factors. The team also included the additional storage emissions in the model.

Nonetheless, the model comes with some limitations. Notably, the model does not consider the possible rebound effects of cold chain development. The development of cold chains may have an effect on consumption patterns – for example, as a result of the easier market access of goods, there may be an increased supply and demand of CO_2 intensive foods, such as red meat. Increased development and urbanization veritably improve infrastructure, including as cold chains, permitting trade and transport of perishable goods[21]. As perishable goods become more available, and more affordable, the demand for livestock products increase. However, our model assumes that consumption and production habits do not change and therefore does not consider the increased emissions from this change. Furthermore, we did not consider the building of infrastructure that would be needed for the development of cold chains (i.e. the construction of storage spaces, refrigerated trucks, etc.) which also has a considerable initial impact on CO_2 emissions.

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[21] World Health Organization, Availability and Changes in consumption of animal products, http://www.who.int/nutrition/topics/3_foodconsumption/en/index4.html

3. Results from the model

Based on the methodology presented in previous chapters, Figures 3 presents the order of magnitude of the carbon footprint of FLW for perishable food in developing countries as compared to 1) the decrease of FLW carbon footprint and 2) the increase of emissions which are both attributable to cold chains expansion, for each of the three prospective scenarios.

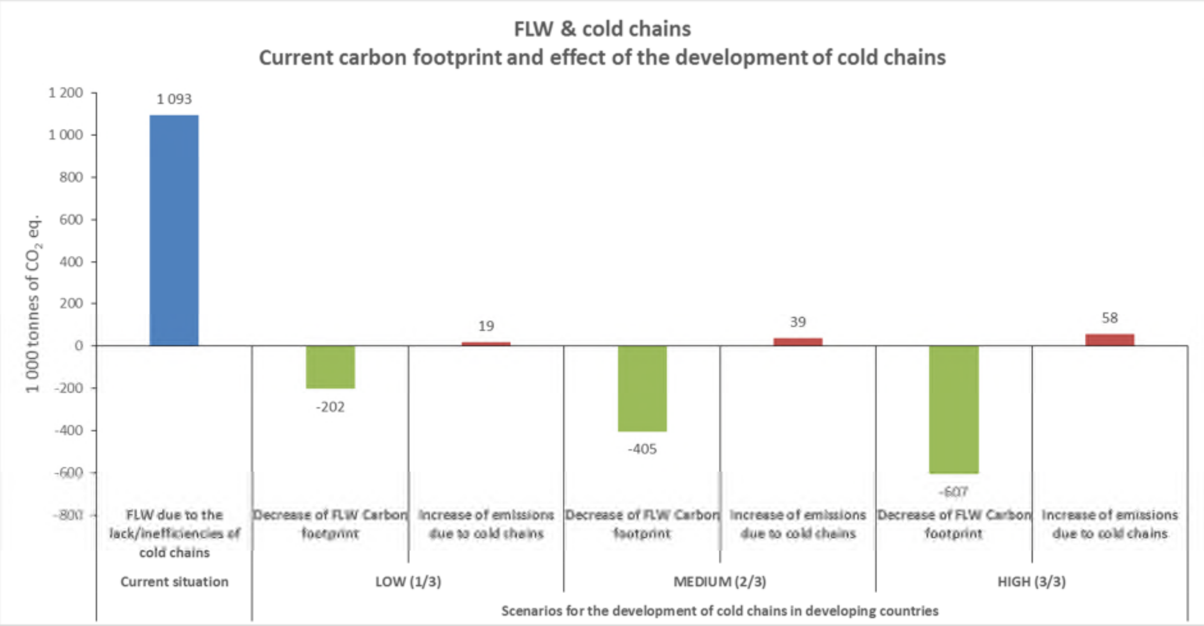

Figure 3 – Current carbon footprint of FLW and effect of the development of cold chains

Figure 3 shows that the total amount of food wastage due to the lack/inefficiencies of cold chains has generated in 2011 about 1 Gtonnes of CO_2 equivalent. In order to perceive the scale of "1 Gtonnes of CO_2 eq.", it can be pointed out that in 2012, the total GHG emissions of road transportation in the US accounted for circa 1.5 Gtonnes of CO_2 eq. (and 0.9 in the EU)[22]. Moreover, according to the model used, in all prospective scenarios, the decrease of FLW carbon footprint from cold chain expansion clearly outbalances the newly created emissions, by a factor 10 approximately.

Figure 4 presents the net GHG 'savings' (i.e. difference between green and red bars of figure 3) for the three prospective scenarios. In scenario 1, which considers a limited cold chain expansion in developing countries (i.e. 1/3 of the current penetration rate of developed countries), the net GHG 'savings' would represent circa 180 Mtonnes of CO_2 eq. In scenario 3, which considers that cold chains have reached their full potential in developing countries, the net 'savings' would represent circa 550 Mtonnes of CO_2 eq. (50% reduction of the carbon footprint of FLW). As an illustration of the magnitude of these results, they can be compared to the total emissions of France – i.e. circa 450 Mtonnes of CO_2 eq. in 2012[23].

