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Improving milk value chains through solar milk cooling

Ana Salvatierra Rojas, Victor Torres Toledo, Farah Mrabet, and Joachim Müller

Abstract

Smallholder dairy farms are the major providers of marketed milk in Kenya, producing one to ten liters per day. Due to this low production level, farmers are usually associated in cooperatives. Dairy cooperatives are responsible for collecting the raw milk from the members to supply bigger volumes to dairy plants or to the market. These farms and cooperatives are often constrained by minimal hygienic standards and the lack of cooling systems leading to high microbial contamination of the milk. Moreover, under warm climatic conditions raw milk can exceed the maximum bacterial count established by food safety standards. As a result of these factors, 20-30% of the milk is estimated to be lost. Therefore, the Institute of Agricultural Engineering of the University of Hohenheim has conceptualized a solar milk cooling system based on the use of conventional milk-cans in Tunisia. The adopted strategy aims to offer a solution that can be adapted to different farm sizes and milk collecting scenarios. The ice, produced in a solar powered freezer, is used in the milk cans, which were designed with an integrated ice compartment and an external removable insulation for an effective cooling. The solar cooling system was transferred from the Tunisian context and adapted to the primary milk production in Siaya, Kenya. Depending on the amount of ice used, the milk cans can be used to preserve milk quality for six to 16 hours. This technology offers steady ice production year round and assures the preservation of milk quality from the farm to the main collection center or the market. The gradual introduction of the technology provided an important upgrade to the current value chain. Furthermore, the solar powered milk cooling system showed great potential to make the dairy value chain more efficient in off-grid contexts by using clean energy.

Keywords: Solar energy, milk quality, milk value chain, stand-alone systems.

JEL classification: O32, O32, Q1, Q42

Acknowledgements

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1 Solar Milk Cooling Technology in the Dairy Value Chain

Milk has a temperature of about 37°C right after milking and it can spoil after three to six hours if it is not cooled to at least 20°C. Milk spoilage can be reduced by considering good hygienic practices and lower temperatures of storage (Lund et al., 2000; Walstra et al., 2005). Therefore, milk should be stored at low temperature to prevent bacteria reproduction and ensure that bacteria stay under the permissible limits established by national standards, as for example the Kenyan standard KS EAS 67:2007 specifies the quality requirements for raw cow milk[1].

The benefit of cooling milk offers longer storage periods and preserves milk quality during transportation. Milk storage is typically done at 4°C for 48 hours (Griffiths et al., 1987; Lund et al., 2000). Often, though, this cooling process is limited or not applied in rural areas due to high energy costs of conventional electric grid and standalone diesel generators. These factors represent an opportunity for introducing sustainable energy based on renewable energy. As photovoltaic systems have the potential to be acquired in rural areas of many African countries, this technology becomes a viable energy source option.

This report is a summary of the several activities pursued within the Program of Accompanying Research for Agricultural Innovation (PARI) to contribute to sustainable agricultural growth, food and nutrition security in Africa and India. The Institute of Agricultural Engineering, Tropics and Subtropics (440e) worked in the identification of technological innovations and further intervention in the dairy value chain, offering a potential solution for cooling milk from the earliest stage of milk production and aiming at the reduction of milk spoilage. The Social and Institutional Change in Agricultural Development institute (490c) worked in the socioeconomic assessment of the technology.

The case studies presented are for Tunisia and Kenya. Preliminary introduction of the technology took place in Tunisia[2] before the commencement of the PARI project. The lessons learned in the introduction of the solar milk cooling technology in Tunisia and the improvements within the PARI project, along the intervention in the value chain in Tunisia, were transferred to Kenya. The protocol involves the documentation of the state-of-the-art milk production, followed by the introduction of the technology, the adaptation and adoption by the farmers.

1.1 Technological aspects

The reduction of milk temperature right after milking restricts the reproduction of microorganisms and reduces chemical or enzymatic reactions that may affect the quality of milk (Rahman, 2007). Therefore, a small-scale solar milk cooling system was developed at the Institute of Agricultural Engineering of the University of Hohenheim (Torres-Toledo et al., 2015). The concept is based on the usage of ice blocks for cooling the milk in a modified milk can that contains an ice compartment and an insulation cover. The system has commercial components that are minimally modified in order to operate efficiently and offer autonomy for at least four days. These components are shown in Figure 1.

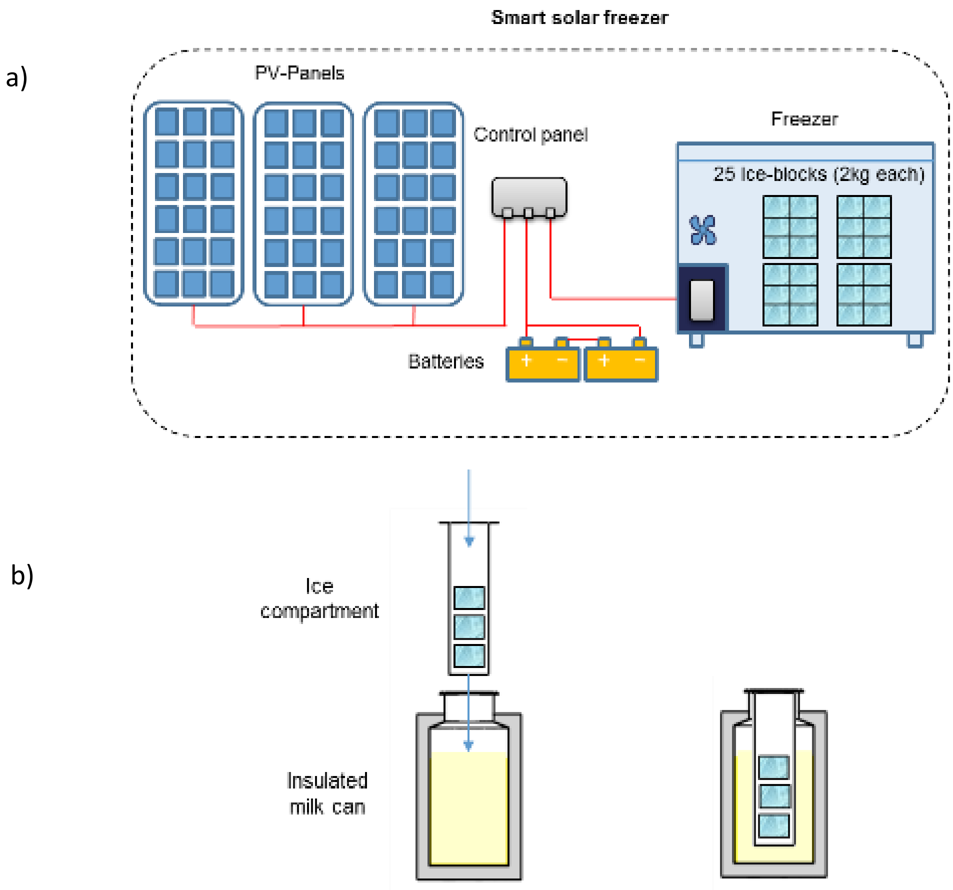
[1] Kenya Bureau of Standards http://onlinecatalogue.kebs.org/webquery.dll

[2] ICARDA https://mel.cgiar.org/projects/spmc

Figure 1: Solar milk cooling components a) insulated milk cans and b) PV modules control panel and DC freezer

The strategy of milk cooling can be divided into two steps: the production of ice blocks through the use of a smart solar freezer in combination with a control panel that manages the solar energy to efficiently produce ice every day, and the cooling of milk done in the insulated milk cans as shown in Figure 2. The ice blocks produced are placed inside the ice compartment and when the insulated milk can is filled with milk, the ice compartment is placed inside the milk can.

