ICCEE

Improving Cold Chain Energy Efficiency in food and beverage sector

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Report on Life Cycle Assessment and Costing

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Project Coordinator: Simone Zanoni, University of Brescia, simone.zanoni@unibs.it

Authors: Fabian Diaz, Riga Technical University - fabian-Andres.Diaz-Sanchez@rtu.lv , Francesco Romagnoli Riga Technical University - francesco.romagnoli@rtu.lv

The ICCEE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 847040.

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Project information

Project Title	Improving Cold Chain Energy Efficiency
Project Acronym	ICCEE
Project Number	847040
Project dates	September 2019 – August 2022
Abstract	The ICCEE (Improving Cold Chain Energy Efficiency) project will facilitate Small and Medium Enterprises (SMEs) in the cold chains of the food and beverage sector to undertake energy efficiency measures (EEMs) after carrying out supply chain energy audits. The focus on the cold chains of the sector is due to the significant energy requirements (refrigerated transport, processing and storage) with large potentials for savings. The implementation of the holistic approach, shifting from the single company perspective to the chain assessment, lead to increased opportunities for EEMs. To enable the update of EEMs, ICCEE will a) implement and apply an analytical energy efficiency tool to support and facilitate decision-making at different company organizational levels and b) launch a capacity building program towards staff and relevant stakeholders and a community dedicated to support a change in energy culture of the sector. The feasibility of EEMs will be evaluated by considering economic, environmental and social impacts encompassing their entire life cycle and the entire supply chain. Non-energy benefits and behavioral aspects will also be addressed and recommendations on financing schemes for SMEs will be assessed. The first part of the trainings will reach 300 companies through 20 national workshops thanks to the collaboration of associations in the consortium. 32 companies will be trained for the use of the tool in 4 EU workshops. At a final step, ICCEE will launch e-learning courses, which will be available also beyond the project's lifetime reaching at least additional 64 companies. ICCEE will introduce primary energy savings (118 GWh/year), increase invested capital in sustainable energy (64 million €), and reduce GHG emissions (40,376 tonCO2/year). Capacity building activities allow to increase stakeholders' knowledge and enhance their energy culture (2000 people). Outcomes from ICCEE will also support policymakers in defining tailored policies for the sector.

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About

The project Improving Cold Chain Energy Efficiency (ICCEE) will accelerate turning energy efficiency opportunities in small and medium sized enterprises (SMEs) of the food and beverage sector into actual investments and create a clear understanding of the opportunities offered by improving energy efficiency for companies' staff.

The specific objectives of ICCEE are:

1) Implement and apply an analytical energy efficiency tool to support and facilitate the decision-making processes of the companies in the supply chains in assessing their current energy performance of the supply chain.

2) Identify the energy saving potential of companies and support investments in viable energy efficiency improvement measures.

3) Create a capacity building programme and a community dedicated to support the change in the energy culture of organizations improving their energy performance through direct training and the development of an e-learning module.

ICCEE will make it easier for SMEs in the cold chains of the food and beverage sector to undertake to understand the relevance of their supply chains for energy efficiency.

The focus on the cold chains was chosen because of the sector's substantial energy requirements (refrigerated transport, processing and storage) and considerable potential for energy savings. The cold supply chain is among the most energy-intensive systems within the food and beverage sector whilst there is limited understanding of its large energy efficiency potential and the economic advantages that can be obtained from energy saving measures.

The implementation of a holistic approach, shifting from the single company perspective to the chain assessment, leads to increased opportunities for EEMs.

ICCEE is coordinated by the University of Brescia with 12 partners: IEECP, FIRE (Federazione Italiana per l'uso razionale dell'energia), Adelphi Research, ATEE (Association Technique Energie Environnement), Fraunhofer ISI, Riga Technical University, ESCAN, SPES GEIE, ECSLA, Chamber of Korinthia, University of Stuttgart, and Romalimenta.

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Table of Contents

List of Figures

Executive Summary

The LCA/LCC tool for assessing different environmental and economic impacts across the food cold supply chain has been developed following the guidelines and methodology proposed by ISO 10040 and 14044 [1] [2], and simplified for delivering a user-friendly interface. The main goal is to provide the practitioner with a tool able to supply accurate and the best possible inventory data results for a given supply chain model. Regarding the LCA tool, three basic impact categories are included, one for global warming potential, another one for the cumulative energy demand, and finally one for the water scarcity. On the other hand, the LCC assessment tool provides output data in terms of Net Present Value, Internal Rate of Return and Profit Index, and others used in the societal evaluation. These set of tools allow the user to insert two types of data, foreground, and background data, then, making of it a very flexible and use friendly evaluation instrument for quick and streamlined LCA and LCC model of cold supply chains.

The data available in the database for the user to create a model range from transport vehicles, distances, fuels to storage and waste scenario activities. All the data are processed using a specific inventory dataset gathered by available commercial and free databases, in terms of conversion factors normalized to 1 kg of the selected food product.

The tool delivers output data in different ways, for different purposes. From simplified charts, to result tables displaying raw data results per each stage and graphs for hotspots detection.

The tool is intended as a resource for training material in the tasks of spreading the findings and advances of the project and it was and still can be, subject to improvements made or suggested by any partner within the project.

1. ICCEE Project

1.1. ICCEE LCA-LCC tool

The ICCEE Life Cycle Assessment (LCA) tool integrates inventory data from existing LCA databases to assess the environmental performance in three different areas of concern. Specifically, the tool is designed to help practitioners and/or interested cold chain actors to quickly identify the environmental impact of cold supply chains in terms of global warming potential, cumulative energy demand, and water scarcity.