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[22] UNFCCC Annual GHG emissions for road transportation in 2012. Available at http://unfccc.int/di/FlexibleQueries.do

[23] European Environment Agency (EEA), June 2014

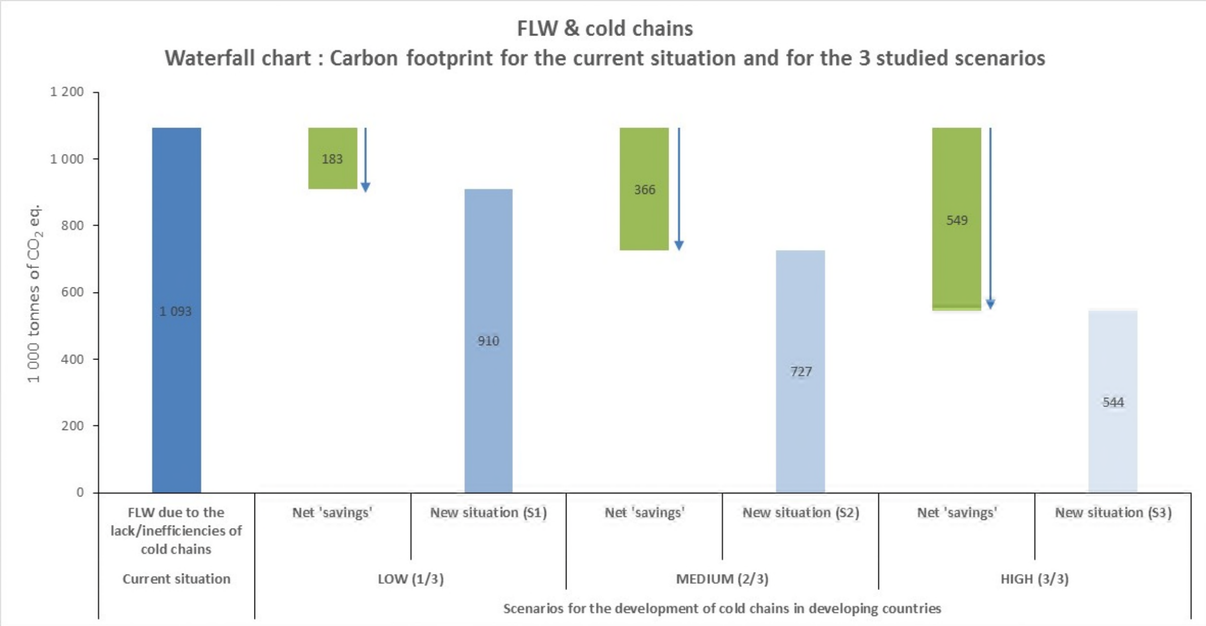

Figure 4 – Current carbon footprint and effect of the development of cold chains 'Waterfall chart' view

Finally, a complementary analysis was conducted in order to identify which world regions/product categories had the greatest contribution to the modelled savings. The results of this analysis are presented in the pie charts below (i.e. breakdown of the green bars in figure 4).

It appears, that China alone contributes to 40% of the savings. In terms of commodities, vegetables and meat play a dominant role. This is mostly because 1) large volumes of vegetables are currently lost/wasted and 2) although the volumes of meat lost/wasted are more limited, this product category typically has a high carbon footprint.