Figure 2: Production of ice-blocks with a) the smart freezer and b) milk cooling in the insulated milk can

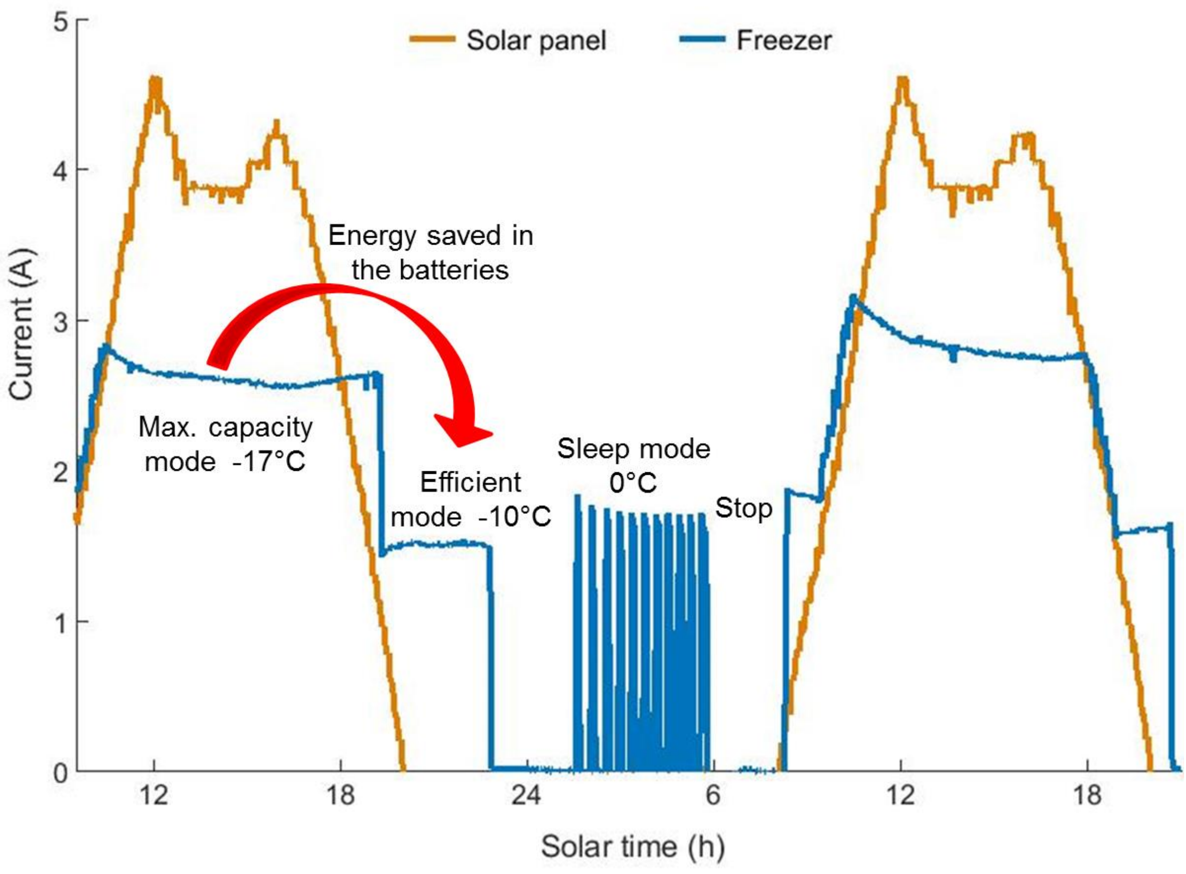


1.1.1 Smart solar freezer

The freezer was slightly modified through the inclusion of a small ventilator which, placed inside the freezer, helped to accelerate the production of ice and regulate the energy consumption of the compressor through a control panel that used an algorithm to react depending on the status of the battery load, compressor speed, and the availability of solar energy (Torres-Toledo et al., 2016).

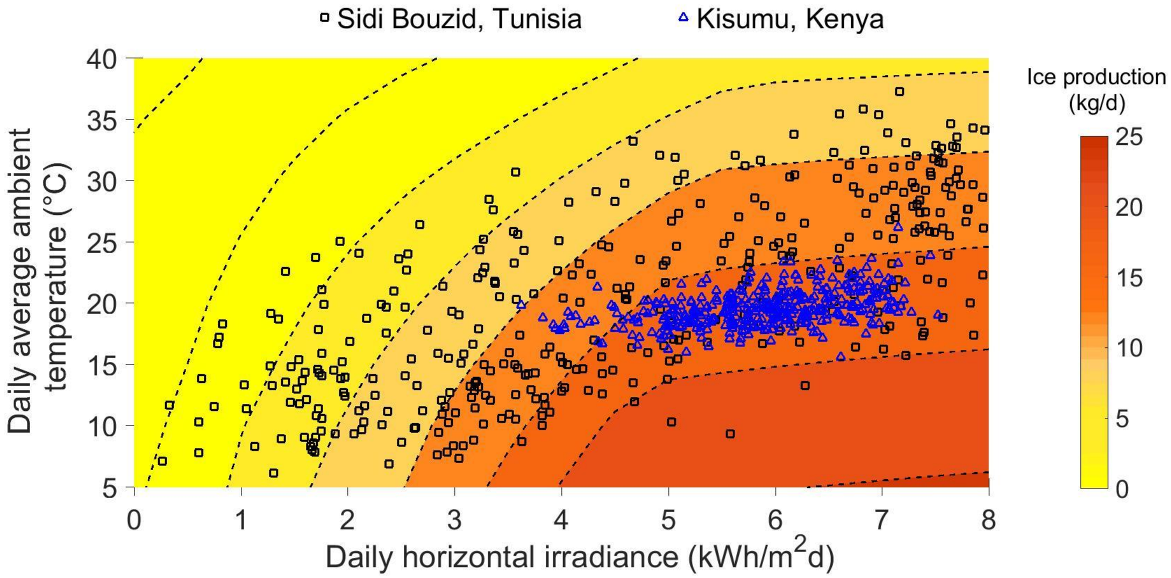
Figure 3 shows the production of ice for a typical day. During daytime, the compressor works at maximum power, reaching a temperature of -17°C. The excess solar energy is stored in the batteries provided in the system. At night, the compressor switches to an energy-efficient mode due to which a constant temperature of -10°C is kept inside the freezer. Lastly, the system goes to a sleep mode, keeping the freezer at 0°C. The following day, the three previous steps are repeated but when the ice blocks are formed, the energy supply to the compressor stops and when ice is depleted and replaced by water, the three steps are re-activated.

Figure 3: Energy consumption of the compressor adapted to solar energy availability



The thermal storage of ice is responsible for the long-term autonomy of the whole ice production and the batteries only help to balance the daily solar energy. Therefore, from the 50kg of ice produced about 16kg of ice can be removed every day according to the evaluation carried out through simulated conditions at the University of Hohenheim (Figure 4). The simulations performed depended on the target country where the system was installed.

Figure 4: Simulations performed for the estimation of daily ice production under weather conditions of Tunisia and Kenya



1.1.2 *Insulated milk cans*

Cooling of milk was performed by using milk cans of different capacities and materials (stainless steel and food grade plastic). Within the scope of the PARI project, commercial milk cans were modified for Tunisia and Kenya. Figure 5 shows the different milk cans with their insulations materials, which were tested at the University of Hohenheim prior to in-the-field evaluations.

Figure 5: Modified milk cans a) 40l stainless steel milk can, b) 40l plastic milk can and c) 10l plastic milk can (Mazzi can)

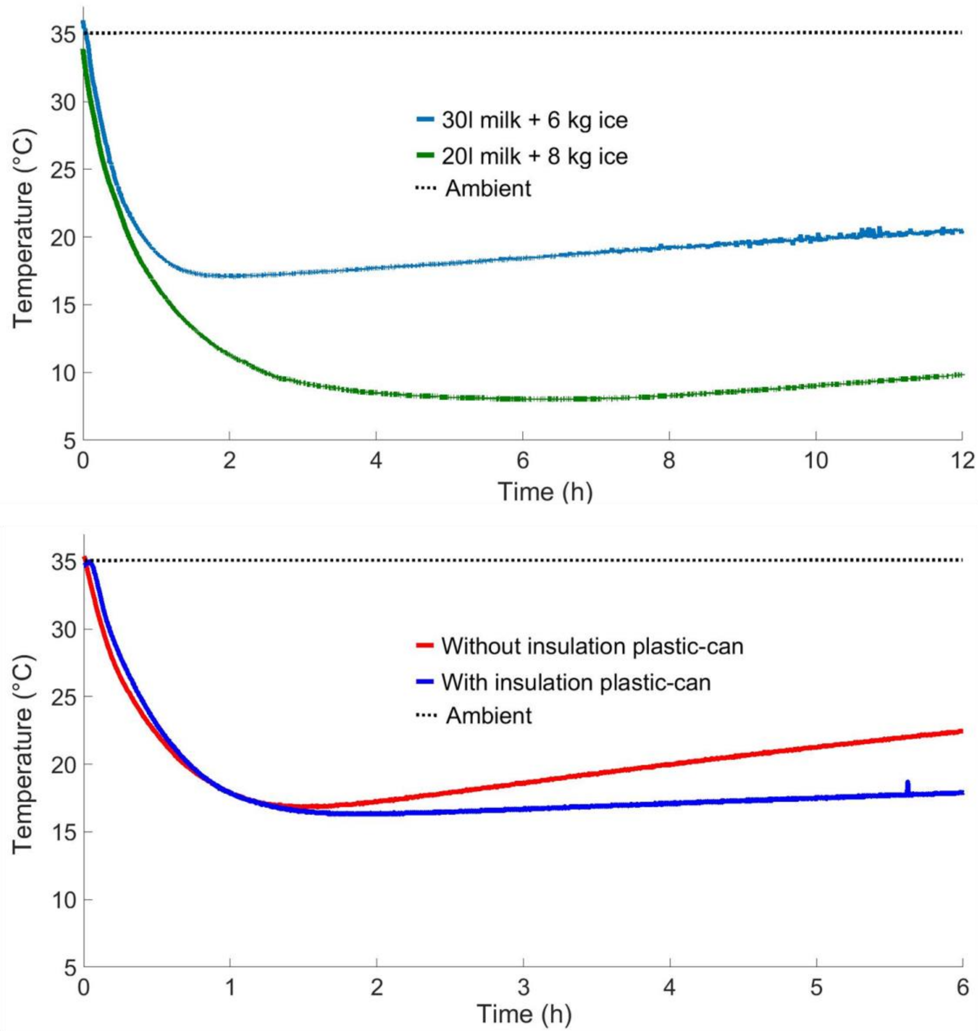
The cooling characteristics of the milk cans shown in Figure 6 were assessed under extreme ambient temperature of 35°C. It was evident that the stainless steel milk can requires a stronger insulation material, compared to the plastic milk can. Nevertheless, the plastic milk cans still required the insulation material in order to reduce the influence of ambient conditions in the cooling process of milk.

