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INTERNATIONAL INSTITUTE OF REFRIGERATION

THE CARBON FOOTPRINT OF THE COLD CHAIN



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on Refrigeration
and Food**



“An improved global cold chain would allow a reduction of almost 50% of the CO₂ emissions of the current cold chain.”

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Summary

According to IIR estimates, 12% of food produced globally in 2017 was lost due to an insufficient cold chain. A more extensive cold chain would limit the need to increase agricultural production to compensate for these losses and avoid the corresponding CO₂ emissions. This raises the question of whether the additional CO₂ emissions resulting from the implementation of a more extensive cold chain are not greater than the emissions avoided by reducing food losses due to a lack of refrigeration.

To answer this key question, the IIR has developed an innovative model to calculate CO₂ emissions for each stage of the cold chain and for all countries in the world. This model allows to compare the CO₂ emissions associated with the current global cold chain with those of an “improved” cold chain. The latter corresponds to a reasonable assumption in which the cold chain in all countries is brought to the same level of equipment and performance as that existing in developed countries. The following results are obtained:

- An improved global cold chain based on these principles would allow a reduction of almost 50% of the CO₂ emissions of the current cold chain.
- This improved cold chain would also avoid 55% of the food losses attributable to the current cold chain.

This Informatory Note was prepared by Jean Sarr (engineering student), Jean-Luc Dupont (Head of the Scientific and Technical Information Department) and Jacques Guilpart (French Delegate of the IIR). It was reviewed by Richard Lawton (President of Section D “Storage and Transport”), Silvia Minetto (President of Commission D2 “Refrigerated Transport”). The methodology and assumptions were developed with the assistance of members of the IIR Working Group on the Cold Chain in Hot Countries. It was proofread by Nathalie de Grissac and designed by Nolwenn Robert-Jourdren (IIR head office).

Introduction

Ensuring sufficient quantity and quality of food for 7.7 billion people today and about 9.7 billion by 2050 [1] is undoubtedly one of today's major challenges, with potential consequences for global economic, social and ecosystem balances.

Temperature is the main factor affecting the safety and quality of perishable foodstuffs [2]. To prevent the growth of pathogens and preserve the nutritional and organoleptic properties of food, part of the production dedicated to human consumption must be subjected to refrigeration at all stages from production to final consumption. Thanks to a set of refrigeration systems, the temperature of these foodstuffs must be controlled throughout the supply chain. The set of refrigeration operations implemented to maintain food at the required temperature is called the cold chain [3].

In a previous Informatory Note, the International Institute of Refrigeration (IIR) showed that for the year 2013, out of 1661 million tonnes of food that should have benefited from a cold chain, only 778 million tonnes (47%) were subjected to refrigeration, resulting in food losses estimated at 13% of agricultural production for human consumption [4]. A more extensive cold chain could significantly reduce food losses and thus improve global food safety and security. According to the same note, a cold chain capable of eliminating food losses due to insufficient refrigeration coverage (or «lack of refrigeration») would save 475 million tonnes of food and thus theoretically feed 950 million people per year [4].

The update, using the same method of calculation, of the results provided in this Informatory Note, based on FAO data for the year 2017 (the most recent available to date), reveals the possibility of saving 526 million tonnes of food, as illustrated in Figure 1.