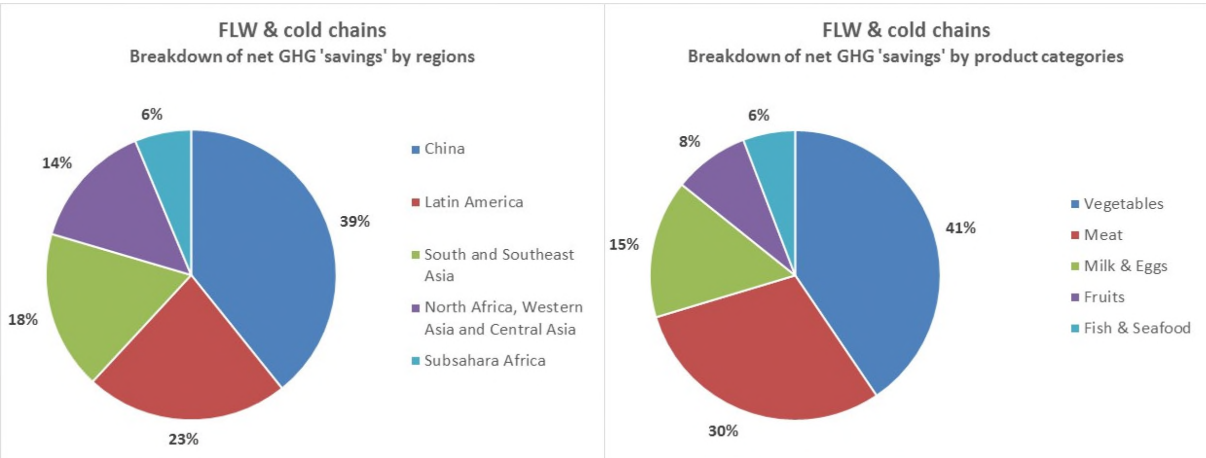

Figure 5 – Breakdown of net GHG savings by regions / product categories

4. Annexes

4.1 Perishable food production

Table 6 – Perishable food production (thousand tons) in 2011

	Apples	Bananas	Citrus	Grapes	Fruits, other	Vegetables	Bovine Meat	Mutton & Goat Meat	Pig Meat	Poultry Meat	Fish & Seafood	Milk	Egg
China	35 987	10 706	29 998	9 174	53 103	564 255	6 491	3 934	49 396	17 800	54 835	41 803	28 476
Eastern Africa	13	20115	992	26	4273	9 865	1748	440	419	517	1 610	12 985	388
Middle Africa		8195	321		1024	4 275	407	126	139	114	619	784	32
Southern Africa	781	390	2415	1706	1031	2 780	939	200	213	1518	999	3 572	523
Northern Africa	1 500	2 019	7 487	2 219	8 214	36 309	1 577	1 104	1	2 000	2 809	19 422	982
Western Africa		9456	5035		6660	16 990	1060	889	369	621	2 612	4 536	896
Central Asia	1 269		11	1 539	1 404	15 964	1 424	497	257	161	70	16 203	491
Mongolia					2	91	54	124	0	0	0	408	0
Western Asia	3 426	685	5 014	5 579	8 208	42 543	1 254	810	97	3 498	1 241	23 378	1 587
South-Eastern Asia		20 289	4 286	93	30 854	35 448	1 820	230	7 368	7 132	26 286	4 552	4 159
Southern Asia	5 438	30 211	12 760	3 904	46 304	143 783	4 917	1 874	384	5 334	12 938	179 360	5 042
Caribbean	2	2 919	761	21	2 439	3 390	223	25	330	508	207	1 420	236
Central America	685	8 680	8 521	298	9 790	15 304	2 298	104	1 376	3 620	2 364	14 518	2 896
South America	4 279	24 118	28 503	8 024	17 094	24 852	14 509	310	5 039	18 467	15 285	66 411	4 575
Total	**53 380**	**137 783**	**106 104**	**32 583**	**190 400**	**915 849**	**38 721**	**10 667**	**65 388**	**61 290**	**121 875**	**389 352**	**50 283**

Source: FAOSTAT – FBS 2011

4.2 Food emission factors

Table 7 – Emission factors over product lifecycle (kg CO_2 eq. / kg food)

	Apples	Bananas	Citrus	Grapes	Fruits, other	Vegetables	Bovine Meat	Mutton & Goat Meat	Pig Meat	Poultry Meat	Fish & Seafood	Milk	Egg
China	0.87	1.26	0.88	1.30	0.94	1.84	24.46	13.95	7.50	6.27	4.95	1.91	6.42
Eastern Africa	0.34	0.30	0.32	0.51	0.36	0.70	26.42	5.89	6.28	5.06	2.01	1.15	6.35
Middle Africa	0.31	0.16	0.17	0.55	0.31	0.71	26.38	5.88	6.21	5.11	1.79	1.15	6.35
Southern Africa	0.73	0.94	0.58	1.08	0.87	1.19	27.04	6.22	6.80	5.41	2.38	1.77	6.56
Western Africa	0.31	0.18	0.27	0.55	0.31	0.72	26.35	5.87	6.16	5.04	1.96	1.15	6.33
Central Asia	0.76	1.27	1.04	1.11	0.97	1.27	23.84	15.57	6.96	6.36	3.41	1.79	6.35
Mongolia	1.14	1.27	1.09	1.54	1.38	1.46	23.71	15.70	5.71	6.36	3.58	1.82	7.25
Northern Africa	0.70	1.20	0.69	0.92	1.00	1.31	23.69	15.37	6.72	6.17	3.54	1.81	6.30
Western Asia	0.70	1.05	0.65	1.13	0.80	1.30	24.02	15.70	7.07	6.49	3.56	1.88	6.38
South-Eastern Asia	1.12	1.04	0.70	1.34	0.72	1.49	23.51	13.53	6.64	5.92	3.90	1.95	6.03
Southern Asia	0.63	0.91	0.61	1.08	0.71	1.45	23.24	13.36	6.36	5.75	4.10	1.76	6.00
Caribbean	1.13	0.72	0.56	1.34	0.82	1.03	30.84	17.23	5.85	5.78	3.10	1.70	6.10
Central America	0.78	0.69	0.57	1.18	0.75	0.95	30.86	17.20	5.96	5.82	2.72	1.63	6.09
South America	0.58	0.76	0.47	1.13	0.78	0.95	30.79	16.91	5.87	5.72	2.56	1.59	6.09

Source: Adapted from FAO, 2013. Food Wastage Footprint – Impacts on natural resources
Note: The emission factors are average for food loss/waste at any point of the supply chain

4.3 Rate of perishable food losses due to the lack and/or inefficiency of cold chain

Table 8 – Losses of perishable food due to the lack and/or inefficiency of cold chain (in % of total production) – Values used in the model

	Fruits and Vegetables	Meat / Egg	Fish and Seafood	Milk
Australia, NZ, Japan, United States , Europe, South Korea	9	9	9	9
China	25	12	15	27.5
Sub-Saharan Africa	36	22	22	21
Northern Africa and Western Asia	44	17.6	24	16
Central Asia and Mongolia	23	23	23	23
South-Eastern Asia	25	12	15	27.5
Southern Asia	18	12	25	17.5
Caribbean	23	23	23	23
Central and South America	10	23	23	23

Table 9 – Losses of perishable food due to a lack of cold chain Sources of values used in the model