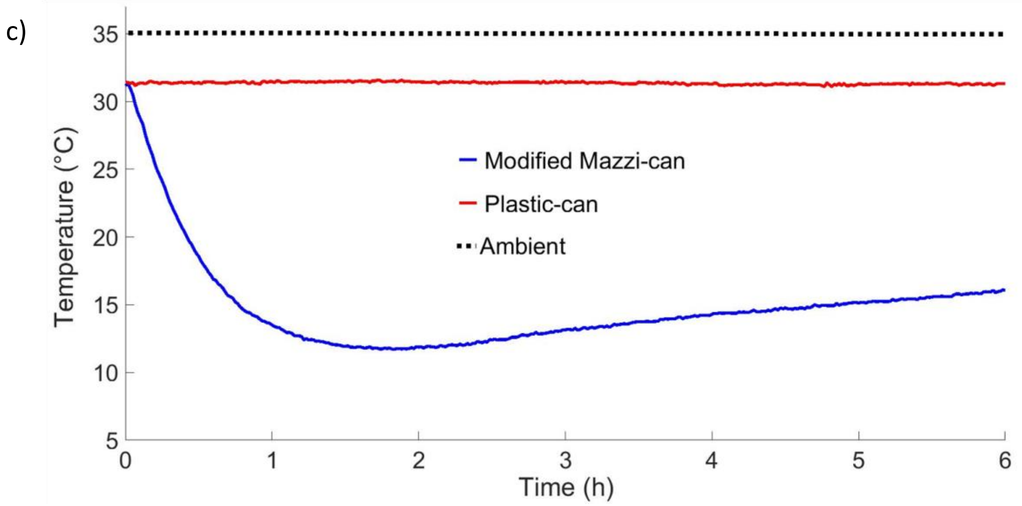
The stainless steel milk can was tested with two different volumes of milk and ice. The cooling curves are as illustrated in Figure 6a. When 30l of milk was cooled with 6kg of ice, milk temperature was able to be kept under 20°C for about six hours, while for 20l of milk and 8kg of ice, the milk temperature stayed under 15°C for more than 12 hours. Figure 6b shows the importance of using insulation material for the plastic milk cans as the temperature of 30l of milk with 6kg of ice increased above 20°C after the first two hours when the insulation was not used, contrary to the usage of the insulation material that resulted in the same performance with the stainless steel milk can, keeping the milk under 20°C for about six hours. Figure 6.c provides the cooling curves using commercial plastic milk cans from Kenya. These milk cans were modified by adding an ice compartment of about 2kg ice capacity and the insulation material. Results show that with the insulated plastic can it is possible to keep the milk temperature below 20°C for about six hours.

Figure 6: Cooling curves at constant ambient temperature of 35°C for a) 40l modified stainless steel milk can with different milk volumes and ice, b) 40l modified plastic milk can with and without insulation and c) 10l modified Mazzi-can and regular plastic milk can

a)

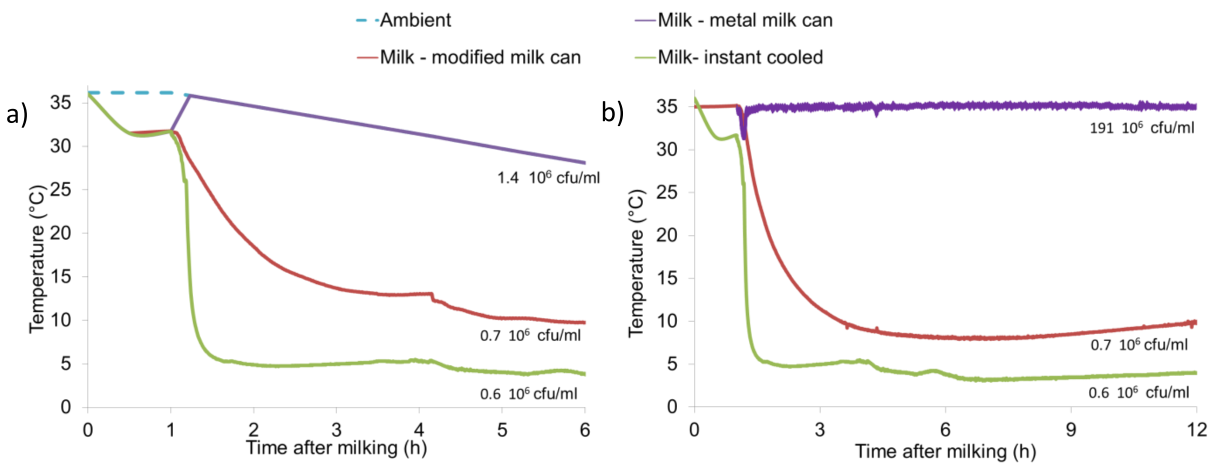
b)





Based on the cooling curves under the simulated steady conditions shown in Figure 6, it was observed that the advantage of cooling milk works within the first six or 12 hours of storage right after milking. Figure 7 illustrates the cooling curves and the microbial load after six and 12 hours and compares the performance of a normal milk can, the insulated stainless steel milk can, and the fast cooling of milk at 4°C. It is possible to conclude that milk is well-preserved when the insulated stainless steel milk can is used and at the same time, it was observed that the microbial load of the milk kept in the insulated stainless steel can had almost the same range as the microbial load of the milk under 4°C.

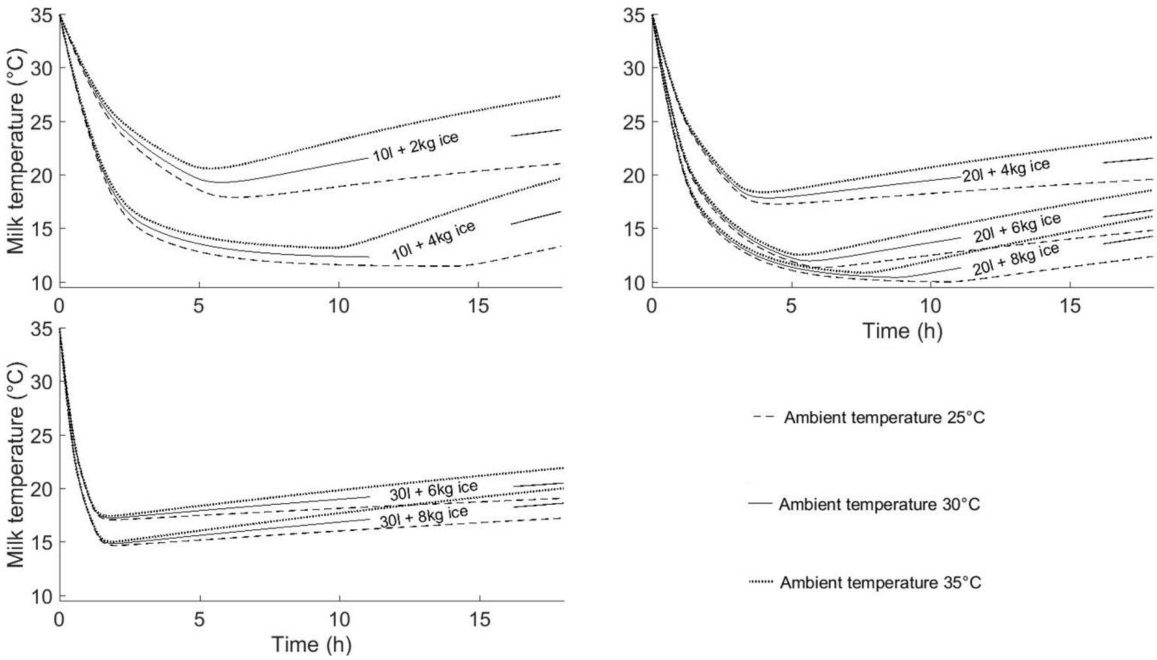
Figure 7: Thermal and microbial load under control conditions after a) six hours and b) 12 hours after milking



According to simulations previously performed, mathematical models were used to obtain the ice ratio for an optimal cooling of milk depending on the existing ambient temperature. Figure 8 provides information on the milk volume and ice amount reacting at three different ambient temperatures. Accordingly, it is possible to achieve optimal cooling performance when 0.2kg of ice per liter of milk is used; this status of optimal cooling lasts for about 6 hours. This observation is independent of the ambient conditions and holds for 10 to 30l of milk.