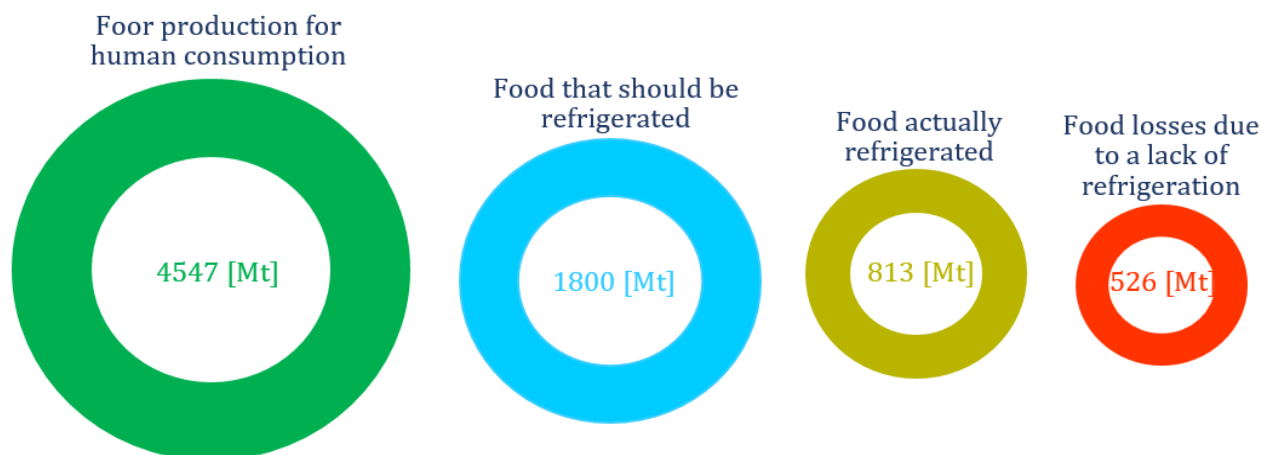


Figure 1

Global food losses due to a lack of refrigeration (2017)

Extending the current cold chain would therefore allow a better use of the food produced and limit the need for increased agricultural production to compensate for losses, thus reducing the negative environmental impact of agricultural activities. According to a 2019 report by the Intergovernmental Panel on Climate Change (IPCC), agriculture, forestry and other land uses account for 23% of greenhouse gas (GHG) emissions [5]. Eliminating or reducing food losses due to lack of refrigeration would therefore also help to avoid carbon dioxide (CO₂) emissions (noted in this document as “CO₂ emissions”) associated with this additional agricultural production.

However, the cold chain also produces CO₂ emissions due to refrigerant leaks into the atmosphere it causes and, above all, to the energy consumption it implies [6]. Moreover, the fuel consumption of refrigerated food transport vehicles adds to these sources of CO₂ emissions.

Total CO₂ emissions associated with a cold chain must therefore include the emissions from:

- the cold chain equipment itself,
- food losses resulting from insufficient refrigeration coverage by the existing cold chain of all food that must be refrigerated for proper preservation.

The aim of this study will initially be to model the

carbon footprint – i.e., all emissions expressed in CO₂ equivalent – corresponding to the current cold chain in all countries. Secondly, based on CO₂ emissions, we will study the interest of an «improved» cold chain that would reduce food losses resulting from a lack of refrigeration, and which would be more efficient.

In this note, an «improved» cold chain corresponds to an extended cold chain, i.e., with more refrigeration equipment, but also with better energy and environmental performance, according to hypotheses that will be specified further on.

Figure 2 below shows the current cold chain and the «extended» cold chain. It is based on the following principles:

Quantity of food that should be subjected to refrigeration:

- part of the food, in green, is actually refrigerated,
- another part, in red, is lost due to lack of refrigeration,
- the remaining part, in blue, although it is not subjected to refrigeration, has properties that allow it to be consumed in certain cases, particularly near the place of production.