Country/Region		Source
China		
Fruits / Vegs	Source use a range for both fruits and vegetables (between 20 and 30%)	Wang, W. et al., 2013. China's food production and Cold Chain Logistics http://ccm.ytally.com/fileadmin/user_upload/downloads/publications_5th_workshop/Wang_paper.pdf
Meat	Used percentages found in source	China's food production and Cold Chain Logistics http://ccm.ytally.com/fileadmin/user_upload/downloads/publications_5th_workshop/Wang_paper.pdf
Seafood	Used percentages found in source	China's food production and Cold Chain Logistics http://ccm.ytally.com/fileadmin/user_upload/downloads/publications_5th_workshop/Wang_paper.pdf
Milk	Source use a range (between 20 and 35%)	Research on Dairy Foods' Cold Chain Logistics Development Based on "Dumbbell" Integration Strategy, 2014 http://maxwellsci.com/print/ajfst/v6-1324-1330.pdf
Southern Asia		
Fruits/ Vegs	"About 18 percent of the country's fruits and vegetables […] go to waste annually because of the lack of cold storage facilities"	Central Institute of Post Harvest Engineering and Technology (CIPHET), Ludhiana "The Food Wastage and Cold Storage Infrastructure Relationship in India"
Meat	Use China's number as a proxy	China's food production and Cold Chain Logistics http://ccm.ytally.com/fileadmin/user_upload/downloads/publications_5th_workshop/Wang_paper.pdf
Seafood	"20-30% of fish spoils through lack of cold" Use India's number as a proxy	University of Birmingham 'The prospects of liquid air cold Chains in India'(2014) http://www.birmingham.ac.uk/Documents/news/The-prospects-for-liquid-air-cold-chains-in-India.pdf

Country/Region		Source
Milk	"Milk losses due to the lack of cold storage are estimated at about 15 to 20 percent of total milk production in some areas". Used Pakistan's number as a proxy	Zia, U., Mahmood, T. & Ali, M. Dairy development in Pakistan. FAO, Rome (2011).
South-Eastern Asia		
All Products	Used China numbers as a proxy	
Sub-Saharan Africa		
Fruits / Vegs	40-50% of production lost primarily due to a lack of cold chain*	FAO, 2014. Développer la chaine du froid dans le secteur agroalimentaire en Afrique subsaharienne' http://www.fao.org/3/a-i3950f.pdf
Meat	25-30% of products originating from animals lost primarily due to a lack of cold chain*	FAO, 2014. Développer la chaine du froid dans le secteur agroalimentaire en Afrique subsaharienne' http://www.fao.org/3/a-i3950f.pdf
Seafood	Used the same information as for meat	FAO, 2014. Développer la chaine du froid dans le secteur agroalimentaire en Afrique subsaharienne' http://www.fao.org/3/a-i3950f.pdf
Milk	Used Tanzania numbers (range of 16-25%) as proxy for dairy loss for the entire region.	Institution of Mechanical Engineers, 2014. A tank of cold: cleantech leapfrog to a more secure world http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0
Northern Africa		
All Products	"The lack of sufficient and efficient cold chain infrastructure is a major contributor to food losses and waste in Near East and North Africa, estimated to be 55% of fruits and vegetables, 22% of meats, 30% of fish and seafood, and 20% of dairy".*	FAO, 2011. Developing the Cold Chain for Agriculture in the Near East and North Africa (NENA)
Western Asia		
All Products	Based on the literature review, the region is considered to be relatively similar to Northern Africa in terms of patterns of production and consumption or technology in place. Therefore the figures for Northern Africa were used for this region.	
South America		
Fruits / Vegs	Used Bolivia as a proxy, the percentage refers to all fruits and vegetables. Percentage based on qualitative info: "Given the condition of the roads and the lack of refrigeration, losses are estimated to be at least 10% based on information collected from market interviews.	World Food Logistics Organization 'Cold Chain Assessmnent: Bolivia, Ecuador and Peru 2014 http://approlog.org/wp-content/uploads/2015/01/Cold-Chain-Assessment-in-Bolivia-Ecuador-and-Peru_FINAL.pdf
Central America		
Fruits / Vegs	Given the similarities of the two regions, South America's figures were applied to the region for fruits and vegetables.	
*Note that a 0.8 corrective factor was applied to assume that other losses are due to other reasons than lack of cold chain.		

4.4 Cold chain penetration rate

Table 10 – Penetration rates for developed and developing countries (%)
Values used in the model

	Fruits and Vegetables	Pig Meat	Meats, other	Fish & Seafood	Milk	Egg
Australia, NZ, Japan, United States , Europe, South Korea	95	100	100	100	Europe: 50 Other: 90-95	Europe: 0 Other: 100
China	5	10	15	23	13	0
Eastern Africa	30	3	3	3	15	0
Middle Africa	0	0	0	0	0	0
Southern Africa	50	50	50	50	50	0
Western Africa	10	5	5	5	20	0
Central Asia	1	15	15	0	0	0
Mongolia	0	15	15	0	3	0
Northern Africa	10	7	7	7	30	0
Western Asia	10	80	80	7	85	0
South-Eastern Asia	32	40	40	32	32	0
Southern Asia	10	4	4	4	20	0
Caribbean, Central and South America	30	25	25	25	45	0

Table 11 – Penetration rates for developed and developing countries
Sources used for values used in the model