Conversely, when longer periods after milking are required, 0.4kg ice per liter of milk is required for optimal cooling. This ratio will preserve the milk quality for about 15 hours but according to Figure 8, it is only applicable for 10 and 20l of milk, as the temperature of milk never goes below 20°C for cans with a 30l capacity.

Figure 8: Cooling curves of different milk and ice ratios at different ambient conditions



Source: Torres-Toledo et al. (2018)

1.2 Experience obtained in the field

1.2.1 Case study Tunisia

Milk production in Tunisia is managed by the government in a centralized system, with milk being collected from the farm and transported by car to the dairy plant. Usually, at the farms in the study region Sidi Bouzid, six to ten cows are kept under zero grazing and each farm produces milk ranging from 60 to 180l per day. After milking, farmers bulk the milk in stainless steel or aluminum milk cans and wait for the collector who picks up the milk from the different farms and brings it to the collection center. The collection center facilities are equipped with cooling tanks with a capacity of about 15,000l per day.

Milk is usually collected twice per day (morning and evening) by car. It is either transported in the described milk cans or it is transferred to bigger tanks assembled on the car. However, no cooling process is applied right after milking or during transport. This method of handling milk reduces its quality as the temperature measured after milking was about 35°C and during transportation, the milk cans were exposed to ambient conditions that in relation with longer transport times were enhancing the growth of microorganisms responsible for the spoilage of milk. According to the Tunisian standards on raw milk for processing and fermented milk[3], more than 1,000,000 CFU/ml represent a risk for the consumer health. In most cases, higher values found result in rejection at the reception area of the dairy plant. Consequently, farmers and collectors face a lot of pressure to milk at the right time and then transport the milk to the dairy plants as fast as possible to avoid spoilage.

The initial designs of the insulated milk cans (Figure 9a) were handmade at the University of Hohenheim as part of the project "Field solar powered milk cooling solution for the higher efficiency of the dairy subsector in Tunisia 2015-2017", supported by the GIZ. Ten solar milk cooling systems

[3] NT 14.141(2004) – Lait cru destiné à la transformation – spécifications, http://boutique.innorpi.tn:8080/web/guest/normes

were installed in seven farms in 2016. According to reports from field testing, the milk can was very heavy and some of the farms reported broken ice compartments after intensive use. Thus, new insulated milk cans were prepared considering the feedback of the users and give continuity to the evaluation of the ten solar milk cooling systems. Thanks to the Program of Accompanying Research for Agricultural Innovation (PARI), the initially distributed cans were replaced by a new design for commercial units shown in Figure 9b. The new design was very comfortable and well accepted by the farmers.

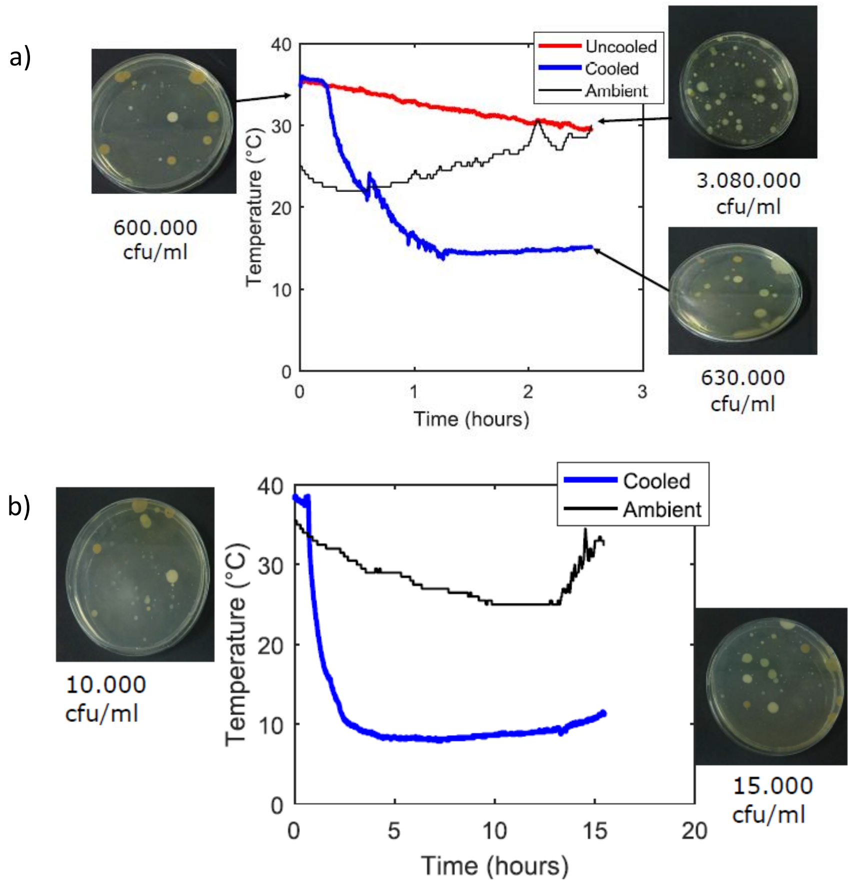
Figure 9: Insulated milk can concept a) initial design and b) improved design

a)

b)

The current milk production in Tunisia fits to the two simulated scenarios previously tested at the University of Hohenheim. The on-field evaluations showed that the morning milk required about three hours of transport to the dairy plant. As shown in Figure 10a, milk is evidently preserved when transported in the insulted milk can, while the milk transported without cooling goes over the limits of bacterial count established by the National Standards. The same was observed for the evening milk that was stored at the farm for about 12 hours in addition to the three-hour transport to the dairy plant (Figure 10b).

Figure 10: Thermal performance and initial and final microbial load for a) morning milk with three hours of transport and b) evening milk with 12 hours of storage on the farm and three hours of transport in Tunisia



The cooling of milk while stored on the farm followed by the cooling during transport could result in a series of advantages for the different stakeholders along the value chain. For example, the farmers who own the system may preserve the quality of the milk from their farms all the way to the dairy plant as the usage of the insulated stainless steel milk cans helps reduce spoilage of milk since temperatures lower than 20°C are maintained. Also, the cooling system offers the collectors, who are short of transport time without cooling systems, more time to transport the milk without risk of spoilage and thus change the milk collection methods as the milk cans are commonly used for transport. These advantages result in better milk quality and reduction of energy consumption for the collecting centers. The dairy plants that collect the milk once a day can be sure of high-quality milk when the insulated milk cans are being used. Finally, the solar milk cooling system may ensure the payment of the farmers at the end of the month due to the preservation of milk until it is delivered to the dairy plants.

1.2.2 Case study Kenya

The lessons learnt in Tunisia helped develop a series of protocols for a successful assessment of the solar milk cooling technology for Kenya. Table 1 shows the seven work packages established to systematically proceed with the introduction, adaption, and adoption of the new milk cans in the study region in Kenya. This table also shows the activities required to accomplish the different tasks of the solar milk cooling concept and the corresponding responsible groups.

Table 1: Work packages for accompanying the introduction of the technology

Work package	Activity	Task (Responsible)
WP1	- Evaluation of Version I via simulations – Germany	- Cover of capital items and supplies (UHOH) - Test of solar powered cooling system (UHOH)
WP2	- Export Version I to Kenya - Project meeting – Kenya - Conduct workshop "solar powered cooling system" – Kenya	- Export and transport the technology to the region (UHOH/PA) - Workshop (UHOH)
WP3	- Testing Version I – Kenya - Preliminary field data collection and analysis	- Cover of: local travel cost (UHOH/ PA); supplies (UHOH); staff time (UHOH/ PA/GIAE)
WP4	- Prototyping Version II and III – Germany - Evaluation of Version II and III – via simulations – Germany	- Cover of capital items and supplies (UHOH) - Test of solar powered cooling system (UHOH)
WP5	- Export Version II and Version III to Kenya - Installation of prototype Version II - Preliminary data collection and analysis - Training milk quality JOOUST - Workshop milk quality – farmers in Kenya	- Export and transport the technology to the region (UHOH/PA/JOOUST) - Cover of: local travel cost (UHOH/ PA); supplies (UHOH); staff time (UHOH/ PA/ JOOUST) - Test of solar powered cooling system (UHOH/JOOUST) - Covering cost of farmers for training (UHOH)
WP6	- Installation of Version III - Preliminary data collection and analysis	- International travel cost master student (PA) - Cover of: local travel cost (UHOH/ PA); supplies (UHOH); staff time (UHOH/PA/GIAE/JOOUST)
WP7	- Workshop "technological aspects of solar cooling in Kenya" - Workshop for promoting solar milk cooling technology	- International travel cost researchers (UHOH) - Cover of: local travel cost (UHOH/ PA); supplies (UHOH); staff time (UHOH/PA/GIAE/JOOUST) - Workshop (UHOH/JOOUST)

GIAE – Green Innovation Centre, PA – Powering Agriculture, JOOUST– Jaramogi Oginga Odinga University of Science and Technology, UHOH – University of Hohenheim

The information generated was divided in different steps to accompany the introduction, adaptation, and adoption of the technology. The first step was related to the understanding of the value chain. The second step was the introduction of the solar milk cooling system already tested in Tunisia and adaptation of the technology in the existing value chain and the last step was the adoption of the technology.