The main novelty brought by this tool is the quick assessment of environmental impacts while creating different scenarios for cold chains within most countries of the EU-27. The Life Cycle Assessment methodology proposed by ISO 10040 and 14044 is simplified in this tool so that the users can create their own product system, changing boundaries to evaluate from a cradle-to-grave to a gate-to-gate system including processes taking place upstream and downstream from a single actor stage.

The ICCEE LCA tool allows to the user selecting the particular and exact type of product to be assessed, hence accounting for the production of it within the LCA. The tool also allows to consider if regional or global cold chains are to be modeled, automatically expanding the boundaries by inserting the proper stages necessary for the evaluation of the latest type of chain.

On the other hand, the Life Cycle Costing (LCC) tool relies only on foreground data supplied by the tool user, but the tool also contains a database with basic economic values that can be changed if, or when needed by the tool user. The main core of the LCC tool is the various approaches it presents, conventional, environmental, and societal LCC, each one of them offering a different evaluation point of view.

The overall tool considering the merge of the LCA and LCC modules can be used by many different users, from students interested in environmental impact assessments or energy efficiency in industrial sectors to technical experts and companies involved in the cold supply chain. Thanks to its simplified approach, both tool's modules (i.e. LCA and LCC) are almost ready to be used at once by any stakeholder with a known defined product system to evaluate, however, basic training might be necessary to avoid calculation errors or misusing the tool.

2. Outputs and Results

The ICCEE LCA tool provides inventory data in terms of outputs to the environment from a simplified Life Cycle Assessment approach. The LCA allows creating product systems by selecting the type of cold chain (regional or global), different input materials (food products and packaging materials), transport vehicles, distances, travel time and payload, energy sources, and other relevant materials or substances required for the model. Furthermore, the tool allows the user to create downstream waste treatment scenarios for several stages (this is optional in the tool and could eventually be sued as sensitivity analysis). LCA results

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are presented as environmental impacts quantified using three different methods for three main impact categories, Global Warming Potential (GWP) as CO_2 equivalent using the IPC100a methodology, energy intensity in MJ with the Cumulative Energy Demand method, and water scarcity as m^3 using the AWARE methodology.

The LCA gives a holistic overview of the environmental performance of a cold chain scenario, linked to its stages and input and output processes. An environmental impact is not only important for a single stakeholder, but for the region country and overall society. This way, the ICCEE LCA tool delivers an overall and wide picture of the environmental impact of a specific cold chain whose outputs can be used and relevant for different target groups. These can be investors, food producers or processors, local communities, supply chain partners, and customers, or eventually LCA practitioners.

The main benefits can be as broad as financial, by reducing transport vehicle numbers or by switching to another type, by making changes in the energy use section, and by improving the regulatory compliance burden and waste disposal costs. It can also deliver a marketing advantage by showing the environmental performance and sustainability of a company even with respect to the overall supply chain.

The output indicators describe all the activities related to a cold chain over the reference time of one year. The input data must be inserted for the intended product to model and in a one-year calculation base. Nevertheless, data for a simpler scenario, such as a defined single occurrence cold chain, can be modeled, but deeper expertise in the tool might be required.

2.1. LCA Output indicators

The three selected LCA-output indicators or impact categories considered in the ICCEE LCA tool are:

- Global Warming Potential (GWP) quantified in GHG emissions represented by kg of CO_2 equivalent.
- Cumulated Energy Demand (CED) in MJ, which is the accumulated energy required including all background process.
- Water scarcity in m^3, which measures the potential of water deprivation, to either humans or ecosystems, understood as the available water remaining in a watershed (AWARE methodology).

  See section for further information.

2.2. LCC Output indicators

For the Life cycle cost (LCC) assessment within the ICCEE LCA-LCC tool, three main types of LCC approaches were evaluated: conventional, environmental, and societal.

A conventional LCC (C-LCC) is a pure economic evaluation and a quasi-dynamic method. Generally, it includes (conventional) costs associated with a product that are borne directly by a given actor. This type of LCC is usually presented from the perspective of the producer or consumer alone. In this approach, external costs, that are not immediately tangible, are often neglected. Additionally, conventional LCC (C-LCC) does not always consider the complete life cycle; for example, end-of-life (EoL) operations are not included in any case. C-LCC is, to a large extent, the historic and current practice in many governments and firms [3].

The environmental LCC (E-LCC) uses system boundaries and functional units equivalent to those of LCA and is based on the same product system model, addressing the analysis to the complete life cycle [4]. In this sense, the two analyses (i.e. LCA and E-LCC) are complementary in the fact that all costs are included as directly borne throughout the chain, including the already internalized cost of external effects. It assesses the cost occurred during the life cycle in its LCA related approach [3].

Societal LCC (S-LCC), as developed for cost-benefit analysis (CBA), uses an expanded macroeconomic system and includes a larger set of costs, including those that will be, or could be, relevant in the long term for all stakeholders directly affected and for all indirectly affected through externalities (direct and indirect cost covered by society). S-LCC includes (but not necessarily) the monetized environmental effects of the investigated product as may be based on a complementary LCA [3].

Due to the different approaches in each type of LCC, different output indicators are used for each of them. On the contrary, C-LCC and S-LCC share similarities, thus their indicators. For C-LCC selected and implemented in the tool mostly economic indicators are included, namely:

- Net Present Value (NPV): is the difference between investment and the total present value of future net income (net cash flow).
- Internal Rate of Return (IRR): is an index illustrating the expected profit versus project investment cost. It can be also said that IRR shows the maximum interest rate of loan which can be tolerated by the project.
- Profit Index (PI): is a ratio between total present value (PV) of future income and initial investment.