Product Group		Source
Developed Countries		
Meats and Vegetables	"The development planning of agricultural cold chain logistics 2012-2015", the cold chain of meat in the developed countries like Europe, America, Canada and Japan have achieved 100% and fruits and vegetables are above 95% ** the team applied the percentage of Japan to South Korea, as the two countries are similar in terms of development	Wang Yachao, 2013. The Optimization Analysis of Cold Chain Logistics Distribution Route http://www.globalcis.org/aiss/ppl/AISS2319PPL.pdf
Seafood	Cold chain penetration rate for meat were applied to seafood	
Eggs	Washing and refrigerating eggs is discouraged in Europe, whereas it is regulated in the United States by the USDA. Once an egg has been washed, it must have a continuous cold chain, to avoid making the egg 'sweat' which encourages bacterial formation. Thus, for countries that require eggs to be washed a 100% of cold chain penetration was assumed for eggs. For countries that discourage washing eggs,	Food Safety News 'Why Most Americans Refrigerate Raw Shell Eggs and Europeans Often Don't' 2014. http://www.foodsafetynews.com/2014/07/why-americans-refrigerate-raw-shell-eggs-and-europeans-dont/#.VZ6L-o0w_oY Australia has standards on egg processing, including washing and refrigerating: Australia New

Product Group		Source
	no cold chain (0%) was assumed, because unwashed eggs do not have to be stored in the cold. Developing countries do not have an integrated system for washing eggs and storing them continuously along the supply chain in the cold. Therefore, the cold chain penetration rate for them is 0%.	Zealand Food Standards Code- Primary Production and Processing Standard for Eggs https://www.comlaw.gov.au/Details/F2011L00860 NPR 2014 'Why the US Chills its Eggs an Most of the World Doesn't' http://www.npr.org/sections/thesalt/2014/09/11/336330502/why-the-u-s-chills-its-eggs-and-most-of-the-world-doesnt
Dairy	UHT milk does not require refrigeration for storage. Therefore the market penetration of UHT milk was subtracted from 100% to get the percentage of 'fresh milk' that is assumed to need an extensive cold chain. In Europe, the market for UHT is very high, whereas in countries like the US, fresh milk is preferred by consumers.	Europe: The Times 'The UHT route to long-life planet' 2007 http://www.thetimes.co.uk/tto/news/politics/article2024017.ece United States: Fluid milk products sales in the United States in 2014 by milk category (in million pounds) http://www.statista.com/statistics/257290/us-milk-product-sales-by-category/ Australia (also used as a proxy for New Zealand and Canada as they are commonwealth countries):Dairy Australia 'Drinking Milk Sales' 2014 http://www.dairyaustralia.com.au/Markets-and-statistics/Production-and-sales/Milk/Drinking-Milk-Sales.aspx
China		
Fruits / Vegs	The percentage comes from figure for both fruits and vegetables	2015 The 7th China International Cold Chain Expo. China's Cold Chain http://www.coldchainexpo.com/en/zhgk/scxx.asp The University of Nottingham. Cold Chain Opportunity Assessments http://naturalleader.com/wp-content/themes/natlead/images/CRC3656-ColdChainOpp.pdf
Meat	Percentage comes directly from source	The University of Nottingham. Cold Chain Opportunity Assessments http://naturalleader.com/wp-content/themes/natlead/images/CRC3656-ColdChainOpp.pdf 2015 The 7th China International Cold Chain Expo. China's Cold Chain http://www.coldchainexpo.com/en/zhgk/scxx.asp China's food production and Cold Chain Logistics http://ccm.ytally.com/fileadmin/user_upload/downloads/publications_5th_workshop/Wang_paper.p
Seafood	Percentage comes directly from source	The University of Nottingham. Cold Chain Opportunity Assessments http://naturalleader.com/wp-content/themes/natlead/images/CRC3656-ColdChainOpp.pdf 2015 The 7th China International Cold Chain Expo. China's Cold Chain http://www.coldchainexpo.com/en/zhgk/scxx.asp
Dairy	Applied percentage of total market penetration of cold chains in China to dairy	2015 The 7th China International Cold Chain Expo. China's Cold Chain http://www.coldchainexpo.com/en/zhgk/scxx.asp