1.2.2.1 Milk value chain in Kenya

A preliminary assessment was performed to identify the stakeholders together with the inputs and outputs of the value chain. The HACCP approach was partially used in order to systematically document the dairy value chain in Kenya. The work was performed in collaboration with two GIZ initiatives: the Green Innovation Center (GIAE) in Kisumu and the Powering Agriculture in Nairobi. The GIAE group was already settled in the target region and they guided and advised the potential sites for the implementation of the milk cooling system. Detailed information on the value chain was collected and reported.

Small-scale farmers are the main actors in the production of milk in rural Kenya; the bigger dairy plants do not usually collect milk from these regions due to insufficient supply volumes. Therefore, cooperative systems were initiated as a form of business organization. The cooperative is responsible for the arrangement of the milk transport from their farms to the market.

In the study region, farms have one to three dairy cows on average and provide 1 to 10l of milk per day to their cooperative. Milking is performed twice per day (morning and afternoon). Figure 11 shows the raw milk handling procedure in Siaya County. The milk handling has three stages at which the milk is kept on hold: the farm, the satellite (a collecting point established in the surroundings of the cooperative), and the cooperative (the building of the cooperative usually serves as a selling point). Farmers are used to transport their milk to satellites walking five to 60 minutes. At this stage, milk is bulked in a 50l milk can and transported to the cooperative within one to two hours by motorbike. In contrast, the afternoon milk never reaches the cooperative premises due to the lower volumes and the time of collection (14:00 to 16:00). This milk is sold in the surroundings of the farm or some hawkers with motorbikes collect the afternoon milk to sell it by the roadside or at the local markets. Another strategy that farmers apply to keep the milk in good conditions is to submerge the milk containers in a water stream. In so doing, they reduce the temperature of the milk and thus delay the spoilage of the milk. However, this practice is not recommendable for large volumes of milk as cooling cannot be guaranteed.

Figure 11: Milk transport from the farm to the cooperative

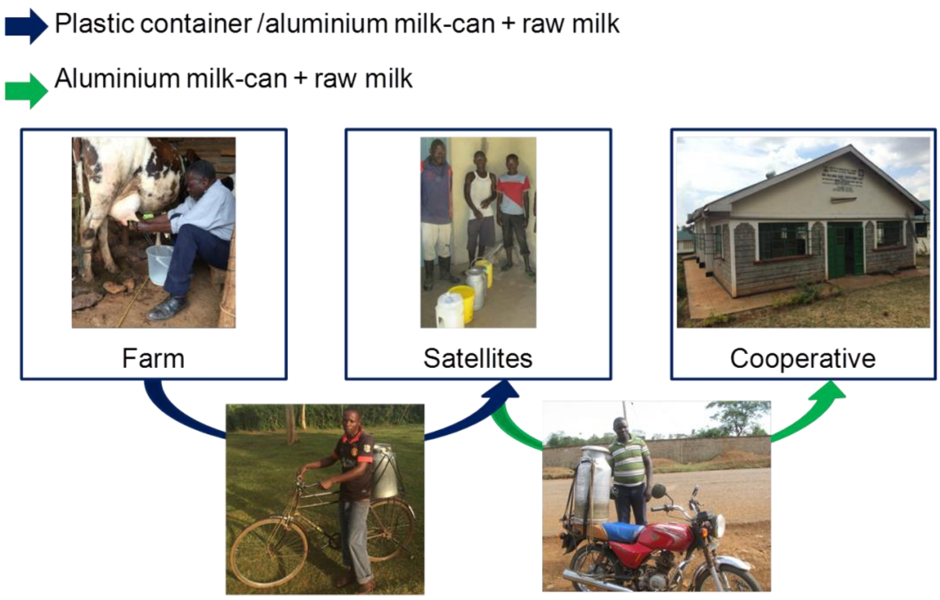


Figure 12 shows the temperature profile of the morning milk during transport from the farm to the cooperative. Milking times take place around 6 to 7 a.m. (morning milk) and commonly, farmers deliver their milk to the satellite between 7 and 10 a.m. According to the evaluations performed in the region, milk temperature is kept above 25°C for about four hours at which point it reaches the cooperative. Despite some cooperatives have cooling tanks or even the whole line to produce pasteurized milk, milk is hardly processed. Most of the time, these machines are not used due to lower volumes of milk collected at the cooperatives in the region (100 to 300l of milk) or high energy cost of operation. Usually the capacity of the milk tanks are ranged from 1000 to 5000 liters (Tristan, 2017).

Moreover, it was observed that due to extended dry season there was shortage of feed and water which affected negatively the milk yield per farm. During this dry period, milk is usually collected are sold on the way and transport to the markets without passing through the cooperatives as the milk price obtained usually is higher than the prices payed by the cooperatives. Therefore, farmers have the incentive to sell their individual milk locally.

Figure 12: Temperature profile of milk and ambient temperature during transport

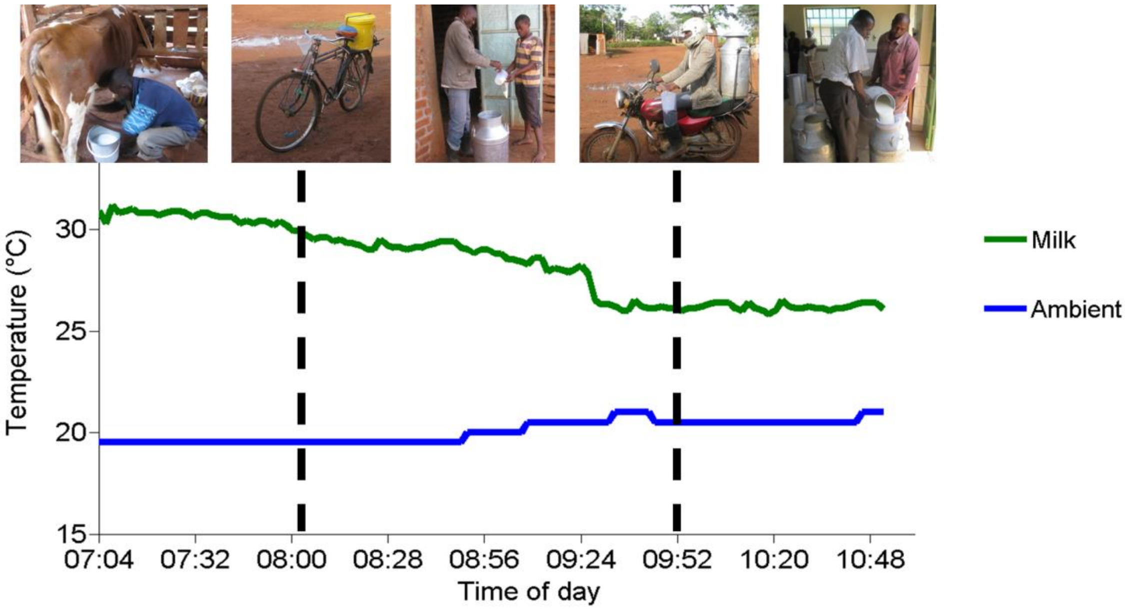
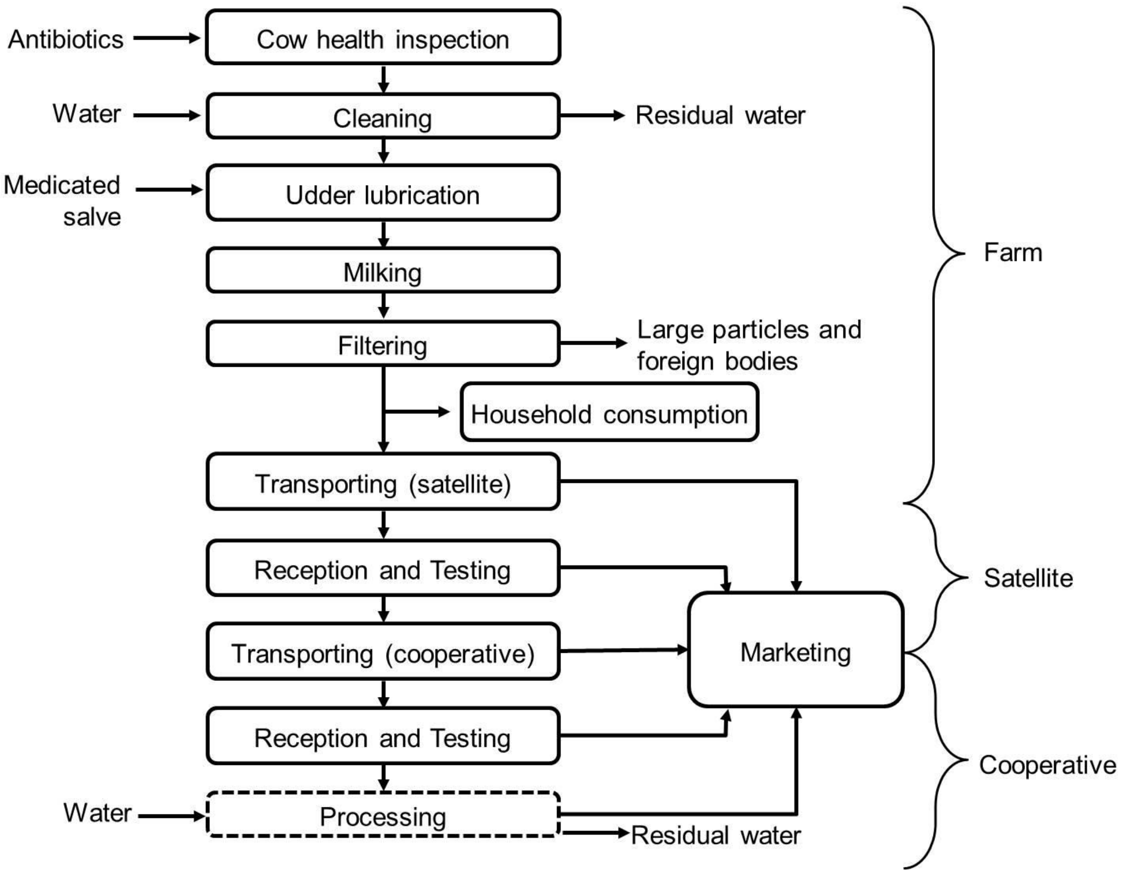


