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An innovative tool to evaluate and optimize GHG emissions in the food supply

Denis LEDUCQ*[(a)], Judith EVANS[(b)] , Pieter VERBOVEN[(c)], Graciela ALVAREZ[(d)]

[(a)] Université Paris-Saclay, INRAE-FRISE
F-92761 Antony, France, denis.leducq@inrae.fr
[(b)] London South Bank University LBG,
London, SE 10AA, United Kingdom, pieter.verboven@kuleuven.be
[(c)] Katholieke Universiteit Leuven,
Leuven, 3000, Belgium, j.a.evans@lsbu.ac.uk
*Corresponding author: denis.leducq@inrae.fr

ABSTRACT

Food systems' contribution to GHG emissions is estimated to be around 30% of the total emissions. Heating and cooling technologies in food supply chains are highly important in maintaining the safety and quality of perishable food, but these operations are also energy-intensive and GHG emitters.

Simulation tools can be essential for the evaluation of the efficiency and sustainability of food supply chains. Such tools can help in identifying critical points in those chains where efforts should be concentrated to reduce energy consumption and emissions. The software tool presented in this paper can perform a detailed analysis of the food supply chains with a focus on quality, energy consumption, and CO2 emissions.

Based on a tool previously developed in the European FRISBEE project about refrigeration technologies, the software is extended to the simulation of non-perishable foods, heating processes, use of renewable energy sources, and use of heat recovery. This simulation tool will suggest possible improvements of simulated chains to reduce GHG emissions, based on roadmaps developed in ENOUGH European project.

Keywords: food supply, cold chain, sustainability, software, refrigeration, emissions

1. INTRODUCTION

Most of the existing software solutions to evaluate supply chains currently available aim to model the growth, inactivation, and survival of micro-organisms in food products such as the "Baseline Software Tool" (www.baselineapp.com), or "Combase" (www.combase.cc). Other examples are Sym'Previus (www.symprevius.net). For energy calculations, software applications have been developed to calculate energy consumption and emissions of CO2 for some refrigeration equipment. Examples include Pack Calculation Pro, an application for comparing the yearly energy consumption of refrigeration plants developed by the company IPU Innovative factory (http://en.ipu.dk/), "SuperSim" and "Cybermart" developed by Ge and Tassou (200018) and Arias et al. (201019) respectively, both for the simulating energy use of display cabinets in supermarkets, and VCRS (Vapour Compression Refrigerator Simulator) developed by Eames et al. (201220) to study the implications of design choices in terms of energy usage and carbon generation by refrigeration systems for chillers, freezers, and storage rooms.

The FRISBEE tool is a user-friendly software recently developed in the FRISBEE project (Food Refrigeration Innovations for Safety, consumers' Benefit, Environmental impact, and Energy optimization along the cold chain in Europe) that can be used to simultaneously evaluate the effect of time-temperature profiles on the final quality of refrigerated products, and to calculate the energy use and environmental impact of the refrigeration systems being part of the simulated cold chain. This is particularly important because these three sustainability indicators (food quality, energy use, and CO2 emissions) are coupled through temperature.

The use of RES or innovative low-carbon technologies in the FRISBEE tool was not the focus. The innovation potential of the tool presented in this paper rests in the development of a user–friendly web-based tool committed to increasing energy efficiency, reducing carbon emissions, and more generally GHG emissions in food supply chains, but also simulating food quality along the cold chain. This new tool uses the FRISBEE calculation core and incorporates all the experience from the team who developed the FRISBEE tool and the new experience acquired from the ENOUGH group. The tool developed will be completely novel and will be applied to several representative food products in the food supply chain.

The new tool adds novel and innovative outputs to the FRISBEE tool:

- Simulation of whole food chains, from farm to fork. Post-harvest operation and transport to the farm are also included as well as food processes including heating and mechanical operations
- Simulation with renewable energy sources and innovative "green" technologies such as those demonstrated in the ENOUGH project
- Assessment of where the greatest levels of GHG emissions can be saved and the impact on the overall food supply chain through a systems-based assessment. For each sector, we will be able to include suggestions for heat and cold symbiosis, as well as propose the most promising low-carbon technologies (RES, thermal stores, high-temperature heat pumps…).