Product Group		Source
Southern Asia		
Fruits/ Vegs	The percentage comes from figure for both fruits and vegetables for India	Used India as a proxy for this region's category
Meat	Applied percentage of total market penetration of cold chains in India to meat for the entire region	University of Birmingham, 'The prospects for liquid air cold chains in India' (2014) http://www.birmingham.ac.uk/Documents/news/The-prospects-for-liquid-air-cold-chains-in-India.pdf
Seafood	Applied percentage of total market penetration of cold chains in India to meat for the entire region	University of Birmingham, 'The prospects for liquid air cold chains in India' (2014) http://www.birmingham.ac.uk/Documents/news/The-prospects-for-liquid-air-cold-chains-in-India.pdf
Dairy	Based on information of the percentage of 'formal milk market' that processes and refrigerates milk in India	Overview of Indian Dairy Industry by Dessence Consulting http://fr.slideshare.net/chandnisahgal/overview-of-indian-dairy-industry
South Eastern Asia		
	The team used a proxy of production from a study on Jakarta consumption of products coming from Cold Chains. We assume that Jakarta is an accurate representation of consumption patterns in urbanized areas in SE Asia. Based on the fact that about half of the Southeast Asian population is urbanized (according to world bank data) we then apply the consumption habits to half of the population of SE Asia. We reasonably assume that the rural areas have little access to cold chain and have a diet that is based on fresh food or processed/dry foods that do not need cold chains for distribution. Therefore, we assume that half of the products consumed are consumed in by the rural population, and the other half by the rural population. Therefore, we take assumed a 0% penetration rate for rural population, and the 65% penetration for urbanized population. Consequently we arrive at a figure of about 32% of cold chain penetration rate for Southeast Asia. This figure corresponds well considering the highly dense urban areas, and the geographical scope of the countries make it feasible to arrive to this assumption. (We used the same estimation for meats, that was estimated to have a higher penetration relative to the other products and therefore is calculated to have 40% on average of cold chain penetration) In addition, data about the Philippines supports this estimation: Description of Postharvest Loss Challenge: Lack of adequate cold chain for meat and poultry products. A vast majority (over 70%) of local meat and poultry products are sold warm and do not go through the cold chain process. The majority of meat and poultry sources are slaughtered and then immediately sold to consumers.	Source of Jarkata numbers of consumption of cold chain products: Indonesian Commercial Newsletter (2011) 'Cold Storage Industry in Jakarta and Surrounding Area' http://www.datacon.co.id/ColdStorage-2011IndustryProfile.html US Department of State (2013) Postharvest Loss Challenges Discussion Paper http://www.state.gov/documents/organization/220958.pdf
Eastern Africa		
Fruits/ Vegs	Based on supermarket share in food retail	FAO Food Wastage Footprint technical report, Table 18 in Annex X on the Supermarket Share in Food Retail
Meat	Tanzania used as a proxy for the entire region	Institution of Mechanical Engineers. A tank of cold:

Product Group		Source
		cleantech leapfrog to a more secure world (2014) http://www.imeche.org/docs/default-source/reports/a-tank-of-cold-cleantech-leapfrog-to-a-more-food-secure-world.pdf?sfvrsn=0
Seafood	Based on Uganda FAO presentation: Uganda produces about 15 000 tonnes of fish but has about 400 tonne capacity for cold chain storage (or less than 3%)	http://www.fao.org/fishery/countrysector/naso_uganda/en Regional Workshop on the use of cold chain to promote agricultural and agro-industry development in Sub-saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/4_uganda.pdf
Dairy	Used Kenya and Uganda numbers for dairy market penetration, taking their average. The formal milk chains using cold chains which accounts for 20% of all milk produced in Kenya Uganda has about 10% production by large holders, which we can reasonably assume that means they use cold chains for production and distribution	Entrepreneural Development of Value Chains in Kenya: A Kenya Dairy Sub Sector Example http://www.value-chains.org/dyn/bds/docs/497/BillingGuchu_BSMDP.pdf Ebony Consulting International, (2001) The Kenyan Dairy Sub-Sector http://www.value-chains.org/dyn/bds/docs/759/KenyaDairyMktAnalysis.pdf Regional Workshop on the use of cold chain to promote agricultural and agro-industry development in Sub-saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/4_uganda.pdf
Middle Africa		
Fruits/ Vegs	Used Cameroon as proxy for region: 'There is no local infrastructure of cold chains for domestic consumption of fruits and vegetables in Cameroon'	FAO Presentation of Cameroon at the regional workshop on the use of cold chain in agriculture development in Sub Saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/3_Cameroun.pdf
Meats	Local consumption is primarily fresh meat for both proxy countries, Democratic Republic of the Congo and Cameroon	Democratic Republic of the Congo: http://www.fao.org/fileadmin/templates/ags/docs/I3950F/10_DRC.pdf Cameroon: FAO Presentation of Cameroon at the regional workshop on the use of cold chain in agriculture development in Sub Saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/3_Cameroun.pdf
Seafood	Used Cameroon as proxy for the region	FAO Presentation of Cameroon at the regional workshop on the use of cold chain in agriculture development in Sub Saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/3_Cameroun.pdf
Milk	Used Cameroon as a proxy. Local milk consumption does not have cold chain infrastructure	FAO Presentation of Cameroon at the regional workshop on the use of cold chain in agriculture development in Sub Saharan Africa (2012) http://www.fao.org/fileadmin/templates/ags/docs/I3950F/3_Cameroun.pdf
Western Africa		
Fruits/ Vegs	A case study of pineapples grown in Ghana was used to represent the region's fruit and vegetable production, where 40 pineapple farmers were interviewed: 10% stated they use a fully integrated cold chain for the production of the product	University of Ghana. Cold Chain Management of Fruits in Ghana (A case study of the pineapple sector) 2011 http://ugspace.ug.edu.gh/bitstream/handle/123456789/5971/Roland%20Nii%20Ayi%20Quaye_%20Cold%20Chain%20Management%20of%20Fruits%20in%20Ghana_2011.pdf?sequence=1