Figure 13 provides the gathered information on the milk production and groups the individual processes which take place at the farm, satellite, and cooperative stages (Tristan, 2017). Farmers are aware of good practices for milking in the study region. The flow diagram mostly represents processes for obtaining the morning milk. Some farms keep 0.5 to 1l for their own consumption, but most of the milk is transported in plastic containers to the satellite where milk is bulked in a milk can with a 50l capacity. Upon reception, farmers that are in charge test the milk by inspecting its odor and color. The milk is sold when all the farmers assigned to the satellite have arrived, and then the milk is transported to the cooperative by attaching the milk can to the back of a motorbike. Upon reception at the cooperative, farmers that are in charge test the quality of the milk by using a lactometer and performing an alcohol test. Depending on the volume of milk collected from the satellites, the cooperative proceeds to pasteurize the milk or produce *Mala* (fermented milk).

It was also observed that during the rainy season when higher volumes of milk are achieved some of the cooperatives process their milk while during the dry season the milk is commonly sold without pasteurizing due to low production. The difference in production may due to a lack of feeds as well as to elevated temperatures during the dry season which both reduce the production volume.

Figure 13: Flow diagram of milk production in Siaya – Kenya



Source: Tristan (2017)

1.2.2.2 Process of introducing and adapting the solar milk cooling system

The solar milk cooling systems were imported in collaboration with Powering Agriculture and selection of the installation sites were done in collaboration with the Green Innovation Centre in Kisumu. Table 2 provides information on the solar milk cooling system installed in Siaya. In this county, the solar milk cooling systems were gradually evaluated at the different stages at which milk is kept (farm, satellite, and cooperative). The adaptations of the solar cooling systems were according to the milk handling and the volumes collected in Siaya County. Therefore, the insulated milk cans were adapted together with the production of ice blocks.

Table 2: Description of the solar milk cooling installed at different stages of milk handling

System	Stages	Modified milk cans details			
		Units	Material/Capacity	Capacity of milk per unit (l)	Capacity of ice per unit (kg)
Version I	Cooperative	2	Stainless steel / 40l[4] Food grade plastic / 40l[4]	30	8
Version II	Farm	8	Food grade plastic / 10l[5]	7.5	2
Version III	Satellite	2	Food grade plastic / 40l[4]	30	8

[4] http://www.breuer-versand.de
[5] http://www.mazzican.com

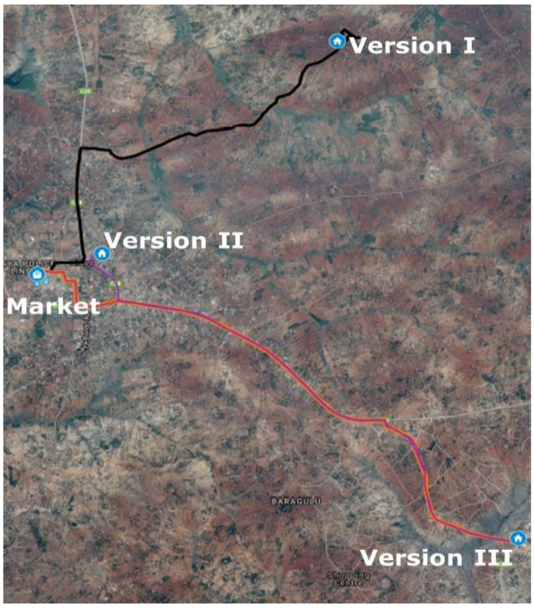
The first system (Version I) was installed at the cooperative. Version I was successfully tested in Tunisia and the same components were import to Kenya. Additionally, it was considered to evaluate the performance of a plastic milk can as they have lower prices in the market compare with stainless steel milk cans. Therefore, modified plastic milk cans of 40l capacity, which were preliminary evaluated under controlled conditions in Germany (see section 1.1.2 - Figure 6), were tested under field conditions. The installation of the system Version I was performed in August 2016.

The second system (Version II) was installed on one farm in May 2017. A commercial plastic milk can promoted in the region (Mazzi can) was adapted to operate with the solar milk cooling system for the production of smaller blocks of ice. The Mazzi can has 10l milk capacity, and when it was adapted to carry 2kg of ice, the volume of milk was reduced to 7.5l. Version II is also capable to cool 60l of milk by using eight insulated Mazzi cans.

The third system (Version III) was installed temporarily at a satellite in September 2017. It was observed by previous evaluations that the modified plastic milk cans were preferred over the modified stainless steel, for which reason two insulated plastic milk cans were tested.

According to the evaluation, ice production at the different locations was performing as expected, while the performance of the modified milk cans differed depending on the material and capacities required. Figure 14 shows the locations of the three versions of the solar milk cooling system.[6]

Figure 14: Locations of the three solar milk cooling systems installed in Siaya County



The **Version I system** comprises two modified milk cans, one plastic milk can and one stainless steel can. The modified milk cans were tested one by one against one aluminum milk can of 20l capacity that was used as a control unit; comparisons were done to observe the performance of the cooled and un-cooled milk during transport (Figure 15). During the evaluations, farmers were trained in the proper usage of the technology.