We expect this new generation of tools will be instrumental in the choice and design of new food chains and the supply of new low-carbon technologies as well as integration within/between each sector of the food supply chain.

2. METHODS

2.1. Software

The general approach has been initiated to develop a web software that can be used to simultaneously evaluate the GHG emissions generated in a particular scenario of food supply and at the same time to compute the time-temperature profile of the refrigerated or heated products, their quality, and safety evolution, energy performance and GHG emissions from heating, cooling and mechanical systems as well as vehicles.

The Frisbee tool (Gwampua et al., 2015) was initially developed in Matlab and available in Windows version, downloadable through a website (https://frisbeetool.eu). To install the software, the user has to first download and install the Matlab Run time. For legal reasons, the Matlab run time could not be directly distributed with the Frisbee software on the website. Installation of this run time also requires admin rights on the computer and can make the installation process difficult for the user.

More conveniently, a web app is a program configured and installed on a remote server and is available using a browser and network access. These applications are developed to run in browsers and do not require any installation on the physical machine. Consequently, they can be run regardless of system specifications (even with low RAM and low processing power) and operating systems. The application is updated directly in the server and is then automatically updated for any user.

For all these reasons, it was decided in the ENOUGH project to work on a web application. The calculation core of the Frisbee tool was isolated from the rest of the code and is called by the web application when needed ("Matlab Core" in Figure 1). "ENOUGH Core" in Figure 1 refers to additional python calculation libraries developed in the ENOUGH project. Part of the Web User Interface (Web UI) and the Web services are handled by the Django framework (https://www.djangoproject.com). Specific features of web apps such as URL mapping, user authentification, site maps, database management (through an object-relational mapper), dynamic web pages (through templates), and administration interface are provided by this framework.