The same case considerations regarding the C-LCC applies for S-LCC, however, the additional damage cost is included in the evaluation of the overall cash flows, due to the assumption of "willing to pay" for the social impact. The output indicators for S-LCC are:

- Social NPV (SNPV): it shares the same definition than NPV but including the additional damage costs included in the evaluation.
- Social Cost-Benefit Analysis (SCBA): it is recommended when S-LCC is conducted and is found by dividing the future scenario SNPV in the baseline scenario SNPV. A SCBA value greater than 1.0, shows a social profit from the investment or project evaluated, while a value lower than 1.0 would show a social drawback from the project.

For the E-LCC assessment, the selection of output indicators is more difficult. This is because E-LCC is an approach focused on the estimation of the economic dimension alone or as part of a sustainability assessment. The results are presented as monetary values for each stage within the life cycle without using any discounted rate.

3. Data collection procedure

The first aspect to be considered in connection to the data collection and use in the ICCEE LCA tool is the definition of the type of data to be collected. According to the developed LCA approach there are two types of product systems: the foreground, and the background one.

The foreground system has the purpose of identifying where specific data should be used versus where average or generic background data can typically be used by default ("specificity perspective"). The foreground system is defined as those processes of the system that are specific to it; processes are hence those that are under the direct control of the producer or other actor within the cold chain.

The background system has the purpose of identifying which processes can be managed by direct control or decisive influence from the point of view of the decision-context of a study ("management perspective"). The background system is referred to as those processes, where, due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process. Meaning those processes that are operated as part of the system but that are not under the direct control or decisive influence of the producer of the good.

Within the LCA ICCE tool, the foreground data must be collected mostly from primary data collection activities directly from the actor responsible for the unit process under evaluation. This is the most relevant data to gather, as it represents the input data in the ICCEE LCA tool the user needs to insert all along the tool fields. On the contrary, background data collection activities are already proposed by the tool developers and are the main core behind the tool database matrix.

Foreground data must be collected in energy audits and site-visits to the actor's company during what is part of the secondary data collection activities.

In practice, the developed LCA ICCEE tool provides the possibility to use either primary foreground data or data already implemented in the ICCEE LCA tool.

3.1. On-site foreground data collection

The most important data to be potentially implemented in the LCA tool based on a real audit are more clearly reported in task 3.1 of the ICEE project and normally can be divided into four parts:

1. **General information** on the company including the country where the main operation is conducted, the food sector, and the stage in which the organization is active. Other important details are the yearly product demand, conversion factors

from raw materials to the final product, space occupation in the warehouse and total warehouse area or volume, and average temperature value in the hottest season.

2. **Storage activities**: annual data for production rate, warehouse temperature, annual electricity consumption for refrigeration, and all other energy sources and consumption used for refrigeration purposes. The warehouse utilization factor is quite important for normalizing the energy consumption to the functional unit (FU) under the LCA, hence the warehouse size and average product occupation must be collected, just as the average time, the product is stored in the warehouse. There are other materials that should be tracked down during this data collection phase, as the water consumption and water source, and the annual refrigerant consumption including the type of refrigerant. Finally, any packaging material used for activities related to the unit system must be also included.
3. **Transport activities**: Information regarding the types of vehicles used for the operation under survey is necessary, as well as the type of fuel used, distance, and time to cover such distance. The refrigeration technology within the vehicle is also an important part, just as the source driving the refrigeration unit (truck engine, additional diesel engine, etc.). Within the refrigeration activities, there exist additional valuable information to collect, as the average payload for each type of truck, the refrigerant consumption per year, and if any, the annual water consumption.
4. Finally, information regarding **energy efficiency measures** (EEMs) should be collected. It could be already implemented in measures or measures in the implementation phase. EEM could be encountered in several different areas and might correspond to different types. Changes in the refrigeration systems are the first one that always come to the mind of actors, followed by improving or replacing insulation materials. Yet, EEMs could also be related to changes in auxiliary technologies like ventilation or lighting systems, or changes performed in the building's infrastructure. However, there could be other types or EEMs to be implemented along the cold chain, like technology deployment towards energy recovery or generation, improvements in maintenance procedures resulting in energy savings or even training activities for employees having an outcome that represents savings in either monetary or energy terms due to behavioural changes. Finally, there exist other types of EEMs: Those that come from management activities, i.e. energy audits, adjustment on operation parameters, new energy management systems and others; and those coming from monitoring and control technologies and procedures.

3.2. Background data collection

Data collection for the background system was performed by authors of the ICCEE LCA tool following the framework found in the ISO 14044 for Life Cycle Assessment, most precisely, following the Life Cycle Inventory step methodology. The Life Cycle Inventory activities consist of collecting, tabulating, and performing a preliminary analysis of emissions and resource consumption, and it is necessary to calculate and interpret indicators of potential impacts associated with the exchange of such flows with the natural environment. In general, the background data necessary for the tool was divided into similar groups and subgroups than the foreground data. The data collected for each inventory item corresponds to the environmental impact associated with it, for the three selected impact categories: GWP, CED, and water scarcity.

Hereafter is reported more clearly which data and which categories are included within the proposed database:

1. **Transport**. In this group, several types of vehicles were added to the tool's database:
    a. *Road transport*. Mainly trucks used for long-distance transport were included in this subsection, from freight light commercial vehicles up to 32-ton capacity lorry. Only vehicles with diesel engines EURO 5 and EURO 6 were included.
    b. *Road refrigerated transport*. In this sub-category, the same type of trucks than in the latest one is found. Yet, an important difference exists for this group, as the data collected for the impact categories correspond to vehicles where the refrigeration unit is driven by the main truck engine. Hence, if one of the lists under this type of vehicle is chosen in the tool, it is assumed the refrigeration unit does not require any additional source of power or fuel to run.
    c. *Global transport*. Within this subgroup, types of transport commonly used for transoceanic shipping are found including trains, aircraft, and ships.
2. **Products and materials**. Manufactured/Finished products or ready for distribution of raw materials, and packaging materials are aggregated in this category. It must be clear, that the environmental output resulting from selecting any item of this group contains the total impact of the back-stream process of that specific good produced in a cradle-to-gate perspective. This means that the goods under this group do not correspond to a consumable or auxiliary item within a specific cold chain. Nevertheless, taking into account the input entering a specific cold chain (for example fresh fish, or fresh meat) the selection of a specific still unfrozen product will give the possibility to reflect also in the downstream cold supply chain process the associated environmental burden of all is specific transformation activities necessary for its production.
    a. *Products*
        i. Dairy products. Cream, cheese, and processed milk are included in this sub-category.
        ii. Fish products. Fresh fish, super chilled fish and frozen fish products are included in this sub-category
        iii. Meat products. Poultry, frozen eggs and meat and frozen meat products are found under this subcategory.
    b. *Packaging materials*. Some of the main packaging materials used nowadays in the food industry are encountered in this category, from food-grade glass to different type of polymers and plastics.
    c. *Water*. Different sources for water consumption are included in the database, from underground water to deionized water.
3. **Energy sources**. A wide range of energy sources is available in this section in order to provide the maximum flexibility to the tool user, despite the type of actor and stage in the cold chain to model.

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   a. *Electricity*. Two types of electrical sources have been included in this sub-category, the electricity taken directly from the country grid and electricity self-generated from other energy sources.
      i. From country mix. Electricity for most countries within the Eurozone at medium voltage level is included in terms of transmission of 1 kWh.
      ii. From fuels. Electricity generated from different types of fuels is gathered on this list. Includes but not limited to photovoltaic, natural gas, and fuel oil.
   b. *Fossil fuels*. In this subcategory, three main fossil fuels are aggregated, natural gas, oil, and coal. For each one of them, several options are available to the user, depending on the country or region, and in some fuel's features such as low- and high-pressure natural gas. On the contrary than electricity, their units correspond to mass/volume depending on the fuel, hence, this must be clear at the moment of an energy audit.
   c. *Biofuels*. The most common biofuels are found in this list: biogas, bioethanol, biomethane, methanol from biomass, and biodiesel. Just as in the previous subcategory, the unit measure depends on the type of fuel (kg or m^3).
   d. *Heat*. Several heat sources are included here, organized by type of fuel and then by the plant size. Coal and natural gas are the predominant sources and cogeneration technology is also included. Options go from 5 kW up to 10 MW plants, and district or industrial heating can also be found as energy sources to include within the model.
4. **Refrigeration materials**. This section aggregates the refrigerants required for the refrigeration units at the warehouses and transport vehicles, and the fuels required to run independent refrigeration units (those not driven by the main truck engine).
5. **Waste disposal**. This database set presents several and the main disposal scenarios for the most packaging materials used in the food industry, for wastewater, for wastes resulting from slaughterhouses, and for other biodegradable materials. The options presented are for a mass unit of material subject to the chosen waste treatment technology. Within the tool, transport to the treatment plant is included in the waste disposal scenario.

The data collected for creating the database comes from several different sources and methods, but all of them recognized and used by the academic and industrial sectors. The data inventory refer to a dataset gathered by available commercial and free databases.

4. Data processing

The ICCEE LCA tool focuses on three main environmental indicators. These indicators are calculated following the LCA methodology approach according to ISO 14040 and ISO14044 [1]. For example, the GWP resulting from the consumption of 1 kg of light fuel oil does not only include the direct impact in terms of emissions from its combustion as an energy source but includes the emissions associated to its life cycle: extractive activities and raw materials, infrastructure and transport of the material itself, etc.

Hereafter is reported a brief description of the selected environmental indicators.

- **Global warming potential** - GWP (in kg $CO_{2\,eq}$, according to the method IPCC 2013, 100a) [5]. IPCC 2013 is the successor of the IPCC 2007 method, which was developed by the Intergovernmental Panel on Climate Change. It contains the climate change factors of IPCC with a timeframe of 100 years. The core idea is to provide a quantitative approach to allow comparisons of global warming impacts of several gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).
- **Cumulative energy demand** – CED is a Life Cycle Impact Assessment methodology quantifying the direct and indirect energy use in units of MJ throughout the life cycle of a product or a process. CED takes into account primary energy use, both renewable and non-renewable, and energy flows intended for both energy and material purposes in MJ. This is a useful approach to determine and compare the energy intensity of certain processes [6] [7].
- **Water Scarcity** – AWARE (in m^3) is evaluating water deprivation in watersheds after human and aquatic ecosystem demands are fulfilled). Namely AWARE evaluates the relative **A**vailable **Wa**ter **RE**maining per area in a watershed after the demand of humans and aquatic ecosystems have been met [8]. Thus, the goal of AWARE is to define the extent to which other water users in a specific area coping against risk of water scarcity. It can be used to calculate the water scarcity footprint in accordance with the ISO standard 14046. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived. The method was endorsed by the EU Joint Research Centre in May 2016. AWARE is to be used as a water use midpoint indicator within the Life Cycle Impact Assessment according to ISO 14044.

The calculation procedure for the three impact categories included in the ICCEE tool is represented by:

$$\text{Output indicator} = \text{input value X conversion factor}$$

A quick example on this calculation is the CED for the consumption of 10 kg of average light fuel oil in Europe

$$10 \text{ kg X } 52.6 \text{ MJ/kg} = 526 \text{ MJ}$$

The input data is collected following the procedure explained in section 3.1 and must be entered into the ICCEE tool by the user, whereas the conversion factors are provided by the tool core. The outputs can be seen either in the sheet for results or directly in the graphs presented in the user dashboard.