Figure 16 shows the fluctuation of the milk and ambient temperature collected from the sensors placed inside the modified milk cans the aluminum milk can. During transport from the satellite to the cooperative, the milk temperature was about 25°C and the ambient temperature was 30°C. The milk cooling curve of the modified milk cans were as expected, reducing and maintaining the milk temperature below 20°C throughout three hours of transport. The temperature of milk in the aluminium milk can showed an increment of temperature that reached ambient temperature, thus

[6] Also available at https://drive.google.com/open?id=1RlSDei50wcHhThVrbaQoxQ2uOuE&usp=sharing

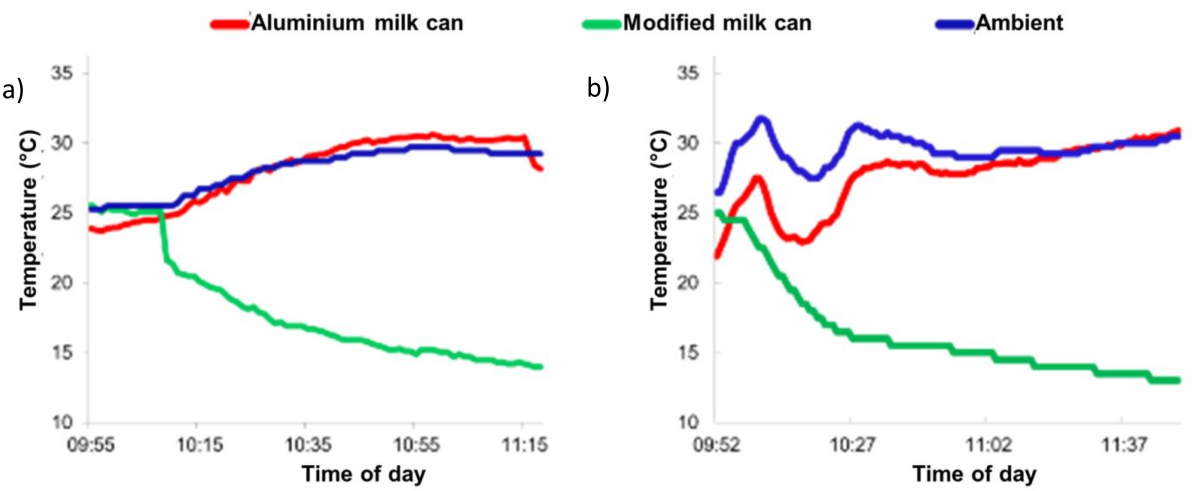
emphasizing the importance of the modification of the milk cans for transporting small volumes of milk.

Figure 15: Transport of the modified milk cans a) Plastic-prototype and aluminium milk can (control condition) and b) Stainless steel-prototype and aluminium milk can (control condition)

a)

b)

Figure 16: Temperature profile during transport for a) modified plastic milk can and b) modified stainless steel milk can compared with the aluminium milk can



The introduction of the **Version II system** was possible due to the flexibility of the cooling concept and aimed at reducing the milk can capacity since a single farm in the study region produces only about 10l of milk. Therefore, the insulated milk cans were easily adapted to the size of local plastic milk cans of 10l capacity, called "Mazzi cans". At the same time the reduction of the milk volume also influenced the production of the ice block in that a 2kg ice compartment was designed that corresponds to three ice blocks.

Following the different protocols on the potential use of the local milk can, simulations were performed at the University of Hohenheim during which the principle of the insulated milk can of 30l capacity was transferred to the Mazzi can. The first evaluations were carried out under controlled conditions, and then evaluated at the selected sites in Kenya.

Table 3 shows milk temperature at different stages from the farm to the market. Ambient temperature was recorded together with temperature of cooled (Mazzi can) and uncooled milk. Thermocouples were exposed to the ambient or placed inside the Mazzi can with and without insulation for about ten minutes for measuring temperatures. Results showed that uncooled milk was approaching ambient temperature while cooled milk recorded values below 20°C.

Table 3: Temperature of cooled and uncooled milk measured at the farm, satellite, and cooperative; ambient temperature was also recorded

Time of day	Stage	Temperature (°C)		
		Ambient	Cooled Milk	Uncooled Milk
6:50	Farm	21	20	32
8:00	Satellite	22	15	29
10:30	Cooperative	28	17	27

Figure 17 shows an exemplary performance of the ice production for the **Version II system**. The red curve describes the temperature inside the freezer and the two peaks indicate the loading of 7kg of water that were placed after removing 7kg of ice for two consecutive days. After placing the water, the temperature inside the freezer starts dropping slowly and the air temperature inside the freezer stays around -6.7°C. The following day, the temperature then rises and fluctuates around -5°C. The temperature profile is expected to achieve this performance every time the ice blocks are utilized.

Figure 17: Air temperature inside the smart freezer (Air), outside temperature in Siaya (Ambient) and setting temperature (Setting point) in degrees Celsius over time

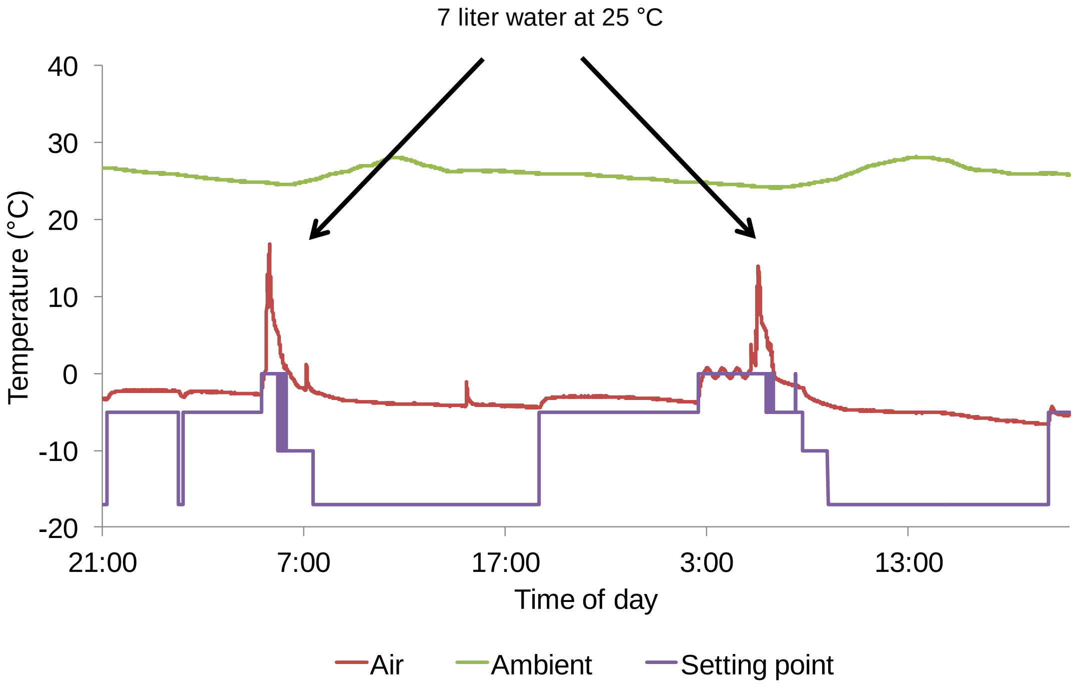


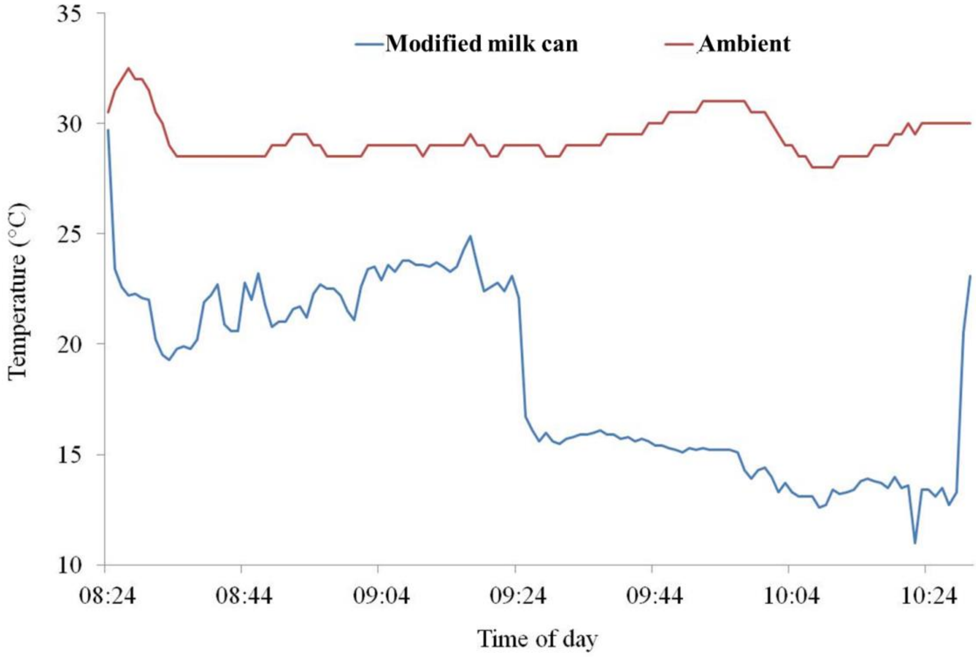
Table 4 shows the microbial load from the samples collected right after milking (farm) and after transport to the market (cooperative). It can be observed that the cooling of milk was limiting the microbial growth, despite the initial load of microorganisms responsible for the spoilage of milk. These results represent a potential preservation system of the milk quality from the farm to the cooperative.