Product Group		Source
Meats	Used a proxy of Ghana for the entire region on the basis of information on the retail food market. 65 percent of total retail is done in open air markets, 30 percent in small groceries and convenience stores, with supermarkets taking 5 percent of the market. We can reasonably assume that 5 percent of perishable food produced takes part of a formal cold chain.	'Revised Safety Plan' Ministry of Food and Agriculture Food Safety Task Force http://siteresources.worldbank.org/INTRANETTRADE/Resources/Ghana_Food_Safety_Action_Plan_Revised.pdf
Seafood	Used a proxy of Ghana for the entire region on the basis of information on the retail food market. 65 percent of total retail is done in open air markets, 30 percent in small groceries and convenience stores, with supermarkets taking 5 percent of the market. It can reasonably be assumed that 5 percent of perishable food produced takes part of a formal cold chain. Also, qualitative information found supports the notion that the cold chain for fish is not well developed despite high production of fish. According to the Department of Fisheries, tilapia forms about 80% of aquaculture production. Most Ghanaian tilapia is caught by artisanal fishers and most of the catch is salted and dried or smoked, and it heads to the domestic market. The handling and storage of the fish is generally considered to be poor.	'Revised Safety Plan' Ministry of Food and Agriculture Food Safety Task Force http://siteresources.worldbank.org/INTRANETTRADE/Resources/Ghana_Food_Safety_Action_Plan_Revised.pdf
Milk	Used Ghana as a proxy for informal milk markets involve milk sale through unregulated channels. Such markets account for over 80% of convenient delivery and lower prices from these informal milk markets	Ghana Medical Journal 'Bacterial Contaminations of Informally Marketed Raw Milk in Ghana' (2007) http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1976296/
Southern Africa		
All categories	60 % of South Africans shop in formal retail supermarkets, which account for about 50% of total food retail. The standards enforced on supermarkets are stringent, and therefore we can assume a consistent cold chain for products is demanded	>Number of South Africans that shop in retail markets 'Traditional Markets Still Trump Formal Retail Outlets In Africa' AFK Insider 2015 http://afkinsider.com/90471/traditional-markets-still-trump-formal-retail-outlets-in-africa/#sthash.7Z4mBctb.dpuf >Estimate of share of total food retail from supermarkets 'The Rise of supermarkets in Africa: Implications for Agrifood Systems and the Rural Poor' (2003) Article in Development Policy Review http://www.researchgate.net/profile/Dave_Weatherspoon/publication/4989229_The_Rise_of_Supermarkets_in_Africa_Implications_for_Agrifood_Systems_and_the_Rural_Poor/links/541059fe0cf2f2b29a40f523.pdf >New standards enforced by supermarkets Losing out to Supermarkets – the transformation of Fruit and Vegetable Supply Chains in Southern Africa' http://www.hiidunia.com/2011/06/losing-out-to-supermarkets-the-transformation-of-fruit-and-vegetable-supply-chains-in-southern-africa/

Product Group		Source
Latin America		
Fruits/ Vegs	Countries for which actual information on cold chains was identified are not representative for the whole region (for example in Ecuador - **5 % penetration rate only**). Information on cool storage capacity identified for the whole region Therefore an assumption was made at the region level : since 60% of total food production is sold in supermarkets (involving cold chain penetration) and 30% of this consists of fresh produce (F&V), we can assume an approximate cold chain penetration of 30%	World Food Logistics Organization 'Cold Chain Assessment: Bolivia, Ecuador and Peru 2014 http://approlog.org/wp-content/uploads/2015/01/Cold-Chain-Assessment-in-Bolivia-Ecuador-and-Peru_FINAL.pdf
Meat	Peru was used as a proxy based on available info	World Food Logistics Organization 'Cold Chain Assessment: Bolivia, Ecuador and Peru 2014 http://approlog.org/wp-content/uploads/2015/01/Cold-Chain-Assessment-in-Bolivia-Ecuador-and-Peru_FINAL.pdf
Dairy	55% of the milk and dairy is distributed in Argentina informally, door to door. No cooling system is used since the milk is distributed locally the same day. The other distribution chains (wholesalers, distribution centres) comply to stricter rules since part of the milk is used for export. Assumption - 45% of the milk is cooled, therefore the same rate was applied for cold chain penetration. Argentina was then used as a proxy for the whole region, except for the Caribbean which does not have the same sector organization	http://www.fao.org/docrep/013/al744e/al744e00.pdf page 13
Fish	Peru is one of the main fishing nations in Latin America, the same % was used as for meat - 25%	
Northern Africa		
Fruits/ Vegs	Information on penetration rate available for Morocco was used as a proxy	Proceedings Expert Consultation Meeting on the Status and Challenges of the Cold Chain for Food Handling in the Middle East and North Africa (MENA) Region PROCEEDINGS, FAO 2011
Meat and fish	Only information on cold storage capacity available.	Assumption
Dairy	75 to 80% of dairy producers are small farms, with usually no cooled infrastructure: an assumption of 30% cold chain penetration rate was made	Page 89 of Proceedings Expert Consultation Meeting on the Status and Challenges of the Cold Chain for Food Handling in the Middle East and North Africa (MENA) Region PROCEEDINGS, FAO 2011
Central Asia		
Fruits/Vegs	Uzbekistan used as a proxy based on the following: less than 5% of fruits and vegetables is stored for future consumption, from this 80% is warehoused in facilities that lack temperature or humidity control. Production on MT is 7 000 000, with 350000 MT stocked, therefore the percent refrigerated is estimated to be 1% maximum.	'Investors sought for Uzbekistan refrigerated warehouses' Refrigerated Transporter (2013) http://refrigeratedtransporter.com/cold-storage/investors-sought-uzbekistan-refrigerated-warehouses
Dairy	Various sources indicate 0 cold chains for Kazakhstan. Used as proxy for the whole region	OECD Review of Agricultural Policies, Kazakhstan 2013 http://www.oecd.org/tad/agricultural-policies/kazakhstan-review-2013.htm FAO Highlights on four livestock sub-sectors in Kazakstan, The Dairy Sub-sector 2010 http://www.eastagri.org/publications/pub_docs/imp_dairy_web3.pdf