4.1. Types of data input

4.1.1. Material and energy flows

It is important to notice, all data regarding material and energy flows must be entered in an annual basis. Material flows are:

- Water consumption;
- Electricity consumption;
- Other energy sources consumption;
- Refrigerants (annual pre-charge);
- Waste materials.

Materials and energy flows are entered on an annual basis in order to make the tool easier to use for industrial (producers or transport) actors, as data collected from energy audit is usually recorded by year. For example, in a food company, it would be unlikely to find data regarding electricity consumption disaggregated per product stored in the warehouse, unless single warehouses are used per each product processed within the facility, which rarely occurs, or if cost allocation of materials and energy flows (utility services) has been performed. On the other hand, water, electricity, and other fuel consumption is easily recovered from annual records from any type of company involved in the cold chain, making it the preferred input basis for such flows.

4.1.2. Payload related data

Another set of input data required in the ICCEE LCA tool is the data concerning the payload. This data, on the contrary to material flows, is not entered on an annual basis due to its intrinsic nature. It is the data concerning the volume/mass of the product to model for transport across the cold chain and to transport activities or stages. These set of data correspond to:

- Distance travelled by each vehicle;
- Travel time;
- Amount of product transported per vehicle;
- The electrical power required for refrigeration and ventilation in independent units (if any);
- Water consumption for any purpose within the transport activities.

However, there exists one data set within the transport activities that is required on an annual basis: the refrigerant annual pre-charge. This data set must be always entered on an annual basis as the allocation of the environmental impact is calculated considering the percentage of annual leakage. Hence, the calculation basis must correspond to the method.

4.1.3. Other data

There are other types of data sets within the tool that need to be collected in order to perform the proper calculations and present the results in accordance with the defined functional unit: It is the data concerning the warehouse size, the time the desired product to model spends within the warehouse before transport, the payload volume, and the average amount of products stored per year in the warehouse. All this data is used for mass and energy allocation of output data and it is important to enter correctly, as it can affect the results dramatically.

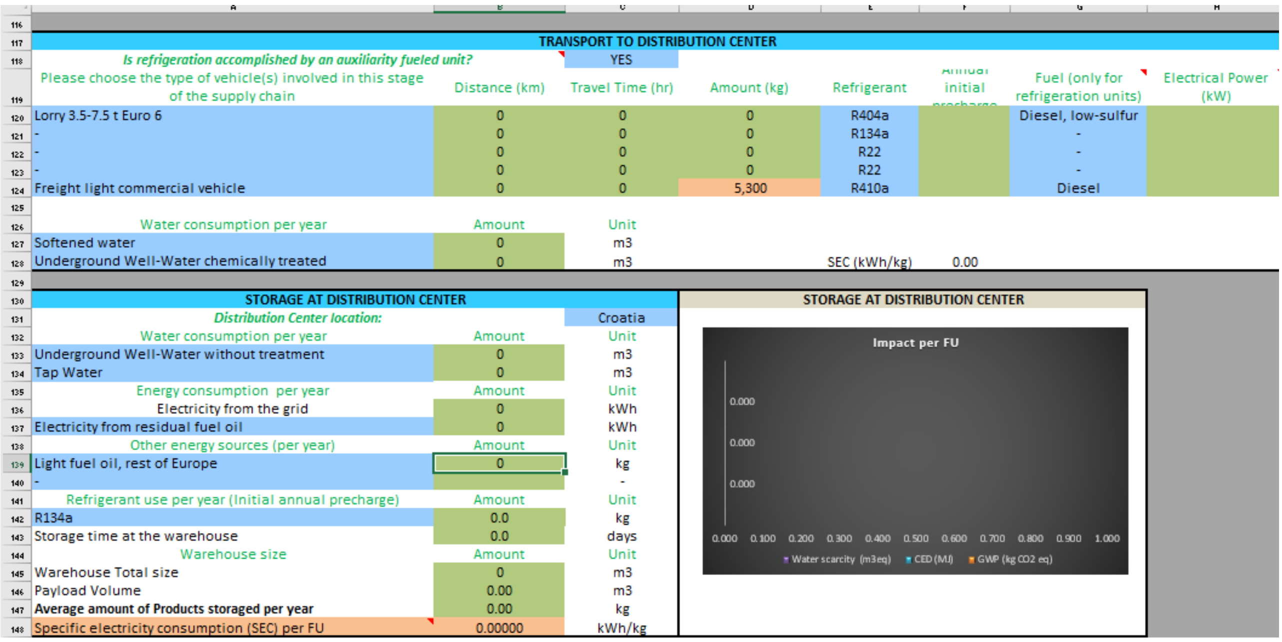
4.2. Data processing in detail

The conversion factors included with the ICCEE LCA tool have been extracted from datasets gathered by available commercial and free databases.

The specific values for each material/process of interest within the cold chain are expressed with an environmental load in terms of GWP, CED, and Water scarcity are included in specific libraries in the LCA ICCEE excel tool and are organized in groups. This approach allows creating specific databases of conversion factors that can be organized by specific types of background data keeping the frame explained in section 3.2. The specific sets of conversion factors are stored in the different data categories aforementioned within the tool.

The latest ICCEE LCA tool available is the v3.3, as the creation and expansion of categories were refined over time to include the material/processes required for successfully assessing a cold chain's environmental impact, and to increase the tool applicability. The newest feature of the v3.3 includes the chance for the user to insert a different food product (not included in the core database) to evaluate its environmental impact across the cold chain. Users must provide the environmental impact assessment for the three different impact categories included in the tool and can play with the storage and transport temperatures the product is going to be subject to along the cold chain. A decision box (Yes/No) for choosing if the own user data is to be applied for the LCA calculation has been included, and the corresponding option must always be selected to ensure correct results.