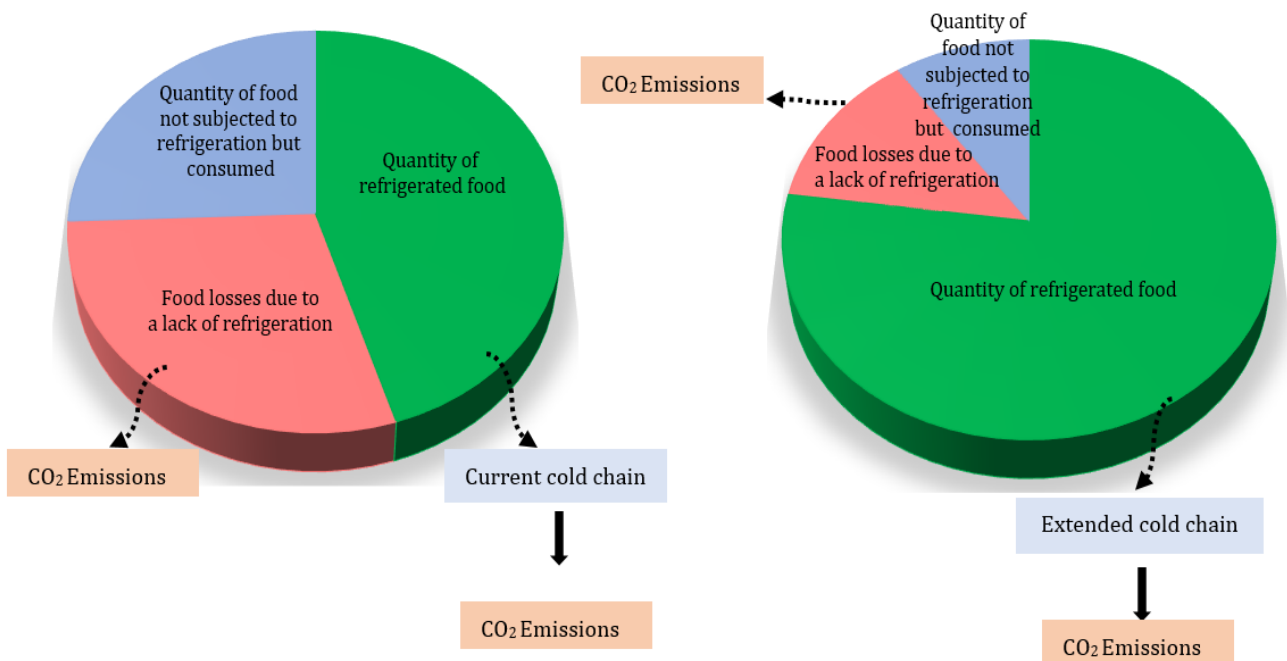


Figure 2a: Current cold chain

Figure 2b: Extended cold chain

Figure 2

Origin of CO₂ emissions from the current cold chain and from an extended cold chain

In Figure 2b, which corresponds to an extended cold chain, food losses are reduced through the installation and use of more refrigeration equipment as part of a cold chain that provides better refrigeration coverage.

The modelling of these two cold chains aims to compare the total CO₂ emissions associated with them.

One of the questions that will be important to answer is: are the additional CO₂ emissions resulting from the implementation of an improved cold chain not greater than the emissions avoided through a reduction in food losses due to lack of refrigeration?

The cold chain

A cold chain is an uninterrupted system of temperature-controlled transport and storage of refrigerated food products between upstream producers and final consumers, designed to maintain the quality and safety of these products [7][8].

In this study, the cold chain consists of 5 stages:

- Pre-cooling: this stage corresponds to the first cooling of food products, just after harvest for agricultural products for example.
- Refrigerated transport: this corresponds to the transport under optimal temperature conditions of refrigerated products. It should be noted that refrigerated transport can occur several times in the chronology of the cold chain.
- Cold storage: this is the storage stage for refrigerated products. As with the refrigerated transport stage, cold storage can occur several times in the cold chain.
- Retail: this stage corresponds to the distribution of refrigerated and frozen products in supermarkets and other sales outlets.
- The final consumer: this is the stage of cold storage of the products in the refrigerator and/or freezer of the final consumer.

The figure below represents a typical cold chain considered in this study:

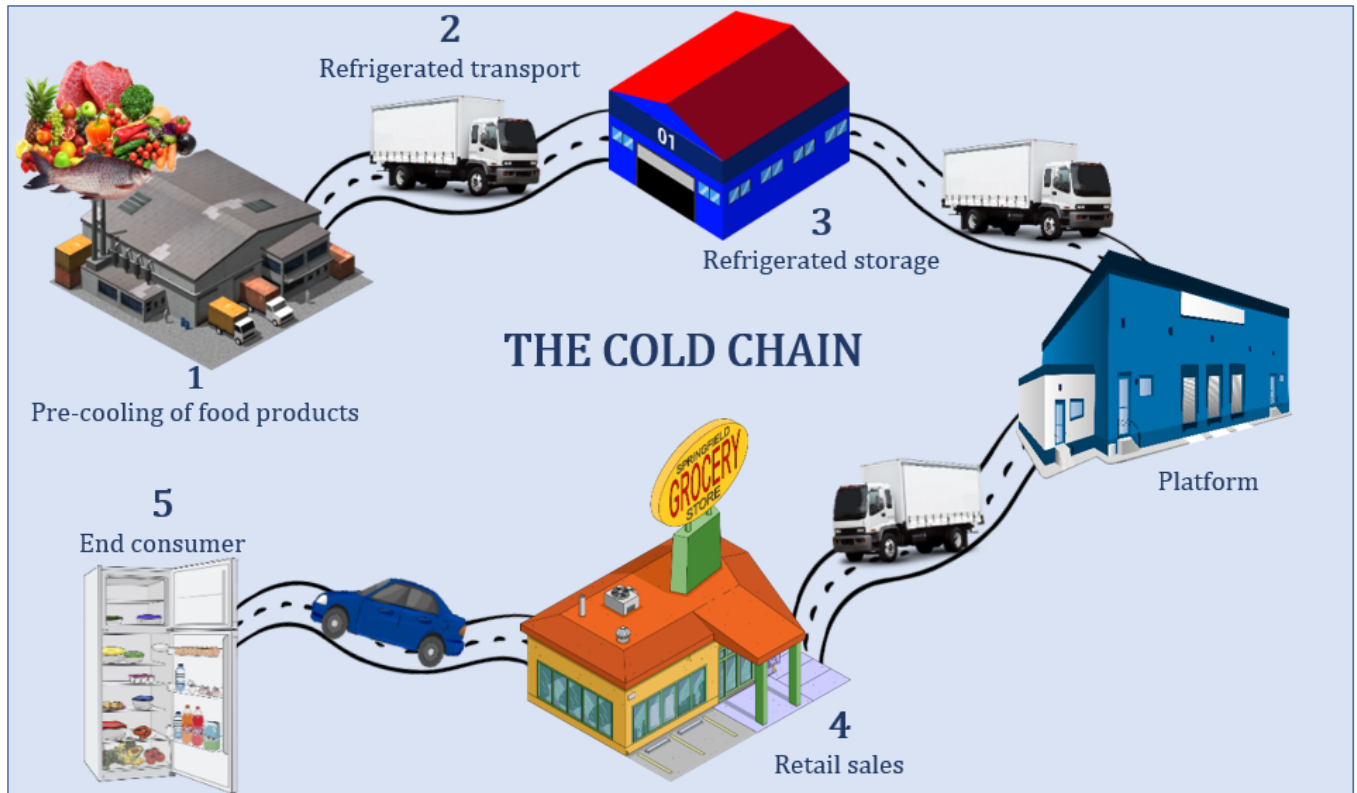


Figure 3
The cold chain

Modelling of CO₂ emissions

REFRIGERATION EQUIPMENT DATA

The modelling of CO₂ emissions from a cold chain first requires an assessment of the refrigeration equipment used throughout the cold chain, and first of the following parameters:

- Number of refrigerated transport vehicles,
- Cold storage volumes,
- Linear meters of refrigerated display cabinets in supermarkets,
- Number of household refrigerators and freezers.

The estimation of this stock of refrigeration equipment is made here from the quantity of food that is refrigerated. This quantity, estimated at 813 Mt at the global level (Fig. 1), was calculated from FAO data from 2017^[9]. As these data are available for each country¹, it is possible to estimate the stock of refrigeration equipment per country.

The food products considered in this modelling are meat, milk, fish, fruits, vegetables and tubers.

The assumptions and calculation methods related to the model are specified in a [methodological annex](#)².

¹ The data provided by FAO for the years 2013 and 2017 do not include those of the following countries: Bhutan, Burundi, Democratic Republic of Congo, Equatorial Guinea, Eritrea, Libya, Papua New Guinea, Somalia, South Sudan, Syria. The trends given in this document at the global level therefore exclude these countries.

² The annex is also available in FRIDOC: <https://doi.org/10.18462/iir.INfood07.04.2021>

MODELLING PRINCIPLES

The CO₂ emissions caused by refrigeration equipment in a cold chain come from:

- Electricity consumption: the production of the electrical energy consumed by this refrigeration equipment to cool food is the source of CO₂ emissions into the atmosphere. The carbon equivalent of the kWh of electrical energy consumed depends on the primary energy sources used to produce this electrical energy (renewable energies, nuclear energy, coal, fuel oil, etc.).
- Refrigerant leaks: a refrigerant has a global warming potential (GWP) and causes CO₂ emissions when released into the atmosphere.
- Diesel consumption of refrigerated transport vehicles: the engines which propel the vehicle and operate the refrigeration unit, allowing the temperature of the food transported to be maintained, emit CO₂.

CO₂ emissions from refrigeration equipment are calculated for each stage of the cold chain. These emissions are of two types:

- Direct emissions: these are the emissions from refrigerant leaks.
- Indirect emissions: these are emissions from electricity consumption and diesel fuel.

The method for calculating the CO₂ emissions of cold chain equipment is therefore as follows:

1. Estimate of the quantity of the food currently refrigerated per country.
2. Evaluation of the stock of refrigeration equipment for each stage of the cold chain.
3. Calculation of the CO₂ emissions associated with this refrigeration equipment.

THE PRINCIPLES FOR CALCULATING CO₂ EMISSIONS

The modelling of CO₂ emissions from cold chain equipment was carried out for all countries in the world. The calculation of these emissions is based on a set of equations that have been implemented in a solver, i.e. a calculation software (see methodological appendix)

This modelling of the CO₂ emissions of the cold

chain via equations involves a large number of parameters to be set for each country and for each stage of the cold chain. The advantage of using a parametric model is that the parameters are easily adaptable to the data available for the different countries and can be modified according to the evolution of these data over time.