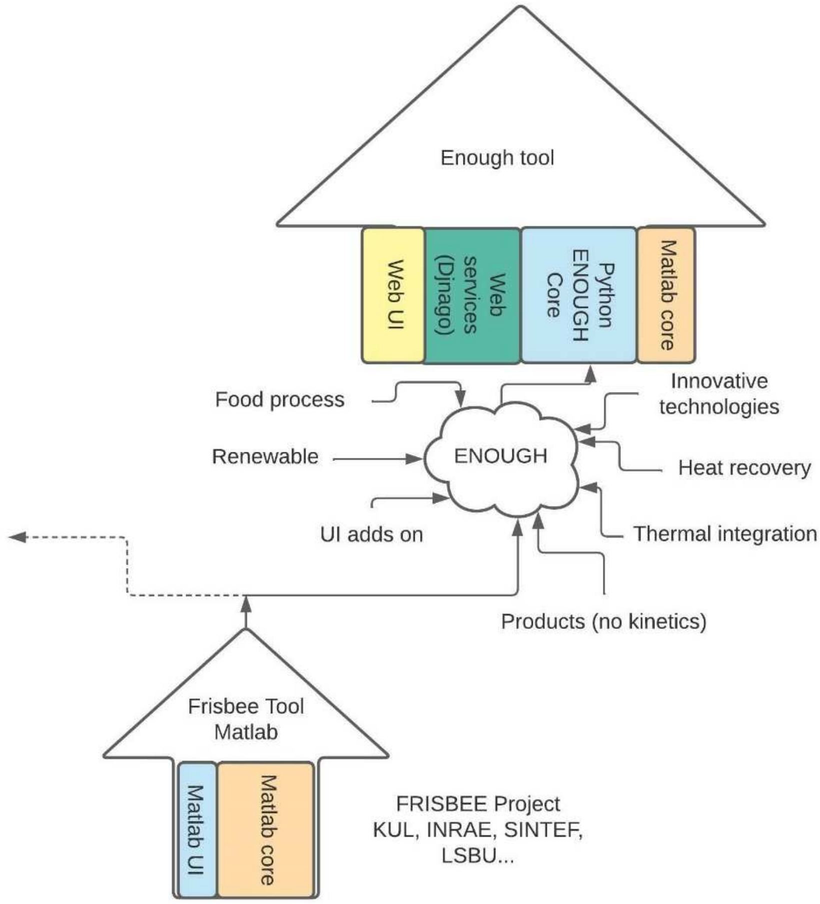


Figure 1: from the FRISBEE tool to the ENOUGH tool

2.2. Calculation procedure

The simulation starts first by computing the time-temperature profile at the surface and the core of the product, taking into account heat transfer by convection at the product surface and conduction inside. Thermophysical properties such as heat capacity, and conductivity of the food product are temperature dependent and evaluated by interpolation in tables obtained from a database.

For every block, energy consumption is then evaluated, depending on the block category (Figure 2). The performance of refrigeration systems and heat pumps is based on vapour compression cycle calculations, taking into account the refrigerant, the temperature sources, the parameters quantifying the efficiencies of the main components, and also the type of refrigeration cycle. The user can modify all these parameters through the UI. Thermophysical properties for refrigerants are obtained from the Coolprop Library (http://www.coolprop.org). Energy use per kg of products is then deduced from the heat load, the systems' performance of the systems and the products' mass.