After the libraries for different categories are defined, a calculation core excel sheet is created in order to process the input data entered in each stage of the cold chain (Figure 1), with the conversion factors stored in the libraries.



	A	B	C	D	E	F	G	H
116								
117	TRANSPORT TO DISTRIBUTION CENTER							
118	*Is refrigeration accomplished by an auxiliarity fueled unit?*		YES					
119	Please choose the type of vehicle(s) involved in this stage of the supply chain	Distance (km)	Travel Time (hr)	Amount (kg)	Refrigerant	Annual initial precharge	Fuel (only for refrigeration units)	Electrical Power (kW)
120	Lorry 3.5-7.5 t Euro 6	0	0	0	R404a		Diesel, low-sulfur	
121	-	0	0	0	R134a		-	
122	-	0	0	0	R22		-	
123	-	0	0	0	R22		-	
124	Freight light commercial vehicle	0	0	5,300	R410a		Diesel	
125								
126	Water consumption per year	Amount	Unit					
127	Softened water	0	m3					
128	Underground Well-Water chemically treated	0	m3		SEC (kWh/kg)	0.00		
129								

	A	B	C
130	STORAGE AT DISTRIBUTION CENTER		
131	*Distribution Center location:*		Croatia
132	Water consumption per year	Amount	Unit
133	Underground Well-Water without treatment	0	m3
134	Tap Water	0	m3
135	Energy consumption per year	Amount	Unit
136	Electricity from the grid	0	kWh
137	Electricity from residual fuel oil	0	kWh
138	Other energy sources (per year)	Amount	Unit
139	Light fuel oil, rest of Europe	0	kg
140	-		-
141	Refrigerant use per year (Initial annual precharge)	Amount	Unit
142	R134a	0.0	kg
143	Storage time at the warehouse	0.0	days
144	Warehouse size	Amount	Unit
145	Warehouse Total size	0	m3
146	Payload Volume	0.00	m3
147	**Average amount of Products storaged per year**	0.00	kg
148	Specific electricity consumption (SEC) per FU	0.00000	kWh/kg

Figure 1. Input data table for different stages.

The final results can be observed directly from the graph that appears beside each stage box (Figure 2) or can be observed in deeper detail in the "LCA Results" sheet of the ICCEE tool.

171	STORAGE IN THE BACKROOM AT FOOD RETAILER OF LARGE CONSUMER FACILITIES		
172	*Food Retailer location:*		Croatia
173	Water consumption per year	Amount	Unit
174	Tap Water	150	m3
175	Underground Well-Water chemically treated	30	m3
176	Energy consumption per year	Amount	Unit
177	Electricity from the grid	5,000.00	kWh
178	-	0.00	kWh
179	Other energy sources (per year)	Amount	Unit
180	Petrol, 15% by volume, ethanol from biomass additive	80.00	kg
181	District or industrial heating	600.00	kWh
182	Refrigerant use per year (Initial annual precharge)	Amount	Unit
183	R22	20.00	kg
184	Storage time at the warehouse	6	days
185	Warehouse size	Amount	Unit
186	Warehouse Total size	120	m3
187	Payload Volume	8.00	m3
188	**Average amount of Products storaged per year**	5,000.00	kg
189	Specific electricity consumption (SEC) per FU	0.00153	kWh/kg

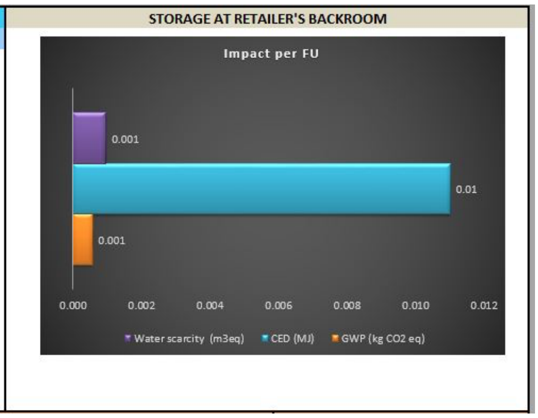


Figure 2. Preliminary results per stage.

In the "LCA Results" sheet, results are presented as follow:

- Total impact of the evaluated cold chain for the three impact categories, and,
- Impact per functional unit (FU) for all impact categories (Figure 3),

	GWP (kg CO2 eq)	CED (MJ)	Water scarcity(m3 eq.)
Total impact of the cold chain	35,593	128,308	2,890

	GWP (kg CO2 eq)	CED (MJ)	Water scarcity (m3 eq.)
Total impact per kg transported (FU)	6.68	23.89	0.59

Figure 3. General output table.

- A chart displays the stage contribution within the analysis for each impact category (Figure 4). Here, the process contribution in each category is presented, and it is valuable for the identification of environmental "hotspot".

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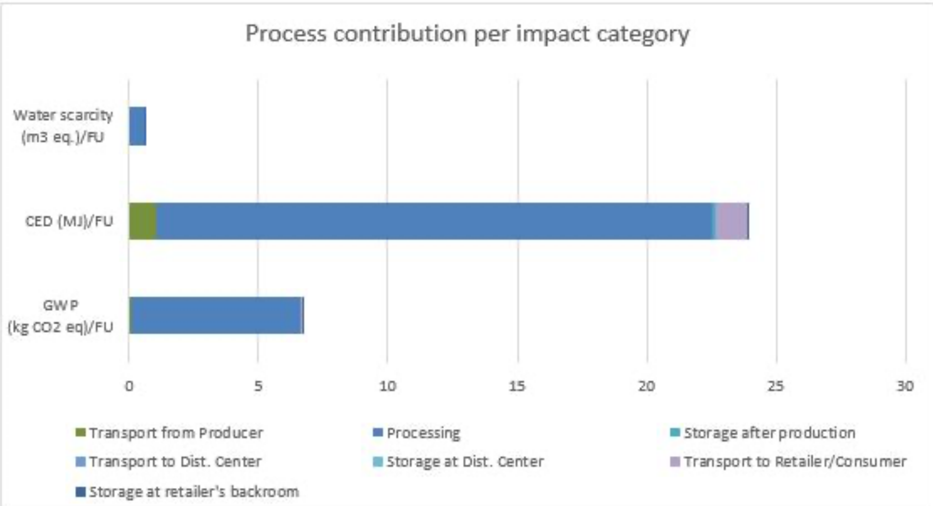

Figure 4. Process contribution chart.