To be able to generalise parameter values to a set of countries, groups of countries have been defined. Each country belongs to the group that best describes its characteristics. Each group of countries has a code for which average values of the parameters are used to calculate the CO₂ emissions of the cold chain. The values of these parameters were estimated by interviewing many experts from the IIR network and its working group on the cold chain in hot countries, as well as by consulting the scientific literature. However, the calculation algorithms rely primarily on precise values of these parameters for each stage of the cold chain and for each country whenever such values are available. Default values have been estimated only if these precise values were not available.

Below, for example, the “CO₂ code” is used to define the CO₂ emissions induced by the production of electricity for four groups of countries:

Table 1:
Defining the CO₂ code

CO ₂ code	CO ₂ Equivalent of electric kWh [kg eq CO ₂ /kWh]	Electricity production
1	0.15	Highly decarbonised
2	0.4	Decarbonised
3	0.6	Predominance of fuel oil
4	1.6	Predominance of coal

For example, a country attached to the CO₂ code “1” means that its electricity production is highly decarbonised because it is essentially based on renewable energies or nuclear power. Other codes corresponding to each stage of the cold chain or to the level of development of the countries have been defined (see methodological annex).

Cold chain scenarios studied

The objective is to compare the CO₂ emissions associated with the current global cold chain with those of an “improved” cold chain, which would result from extending the cold chain and improving its energy and environmental performance.

The current cold chain corresponds to the current stock of refrigeration equipment, which made it possible to keep total of 813 Mt of foodstuffs cold in 2017 (see figure 1).

A more extensive cold chain would make it possible to reduce food losses due to a lack of refrigeration thanks to a greater “refrigeration coverage” and therefore more refrigeration equipment.

However, developed countries³, which have a more extensive and efficient cold chain, suffer significant food losses for a variety of reasons, including imperfect temperature management, for example. A cold chain that would make it possible to completely eliminate food losses therefore seems very unrealistic in practice.

The scenario that will be considered for this improved cold chain therefore corresponds to a more realistic scenario, in which the cold chain in all countries is brought to the same level of equipment and performance as that existing in developed countries. Global food losses due to a lack of refrigeration coverage will therefore decrease but will not be zero.

In this study, it should also be noted that for the refrigerated transport stage, 20% of the diesel consumption of refrigerated vehicles is attributed to refrigerating the food transported ^[11]. The remaining 80% consumption is not attributed to the cold chain because we consider that the transport of food,

refrigerated or not, involves fuel consumption.

THE CURRENT COLD CHAIN

CO₂ emissions related to food losses due to a lack of refrigeration

Global food losses due to a lack of coverage by the current cold chain are estimated at 526 Mt for the year 2017. According to the calculations based on the model developed in this study, these losses are equivalent to CO₂ emissions estimated at 1004 Mt CO₂ eq. These emissions correspond to those resulting from the additional food production needed to compensate for these losses.

CO₂ emissions related to the current cold chain equipment

The modelling of the current cold chain, which allowed 813 Mt of food to be refrigerated in 2017, results in the following values of the world's refrigeration equipment stock and total electricity consumption:

Table 2:

Characteristic values of today's global cold chain

Designation	Value	Unit
Number of refrigerated vehicles	3,400,000	-
Number of refrigerators	1,967,000,000	-
Cold storage volume	449,000,000	m ³
Linear metres of display cabinets	66,078	km
Electricity consumption	281	TWh
Refrigerant charge	413	kt
CO ₂ emissions from equipment	261	Mt eq CO ₂

Based on these values, the current cold chain equipment is estimated to be responsible for the emission of 261 Mt CO₂ eq into the atmosphere.

³ According to the UN, countries can be classified into four groups according to the Human Development Index (HDI) ^[10]. In the model, a country is considered to be developed if it belongs to the group with a very high HDI (0.80<HDI<1).

Figure 4 shows the level of CO₂ emissions from cold chain equipment by region of the world according to the FAO geographical distribution (left vertical axis) and the corresponding cumulative

percentage (right vertical axis). East Asia, North America, Eastern and Western Europe alone are responsible for 65% of these emissions.