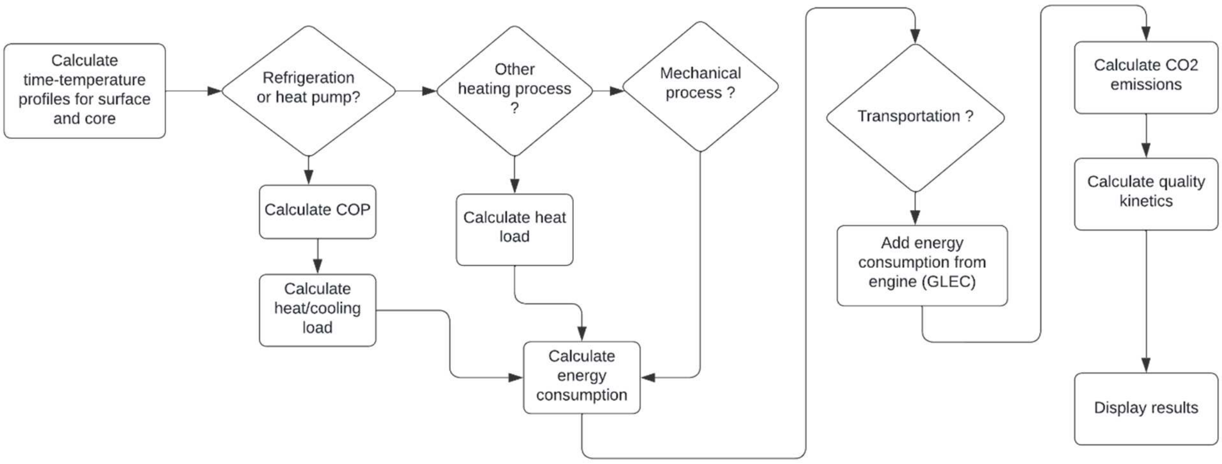


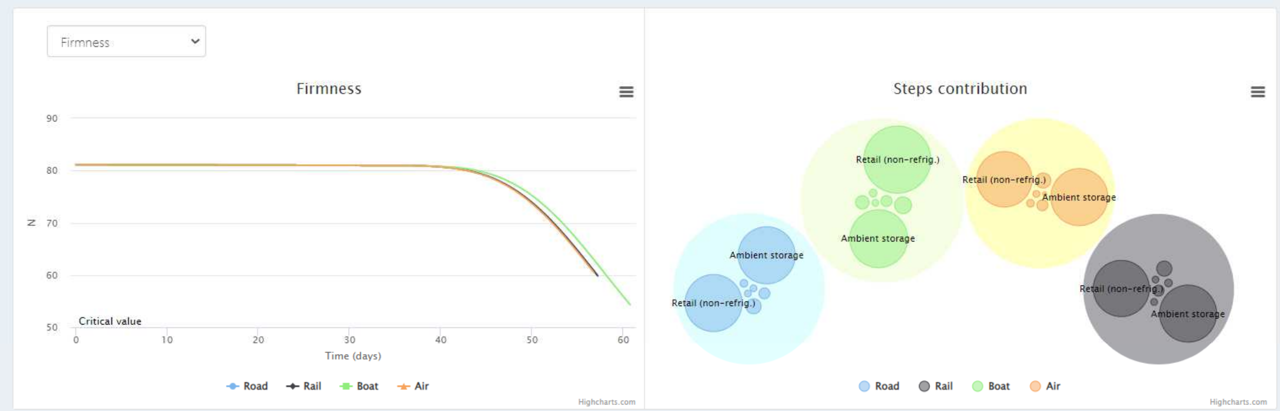
Figure 2: Calculation procedure

CO_2 emissions for refrigeration systems and heat pumps include direct emissions from refrigerants losses and indirect emissions related to energy consumption, using the TEWI concept (Colbourne and Suen, 1999). Indirect emissions depend on the energy source which is specified by the user from a list of options including renewable energy sources.

Emission from transport comes mainly from freight transport, but also includes transport of domestic vehicles, food deliveries, and end-user shopping. There are no ISO standards to measure GHG emissions in logistics. The Global Logistics Emissions Council (GLEC) has released the GLEC framework in alignment with Greenhouse Gas Protocol, the UN-led Global Green Freight Action Plan, and CDP reporting. It seems also in alignment with the European Standard EN 16258. This framework provides a lot of default data representative for Europe. It is a guide on how to measure and report emissions from logistics operations and seems globally recognized as a methodology for harmonized calculation and reporting of the logistics GHG footprint across the supply chain. For example, it is the methodology used by the French National Agency for ecological transition (Ademe). This methodology has been implemented in the tool.

The predicted time-temperature profile for the product is then used as an input to kinetic models of the different quality and safety indicators predicting quality and safety dynamics. Kinetic models are empirical models that describe how storage temperature influences the evolution of different quality indicators.

Results are presented in plots (Figure 3). The sustainability of scenarios for food supply chains can be assessed by a multiple criteria decision analysis approach “ELECTRE III” that can be used as a ranking tool to help the user to make a decision.



Chains ranking

Rank	Chain name	Score	Distance	Firmness	Colour	Relative volatile	Weight loss	Energy consumption	CO2 emission
			km	*N*	*a**	*None*	*%*	*kWh/kg*	*kg CO2/kg*
1	Rail	1.49	805.0	59.91	9.19	561.36	3.05	0.156	0.044
2	Boat	1.1	805.0	54.30	9.81	550.30	3.46	0.13	0.037
3	Road	0.19	805.0	59.77	9.22	561.22	3.06	0.325	0.09
4	Air	-2.78	805.0	60.44	9.10	561.85	3.01	2.733	0.73

Figure 3: Results display

3. USING THE TOOL FOR EVALUATING EMISSIONS

The user starts a simulation by selecting a food product. Then a cold chain can be built by selecting pre-set blocks (Figure 4) from a list depending on the product. Blocks can be moved, edited, or deleted after adding them to the chain. The user can modify the properties of the blocks (such as duration, set-point temperatures, and type of component…) (Figure 5). Different cold chains can be simultaneously built, for example by duplicating the first one and modifying a few parameters) and then simulated for comparison.