- A table summarizes the results for each stage along the cold chain including a column for the cumulative impact per FU (Figure 5). This table gives the practitioner, the possibility to observe the raw output data for each stage

No.	Cold Chain stages	GWP (kg CO2 eq)/FU	Cum. GWP (kg CO2 eq)/FU	CED (MJ)/FU	Cum. CED (MJ)/FU	Water scarcity (m3 eq.)/FU	Cum. Water scarcity (m3 eq.)/FU
1	Transport from Producer	0.071	0.071	1.021	1.021	0.007	0.007
2	Processing	6.527	6.598	21.487	22.508	0.557	0.564
3	Storage after production	0.007	6.606	0.141	22.649	0.013	0.577
4	Transport to Dist. Center	0.000	6.606	0.000	22.649	0.000	0.577
5	Storage at Dist. Center	0.000	6.606	0.000	22.649	0.000	0.577
6	Transport to Retailer/Consumi	0.077	6.683	1.229	23.878	0.008	0.585
7	Storage at retailer's backroom	0.001	6.684	0.011	23.889	0.001	0.586
8	Overall Waste scenario	0.032		0.320		-0.041	

Figure 5. LCA results per cold chain stage.

- Three pie charts present (Figure 6) the process share contribution for each one of the evaluated impact categories. It works fine for easily identification of hotspots and to understand the stage behaviour.

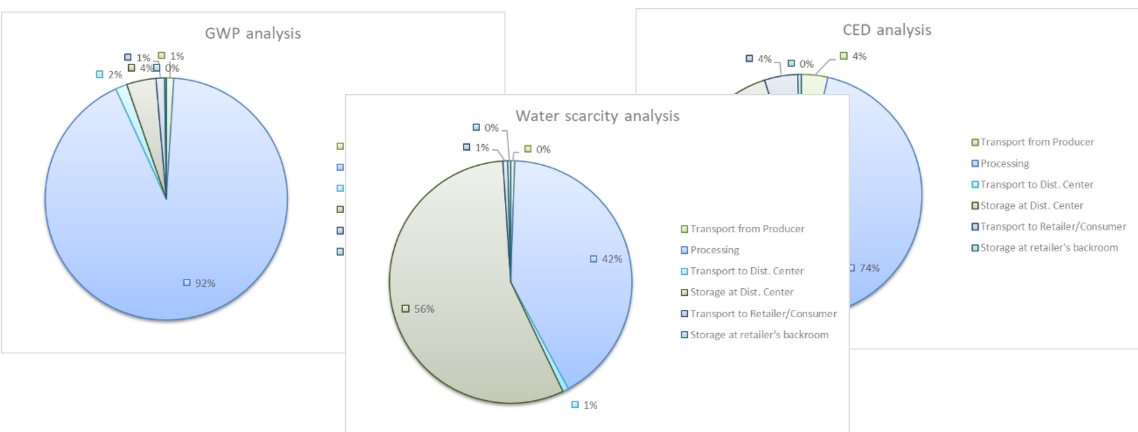

Figure 6. Pie charts displaying the stage contribution (%) for each impact category.

- Finally, three sets of charts presenting the cumulated impact across subsequent stages are displayed, to show the user how different outputs behave downstream the cold chain.

All the data input and output presented up to this point corresponds to the baseline scenario of a determined cold chain. This means it does not include any improvement at any stage in terms of procedures or energy saving. In case Energy Efficiency Measures (EEMs) are to be taken, the resulting changes in flow materials must be entered in a different evaluation scenario.

5. Energy Efficiency Measures

As part of the ICCEE project, the evaluation of several EEMs is performed potentially involving different actors of the cold chain, such as producers, transport companies, or intermediates partners. The potential effect of these EEMs is evaluated within the ICCEE project through and mainly by the impact assessed in terms of Life Cycle Cost (LCC). Hence, the ICCEE LCA/LCC tool gives the user the possibility of assessing up to three different EEMs in a comparative approach with a baseline scenario. A specific data excel sheet "investment data entry" has been thus created in the tool. In this sheet, the costs per each item previously evaluated in the LCA section are defined, and the user can input its own values to assess different regions or markets, under the "Prices" box. The first box, "project costs", is intended for entering all data related to production costs within the actor's business subject to the evaluation. Moreover, the three EEMs investment cost fields are available for the user to insert corresponding data (Figure 7).

Project costs

Project costs			Unit	Baseline	EEM 1	EEM 2	EEM 3	Comments
Definition costs	Design (calculations, internal coordination,... etc)		€					The costs of internal expertise for the project definition phase.
	Technical assistance		€					The costs of external expertise (subcontracted) for the project definition phase.
Investement costs in EEM	Construction	Item 1	€					Correspond to the program costs required beyond the definition phase: the construction costs and the purchase and installation of equipment.
		Item 2	€					
		Item 3	€					
	Equipments and technical instalations	Item 1	€					
		Item 2	€					
		Item 3	€					
		Item 4	€					
		Item 5	€					
Running costs/Cost Categories	Operation and maintenance	Electricity	€/year					Costs for the activities conducted under the cold chain step assessed and directly performed by cost bearer or actor responsible for the stage (internal expertise).
		Fuels	€/year		-	-	-	
		Labour costs	€/year		-	-	-	
		Water	€/year		-	-	-	
		Refrigerants	€/year		-	-	-	
		Other	€/year					
		Vehicle maintenance	€/year					
	Production costs	Raw Material 1	€/year		-	-	-	
		Raw Material 2	€/year		-	-	-	
		Raw Material 3	€/year		-	-	-	
		Packaging material 1	€/year		-	-	-	
		Packaging material 2	€/year		-	-	-	

Figure 7. Project costs and EEMs investment costs.