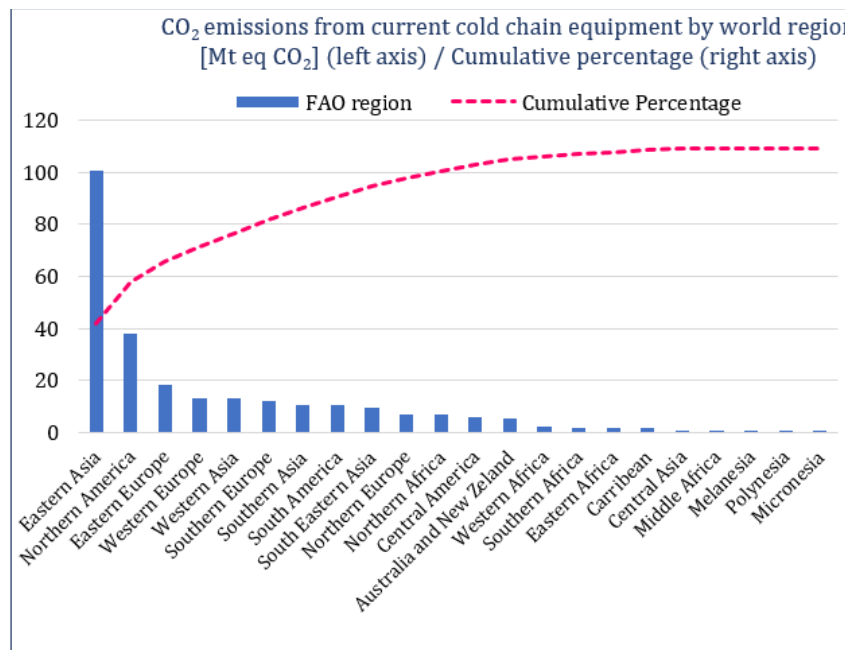


Figure 4

CO₂ emissions from current cold chain equipment by world region

Figure 5 shows the distribution of CO₂ emissions by country:

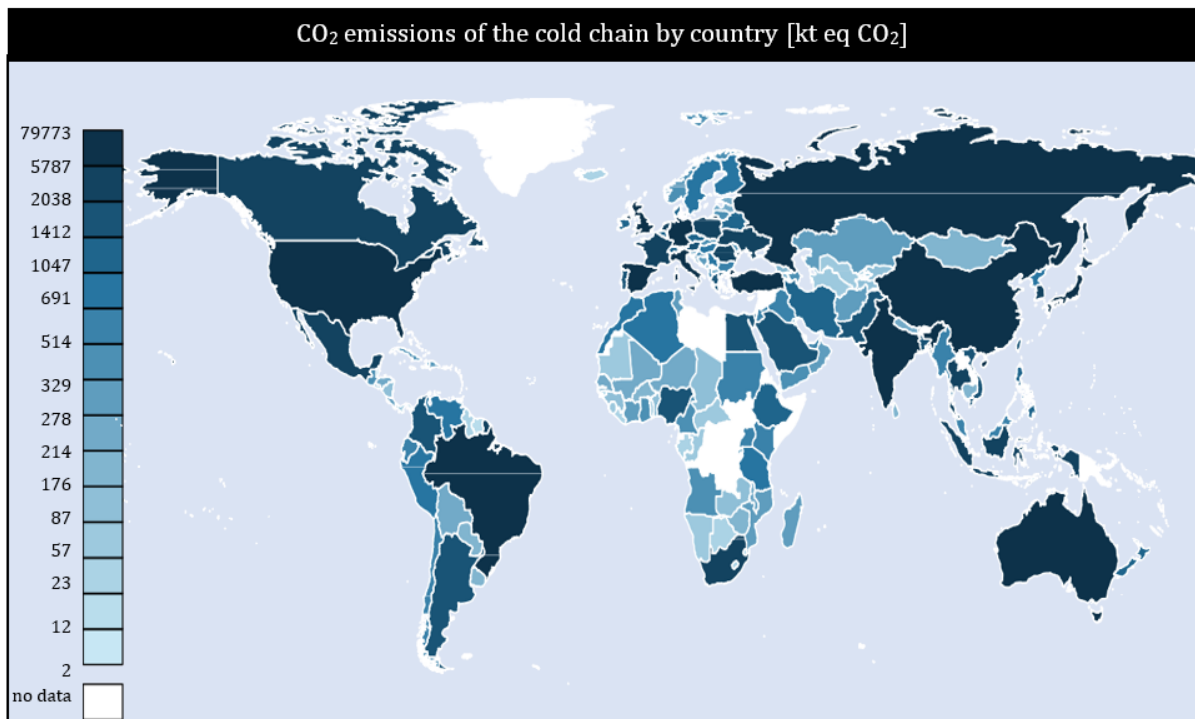


Figure 5

CO₂ emissions from the current cold chain equipment per country

Moreover, as shown in Figure 6, the contribution to total cold chain emissions differs depending on the stages of the cold chain. Thus, the final consumer stage is the largest contributor with 43% of global CO₂ emissions from the current cold chain.

It should also be noted that, in the current cold chain, most of these CO₂ emissions come from the electricity consumption of refrigeration equipment. This consumption is responsible for 60% of emissions, compared with 22% of emissions from refrigerants and 18% from diesel used for refrigerated transport.