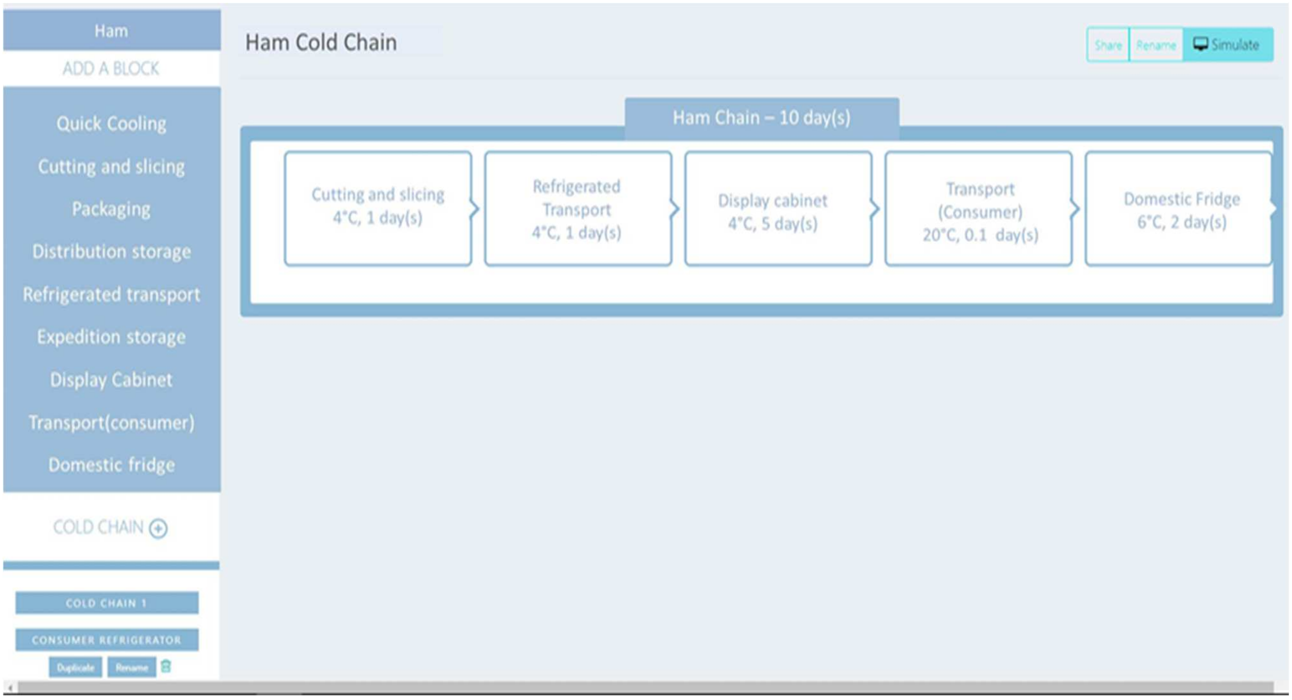


Figure 4: Main graphical user interface for building the chains

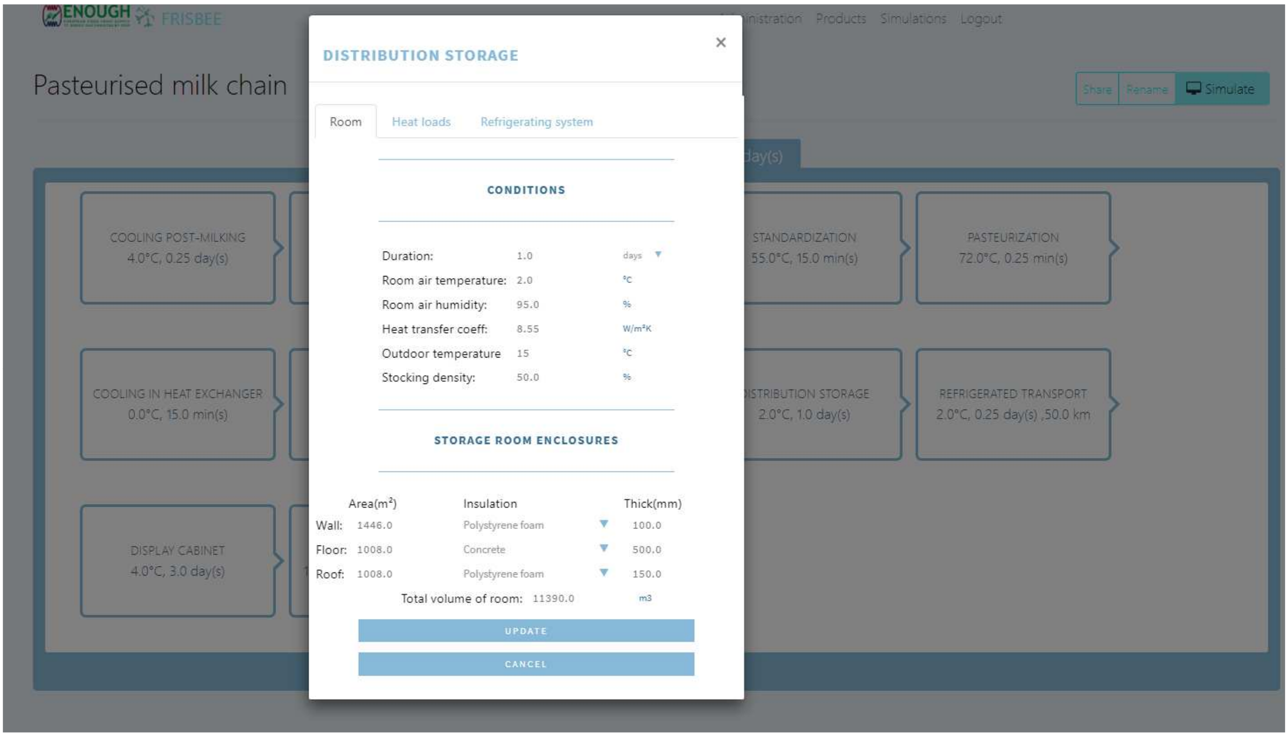


Figure 5: Modifying block properties

To illustrate the use of this tool, a few examples are considered.

In the first example, the effect of the transportation mode is considered. A first chain for apple is defined with a first step of pre-cooling at 1°C, then controlled atmosphere storage for 30 days at 1°C, a short step of packaging, and then transportation of 800 km by road at 15°C, followed by a retail block of 14 days, transportation by the consumer and finally to be placed in a domestic fridge. Three other alternatives are then simulated, replacing road transportation with rail, boat, and air transportation.

Simulation results are presented in Table 1. Quality indicators such as firmness or weight loss show relatively similar results, except for boat which is the slowest transportation mode (air being the fastest). In this case, CO2 emissions as a sum of the emissions of every block are low for both boat and rail, a little higher for roads, and much higher for air. The table also presents the ranking suggested by the tool that aggregates the various indicators (quality, energy consumption, emissions).

Table 1: Comparison of road, rail, boat, and air transportation for apple supply chain

Rank	Chain name	Score	Distance	Firmness	Colour	Relative volatile	Weight loss	Energy consumption	CO2 emission
			km	N	a*	None	%	kWh/kg	kg CO2/kg
1	Rail	1.49	805.0	59.91	9.19	561.36	3.05	0.159	0.044
2	Boat	1.1	805.0	54.30	9.81	550.30	3.46	0.133	0.037
3	Road	0.19	805.0	59.77	9.22	561.22	3.06	0.328	0.09
4	Air	-2.78	805.0	60.44	9.10	561.85	3.01	2.737	0.729

In the second example, the effect of long-distance transportation is investigated, comparing a long chain with road transport with a “local” chain with short distances. The long-distance chain is presented in Figure 6, with transportation by road of 700 km (trailer).