To evaluate the impact in monetary terms, the EEMs should be defined with reference to the baseline scenario, in this way table box "Expected results from EEM" should be filled and the change related to the baseline scenario performance can be visualized, as shown in Figure 8.

Expected Results from EEM

Expected results/Energy savings	Unit	Baseline	-25	EEM 2	EEM 3	Comments
Change in electricity consumption	%		-5.0%	3.0%	-8.0%	Corresponds to the change in the different material or energy flows, and changes in operational parameters due to EMM's implementation. Please enter the corresponding values.
Change in other energy sources	%		0.0%	0.0%	0.0%	
Change in labour costs	%		0.0%	0.0%	0.0%	
Change in water consumption	%		0.0%	0.0%	0.0%	
Change in refrigerant pre-charge	%		-2.0%	-5.0%	-3.0%	
Change in quality factor	%		0.0%	0.0%	0.0%	Corresponds to the change in the quality factor affecting the total amount of units sold per year.Please enter the corresponding values.
Change in carbon emissions (ton CO_2 eq)	ton/year					Expected amount of carbon emission reduction

Figure 8. Table for expected results from evaluated EMMs.

The reduction in energy consumption is usually the main result of implementing an EEM. However, the ICCEE LCC tool allows to the user evaluate changes in other areas, such as water consumption and even improvements in the quality factor, which might affect the product quality and quantity delivered at the end of the cold chain.

The EEMs can vary in a broad range of options, and some of the most common can be:

- Improvement in ventilation and lighting systems;
- Changes in motors, pumps, and other auxiliary devices;
- Changes in equipment directly affecting the refrigeration systems;
- Improvements to the building in terms of insulation, installing curtains or separated compartments;
- Deployment of new energy recovery technologies.
- Behavioural changes from the staff resulting in energy savings;
- Improvement in maintenance procedures;
- Operational changes;
- Technological improvement of monitor and control laces;
- Direct changes in the refrigeration systems
- Improvements in the transport activities, such as better truck insulation, optimizing travel routes, distances covered and fuel monitoring

The "Investment data entry" sheet presents additional boxes to insert production data and financial factors that are later used for the economic valuation of the EEMs in a C-LCC approach. In this way, the user cannot only evaluate the economic impact in the same financial scenario, but also create different investment scenarios considering factors as the required rate of return, inflation, the loan's interest rate, and share of investment. The Conventional LCC results for the baseline scenario and the three potential EEMs are presented in the sheet "C-LCC Results", showing the cash flow tables for each alternative and a summary table with the main economic output indicators, as seen in Figure 9.

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LIFE CYCLE COST COMPARISON (€/unit)			
Baseline	EEM 1	EEM 2	EEM 3
6.13	5.86	6.30	5.69

	INVESTMENT EVALUATION COMPARISON			
	Baseline	EEM 1	EEM 2	EEM 3
NPV	9,882	6,442	4,681	6,754
IRR	-	44.22%	37.41%	41.84%
PI	-	2.61	2.30	2.50

NPV: Net Present value Is the difference between the total present value (PV) of the incoming net cash flow and the investmet (-K).

IRR: Internal Rate of Return shows the maximum interest rate of loan which can be tolerated by the a project. If *IRR* > *WACC*, then a investment could be accepted.

PI: Profit Index is a ratio between total present value PV of future income and initial investment.

Figure 9. Economic output indicators for C-LCC results.

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Conclusions

The ICCEE LCA/LCC tool has been developed for simplification purposes, easing the Life Cycle approach and evaluation of environmental and economic impacts across the cold chain to new practitioners. The goal of the tool is to offer a general overlook of the environmental performance of a cold chain, identifying hotspots and the contribution of each stage and the most relevant materials or processes. It can also be used to acknowledge and recognize improvement opportunities for a determined actor in the food industry participating in the supply chain of the evaluated product.

The tool interface based on excel platform is intended to be as user friendly as possible, using the pattern of colors for different types of cells, like scrollable lists, editable cells, or self-calculated fields. W within the development of ICCEE project the whole tool interface will be reworked within Task 3 with a final harmonized layout. In that way, the user does not have to perform any calculation by himself and the user's responsibility falls only in the consistency of the gathered input data. All stages are presented in a single sheet, making it easy to track and edit previously inserted values. Preliminary results in form of bar charts are presented immediately, so a more experienced user can perform quick analysis on the logic and magnitude of results. The developed tool does not show calculation sheets and the database libraries are protected to avoid undesired changes to the conversion factor that will affect the resulting output data. Nevertheless, the layout for the tool and other tools within the project will be integrated and harmonized in a later state.

The LCA and LCC results are presented in different ways. While the LCA output data is presented mainly in charts to ease the interpretation of the results, LCC output data is presented in cash flow tables and nominal values for the economic indicators. It is up to the ICCEE LCA/LCC tool user to determine how to use the output data, for example for academic purpose or within project evaluation or for sustainability analysis.

During the ICCEE project, the ICCEE LCA/LCC tool was created in an excel file, to permit and enhance the participation of all the partners involved in its development, in order for all of them to check, assess, and make recommendations on the subsequent updates the tool was subjected to.

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