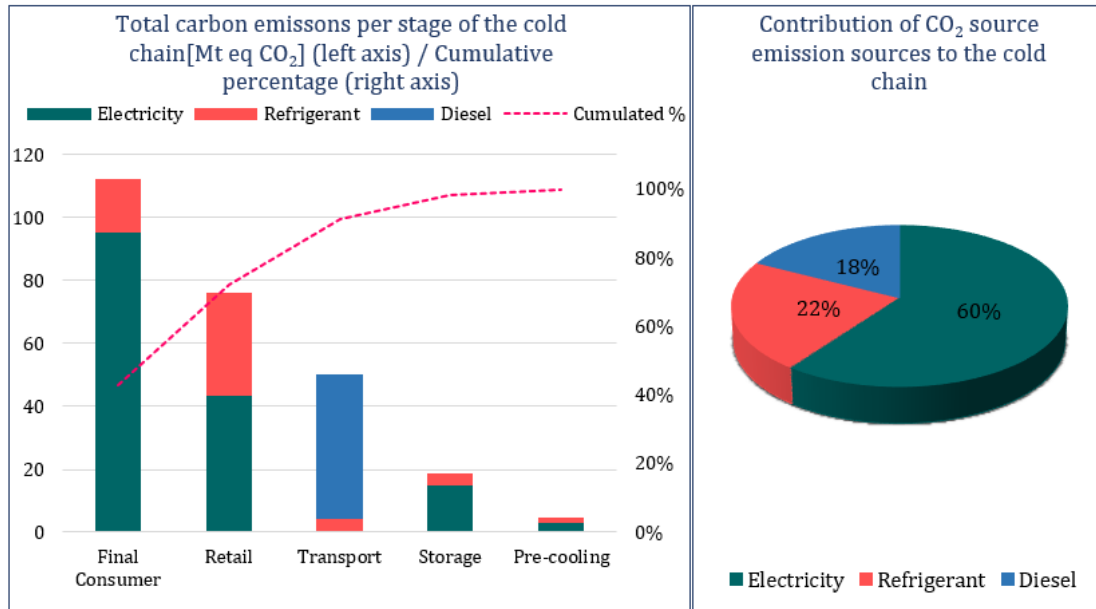


Figure 6

Total CO₂ emissions of the current global cold chain per stage and emission sources

The total CO₂ emissions resulting from the current cold chain correspond to the sum of CO₂ emissions corresponding to food losses due to lack of refrigeration (1004 Mt CO₂ eq) and CO₂ emissions caused by cold chain equipment (261 Mt CO₂ eq).

Total carbon emissions from the current global cold chain therefore amount to 1265 Mt CO₂ eq.

THE “IMPROVED” COLD CHAIN

The “improved” cold chain considered here therefore corresponds, for all countries in the world, to a reduction in food losses due to a lack of refrigeration as well as an increase in the performance of refrigeration equipment at the level of the cold chain currently existing in developed countries. This assumption is reflected in the model by adopting, for all countries:

- a refrigeration coverage rate by the cold chain at the same level as that of developed countries through a corresponding increase in the number of refrigeration units per inhabitant,
- a stock of refrigeration equipment having the same level of performance as in developed countries: upgrade of refrigeration equipment energy efficiency and identical use of refrigerants with lower GWP in particular⁴.

This upgrading of the cold chain’s characteristics therefore generates:

- an increase in the amount of food subjected to refrigeration,
- a decrease in global food losses due to lack of refrigeration,
- a decrease in CO₂ emissions associated with these food losses.

⁴ Upgrading does not concern the sources of energy production. This means that countries that use, for example, fossil fuels and renewables at a certain distribution rate to produce their electricity, continue to use these energy sources in the same proportions in the extended cold chain scenario considered.

CO₂ emissions related to food losses due to a lack of refrigeration

If we consider for all countries a cold chain at the same level as that of developed countries, we obtain the following results concerning food production and losses:

Table 3
Food losses and CO₂ emissions corresponding to an improved cold chain

Designation	Value (current cold chain)	Value (improved cold chain)	Unit
Food production	4,547	4,547	Mt
Food that should be refrigerated	1,800	1,800	Mt
Food actually refrigerated	813	1389	Mt
Food losses due to a lack of refrigeration	526	236	Mt
CO ₂ emissions associated with these food losses	1004	76	Mt eq CO ₂

A very strong reduction in CO₂ emissions associated with food losses due to a lack of refrigeration coverage can be observed. These emissions go from 1004 to 76 Mt CO₂ eq for an improved cold chain, i.e., a reduction of 92%.