Product Group		Source
Fish	Given a very low total production (a few tons), we assume that there are no cold chains in place. In these countries, fish is normally dried or consumed fresh.	
Meat	The penetration rate is estimated based on qualitative information only	FAO, 2013. Food wastage footprint – Impacts on natural resources.
Mongolia		
Fruits, vegetables, dairy and Fish	No cold chain information identified in the literature review; also, production for fish or dairy is low. 0% rate applied for fruits, vegetables and fish. The assumption that cold chain for milk is higher - at around 3% given the existence of some information on cooling systems from a World Bank Report.	World Bank Case Study - The semi-intensive dairy sector in Mongolia (2003) http://documents.worldbank.org/curated/en/2003/11/7074541/mongolia-semi-intensive-dairy-sector-case-study
Meat	According to local sources, the cold chains for meat have a 15% penetration rate.	Local sources (personal communication)
Western Asia		
Fruits/Vegs	Saudi Arabia used as reference for the whole region, based on information on dates	Proceedings Expert Consultation Meeting on the Status and Challenges of the Cold Chain for Food Handling in the Middle East and North Africa (MENA) Region PROCEEDINGS, FAO 2011
Meat	Saudi Arabia used as reference	Proceedings Expert Consultation Meeting on the Status and Challenges of the Cold Chain for Food Handling in the Middle East and North Africa (MENA) Region PROCEEDINGS, FAO 2011
Dairy	An article on cold chain in Middle East indicates a 'high rate' of cold chain penetration for this sector (only qualitative statement). An assumption of 85% was made based on penetration rate for developed countries	AgriLand, The dairy supply chain in the Middle East – 'todays milk today', 2014 http://www.agriland.ie/farming-news/dairy-supply-chain-middle-east-todays-milk-today/
Fish	Assumption based on qualitative information	FAO Food Wastage Footprint, Impacts on natural resources Summary Report (2013)

4.5 Food transportation distance

Table 12 – Maximum travel time (in days) of perishable goods (with and without cold chains)

	Fruits		Vegetables		Meat		Fish and Seafood		Milk		Egg	
	Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC
All developing regions	3	3	2	3	1	1	0.125	3	3	2	1	1.5

Main hypotheses

Maximum transport distance: even if some transports (with cold chain could last for more than one week without prejudice for the quality of the food, all travel distances were limited to a maximum of 3 days or 1 200km[24], because export is not taken into account, most food production facilities are closer than 2 400 km, and longer distances would mean higher prices for food products.

Table 13 – Transportation distances (in km) of perishable goods (with and without cold chains) Values used in the model

		Fruits		Vegetables		Meat		Fish and Seafood		Milk		Egg	
		Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC	Without CC	With CC
Ind. Asia	**China**	518	691	346	691	173	346	102	271	65	346	173	259
Sub-Saharan Africa	**Sub-saharan Africa**	355	474	237	474	118	237	109	289	44	237	118	178
North Africa, Western Asia and Central Asia	**Central Asia & Mongolia**	682	909	454	909	227	454	102	271	85	454	227	341
	Northern Africa	614	819	410	819	205	410	99	263	77	410	205	307
	Western Asia	682	909	454	909	227	454	88	234	85	454	227	341
South and Southeast Asia	**South-Eastern Asia**	317	422	211	422	106	211	88	234	40	211	106	158
	Southern Asia	317	422	211	422	106	211	113	301	40	211	106	158
Latin America	**Caribbean**	768	1024	512	1024	256	512	58	154	96	512	256	384
	Central America	768	1024	512	1024	256	512	111	296	96	512	256	384
	South America	768	1024	512	1024	256	512	90	239	96	512	256	384

[24] Hypothesis: 8 hours of transport per day at 50 km/h (source: expert estimate based on literature review performed)

Table 14 – Sources used for estimation of food transportation distances

	Transport without cold chains	Transport with cold chains
Fruits	Maximum distance of transport used www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf	Maximum distance of transport used (www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf)
Vegetables	www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf	
Meat	Without cold chain animals are transported alive in trucks up to the point of consumption, the meat from dead animals does not travel for more than 2 hours at ambient temperature because of sanitary risks Source : www.fao.org/fileadmin/templates/sfc/fichier/ABATTOIRS_AFRIQUE_CENTRALE.pdf and www.afsca.be/home/com-sci/doc/avis04/Avis_2004-01.pdf	With cold chain the distance of transport is the same as without cold chain because it is considered that slaughterhouses are built as close as possible from livestock (source: expert estimation based on literature review performed).
Fish and Seafood	www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf	Maximum distance of transport used. Production areas are limited to coastal areas and with conservation at optimum temperature up to 10 days, new market can be reached. (www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf)
Milk	www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf	Even if conservation at optimum temperature is up to 14 days (www.postharvest.org/Use%20of%20cold%20chains%20PEF%20white%20paper%2013-03%20final.pdf), travel distances are limited to 800 km (2 days) because production of milk is quite common (source: expert estimation based on literature review performed).
Egg	Source: expert estimate based on literature review performed	Source: expert estimate based on literature review performed

Assessing the potential of the cold chain sector to reduce GHG emissions through food loss and waste reduction

Prepared for the Global Food Cold Chain Council with Support from Carrier