Figure 6: Example of long-distance chain for apple

The alternative is a local distribution chain where the consumer comes to a local distributor as presented in Figure 7. It has to be noted that the quantities involved in the transportation block in this alternative are much lower than the quantity in the trailer used in the long-distance chain.

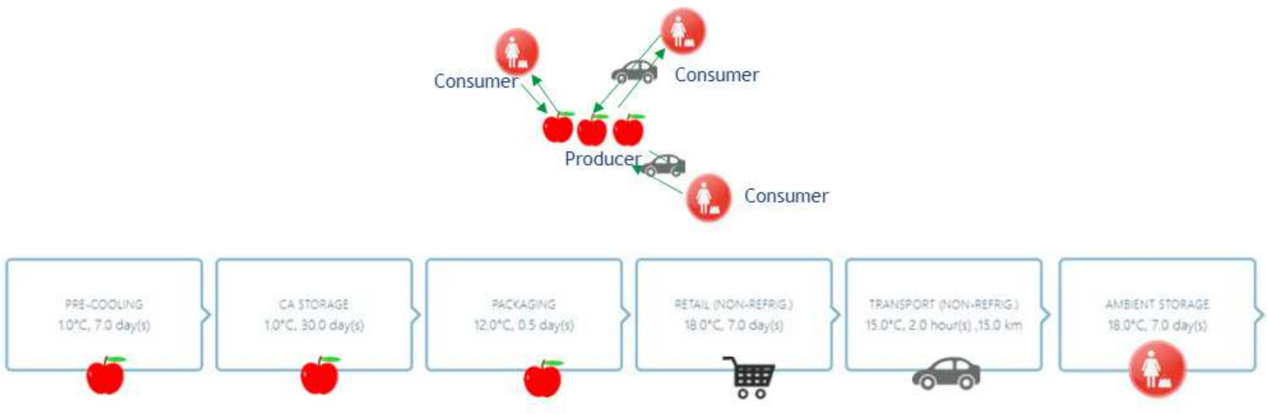


Figure 7: Local distribution alternative for apple chain

The results of the simulation are presented in Table 2. Even if the distances are not comparable, it can be seen that the emissions for the two chains are relatively similar when presented as a mass of CO2 by unit of mass of product. This comes from the low quantities transported by the consumer compared to the few tons of products transported by the trailer. Nevertheless, quality indicators show better values for the local chain since the duration of the global chain is lower than the duration of the long-distance chain.

Table 2: Simulation results comparing long-distance and local distribution chains

Rank	Chain name	Score	Distance	Firmness	Colour	Relative volatile	Weight loss	Energy consumption	CO2 emission
			km	*N*	*a**	*None*	*%*	*kWh/kg*	*kg CO2/kg*
1	Local	0.57	15.0	71.26	4.74	532.26	2.28	0.255	0.071
2	Long distance	-0.57	705.0	70.32	5.30	535.75	2.38	0.287	0.079

How does one compare a sterilized milk chain that does not involve refrigeration with pasteurized milk chain that uses refrigeration all along? What would be the effect of a temperature increase of a few degrees all along the cold chain for frozen products on quality, energy consumption, and CO2 emissions? What is the real impact of storage at ambient temperature for 1 hour for a frozen product at one step of the cold chain? Considering all these questions through simulations using the tool is a good starting point for more investigation.

4. CONCLUSIONS

The first purpose of the ENOUGH tool is to provide a tool for assessing GHG emissions along the European food supply chain. This tool can be used by stakeholders to evaluate the impact of modifications of food supply chains, but also students or researchers looking for a simulation tool, policy decision-makers to help them to quantify the impact of regulation changes, and more generally, everyone interested in it. It is also a dissemination tool for the promising technological solutions demonstrated in the ENOUGH project (https://enough-emissions.eu) which aims to provide tools and methods to contribute to the EU Farm to Fork strategy to achieve climate-neutral food businesses. This tool is still under development, the final version being available at the end of the ENOUGH project in 2025.

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