The magnitude of this reduction is due in particular to the improvement in the rate of refrigeration coverage of meat by the improved cold chain, which has been raised in all countries to the level of that of developed countries, i.e., to a value considered at 100% in the model. This means that for all countries, with an improved cold chain, there would be no loss of meat due to lack of refrigeration.

As the carbon footprint of meat production is very high, this partly explains the sharp drop in CO₂ emissions associated with food losses due to lack of refrigeration.

CO₂ emissions related to the equipment of the improved cold chain

The characteristics of the global stock of refrigeration equipment that would bring the global cold chain up to the level of that of developed countries, as well as the CO₂ emissions associated with this stock of refrigeration equipment, are presented in the following table:

Table 4

Comparison of current and improved global cold chain characteristic values

Designation	Value (current cold chain)	Value (improved cold chain)	Unit
Number of refrigerated vehicles	3,400,000	7,500,000	-
Numbers of refrigerators	1,967,000,000	4,640,000,000	-
Cold storage volume	449,000,000	843,000,000	m ³
Linear metres of display cabinets	66,078	109,901	km
Electricity consumption	281	714	TWh
Refrigerant charge	413	914	kt
CO ₂ emissions from equipment	261	589	Mt eq CO ₂

The total CO₂ emissions from the improved cold chain correspond to the sum of CO₂ emissions corresponding to food losses due to lack of refrigeration (76 Mt CO₂ eq) and CO₂ emissions caused by cold chain equipment (589 Mt CO₂ eq).

Total CO₂ emissions from the improved cold chain therefore amount to 665 Mt CO₂ eq.

This corresponds to a 47% reduction in CO₂ emissions compared to the current cold chain, which have been estimated at 1265 Mt CO₂ eq.

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Overview

The following table summarises the main results obtained in this study:

Table 5
Synthesis of the study results

Designation	Value (current cold chain)	Value (improved cold chain)	Unit
Food losses due to a lack of refrigeration	526	236	Mt
CO ₂ emissions associated with these food losses	1,004	76	Mt eq CO ₂
CO ₂ emissions from equipment	261	589	Mt eq CO ₂
Total CO ₂ emissions associated with the cold chain considered	1,265	665	Mt eq CO ₂

The results of the calculation show that improving the cold chain would increase CO₂ emissions from refrigeration equipment by 126%, from 261 Mt CO₂ eq to 589 Mt CO₂ eq. This increase is mainly due to the increase in the stock of refrigeration equipment. But **the corresponding extension of the cold chain would make it possible to avoid 290 Mt of food losses, i.e. 55% of the food losses attributable to the current cold chain.**

In addition to reducing food losses, **an improved cold chain would also reduce the total carbon footprint of the current cold chain by 600 Mt CO₂ eq, or more than 47%.**

These encouraging results should not obscure the fact that there is still potential for optimising the current cold chain in developed countries, in particular by improving temperature management and the energy efficiency of refrigeration equipment and by reducing the impact of the refrigerants used (reduction of GWP and leaks in particular). This optimisation, if implemented worldwide, would make it possible to further reduce CO₂ emissions from the cold chain.

Conclusion

This study made it possible to compare the current global cold chain with an improved cold chain by extending it and bringing it up to the performance level of that existing in developed countries in terms of the stock of refrigeration equipment available per inhabitant, the energy efficiency of this equipment and the refrigerants used.

The results highlight the very positive contribution of this improved cold chain:

- To food security thanks to a very significant reduction in food losses,
- To the mitigation of global warming thanks to the reduction of CO₂ emissions.

The model developed by the IIR shows that **a cold chain brought in all countries to the level of that of developed countries would reduce the carbon footprint associated with the current cold chain by more than 47% while avoiding 55% of food losses.**

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IIR recommendations

It is important to raise public authorities' and decision makers' awareness of the key positive aspects of extending and improving the current food cold chain.

Deployment policies of an extended and more efficient cold chain must be carried out to reduce both undernourishment and greenhouse gas emissions from the food production and distribution system.

The cold chain should be given priority in national contributions to the fight against climate change, and international funding for the fight against global warming should be earmarked.

Improving the cold chain will have an even stronger induced effect by integrating the preservation of health products such as vaccines, whose losses due to a lack of cold chain are often comparable, if not worse, than those of food products.

Reaching in developing countries the same level of refrigeration equipment as in developed countries may require the concurrent development of road, rail and electricity infrastructure. However, the lack of electricity grids in isolated regions can be compensated for by autonomous local refrigeration solutions such as solar cooling ^[12].



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