Table 4: Total colony forming units per millilitre (CFU/ ml) from samples collected right after milking and at the market

Date	Microbial load (CFU/ ml)			
	Normal Mazzi can		Insulated Mazzi can	
	Farm	Cooperative	Farm	Cooperative
12.05.2017	118000	116000	7000	27000
13.05.2017	131000	123000	37000	115000

The **Version III system** was considered to collect milk at the satellites. Following the established protocol, the system components were evaluated at the University of Hohenheim first and then they were tested in field conditions. The cooling curves obtained for the evaluation of the Version III system are shown in Figure 18 where just modified plastic milk cans were used. The temperature of milk started to cool down gradually as the milk was bulked in the modified milk can in several time slots since not all the farmers bring their milk to the satellite at the same time thus interrupting the milk cooling. The transport started at 9:24 a.m. with a milk temperature of 15°C and during transport the temperature dropped further to 13°C. The samples for the microbial test were taken at 10:30 a.m.

Figure 18: Cooling curve of the modified plastic milk cans and ambient temperature recorded during the reception of milk at the satellite



1.2.2.3 Adoption of the solar milk cooling system

The solar milk cooling systems were socialized through meetings with the cooperative members, the Ministry of Agriculture, Livestock and Fisheries, with extension services, non-profit organizations located in Siaya County, and a local university from Bondo. Nevertheless, the main support came from the cooperative members of SAM Malanga Dairy Cooperative Society who facilitated the introduction process of this technology. The farmers were very supportive and accompanied every installation of the system. Their feedback was valuable for the adaptation processes as they are the users of the present technology.

Figure 19 shows the usage of the **Version I system**. The collection of the ice blocks produced at the cooperative before going to the satellite is required. The insulated milk-cans then are transported with 6kg of ice per milk can to the satellite. Upon arrival, the milk can be immediately placed in the insulated milk cans. Usually, milk is delivered to the satellite from 8:00 to 9:30 a.m. and then transported either to the cooperative or the market.

Figure 19: Handling of the solar milk cooling system Version I installed at the cooperative

The handling of the **Version II system** is shown in Figure 20. The farmers are organized in groups of two to three members to achieve the 7.5l volume per insulated Mazzi can. They assign the farmer nearest to the system to collect the insulated Mazzi cans with the ice. After the insulated Mazzi cans are filled, one of the farmers is responsible for transportation to the satellite. When all insulated Mazzi cans have arrived at the satellite, they are placed in the carrier adapted to the motorbike for further transportation to the cooperative or market. Afterwards milk cans are cleaned and transported back to the farm.

Figure 20: Steps followed for the handling of the solar milk cooling system Version II installed in a farm

The **Version III system**, installed at the satellite, is handled by preparing one insulated milk can at a time, depending on milk reception. Then, both insulated milk cans are transported by motorbike. If the 60l of milk are not reached, the milk can be distributed equally to the two milk cans in order to provide proper balance to the motorbike. The final step involves the transportation of the insulated milk cans to the cooperative or market (Figure 21).

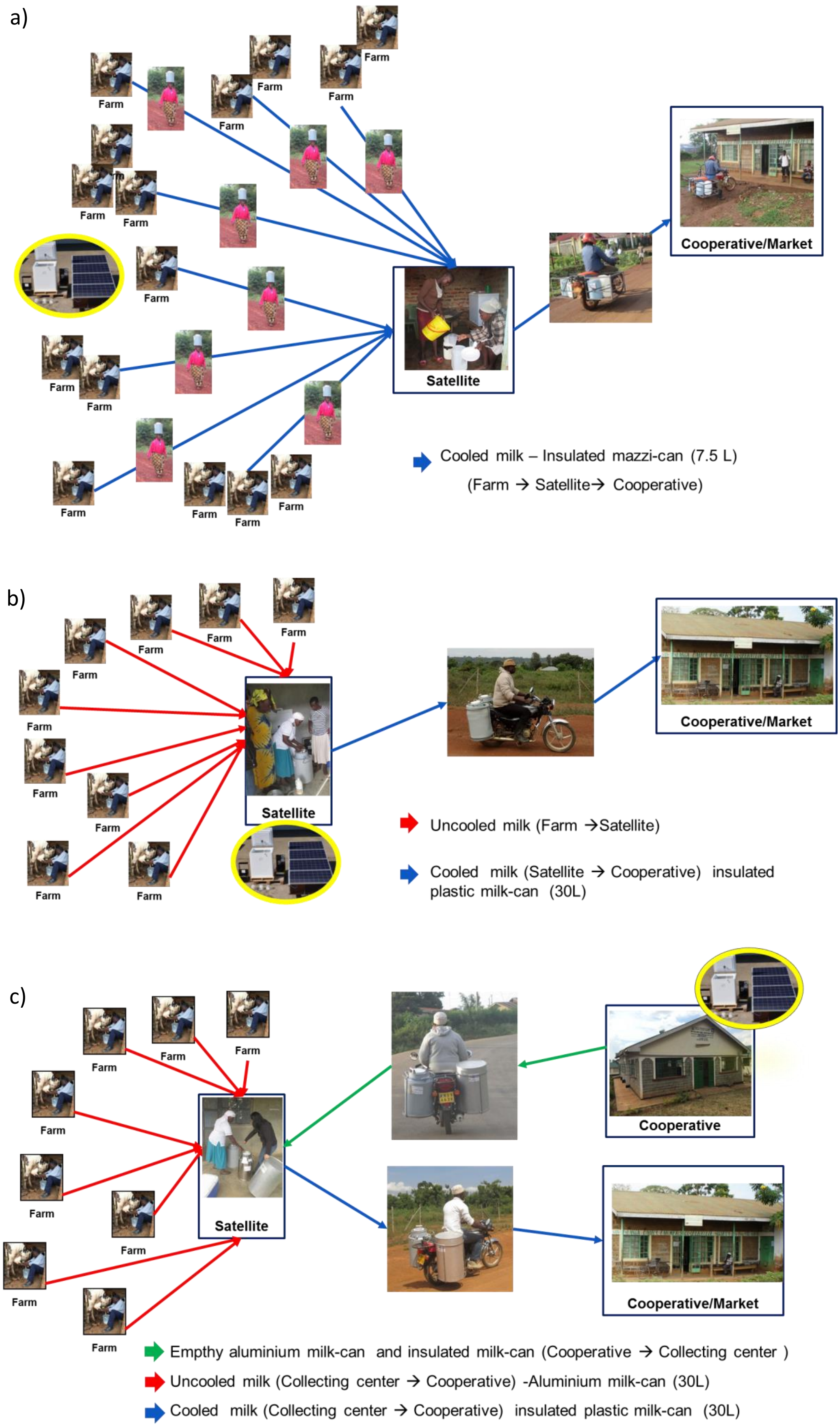
Figure 21: Steps followed for the handling of the solar milk cooling system Version III installed at the satellite

The evaluation of the solar milk cooling systems provides assurance for the preservation of milk quality. The following paragraphs outline the proposed scenarios that could be adopted along the value chain. The intervention is related to the installation of the technology (farm, satellite, or cooperative). The first scenario "Farm", as shown in Figure 22a, has the advantage of cooling milk right after milking. This early intervention with the technology may provide preservation of milk quality for more than 6 hours. At the same time, this technology could open a market for dairy products that require raw milk of good quality. The second scenario "Satellite" provides the opportunity to cool down the milk upon arrival to the satellite (Figure 22b). Good quality milk might be expected from this scenario as some farms are located near the satellite. However, this will depend on the management of the farm and the coordination of milking, bulking, and transport. This scenario also offers the option of storing milk in the insulated milk cans during night time as previously mentioned in section 1.1.2 since the milk can be cooled down and stored for up to 12 hours after milking.

The scenario "Cooperative" presented in Figure 22c may be considered for satellites that are arranged just as strategic meeting points, whether they are located at a street corner or in a small room. However, as a room could result in extra costs for the cooperative this version is less common which poses a challenge to the storage of the entire solar milk cooling system. According to the evaluations carried out, this scenario may offer the same milk quality as the scenario where the milk cooling system is installed at the satellite.

The management of the solar milk cooling system was merged with the current milk handling. This process allowed a proper adaptation of the technology. The farmers, the primary participants along the value chain, had the opportunity to handle the technology very actively and they were involved in the different adaptations performed along the installation of the three solar milk cooling systems. The farmers were also able to adopt the technology and they recognized the important role cooperatives can play as an efficient milk collection alternative. It is possible to conclude that the solar milk cooling system technology proposed by the University of Hohenheim is a proven technology that has been evaluated in two countries under different environmental conditions. Moreover, it offers a steady year-around ice production and assures the preservation of milk quality from the farm to the main collection center or market.

Figure 22: Sketch of the solar milk cooling system scenarios evaluated at a) farm, b) satellite and c) cooperative



2 Social and Economic Insights Related to the Solar Milk Cooling System

This work is based on only the solar milk cooling system in Kenya, as the research was performed in collaboration with the Hans-Ruthenberg-Institute, Division Social and Institutional Change in Agricultural Development, in collaboration with the Institute of Agricultural Engineering in the Tropics and Subtropics.

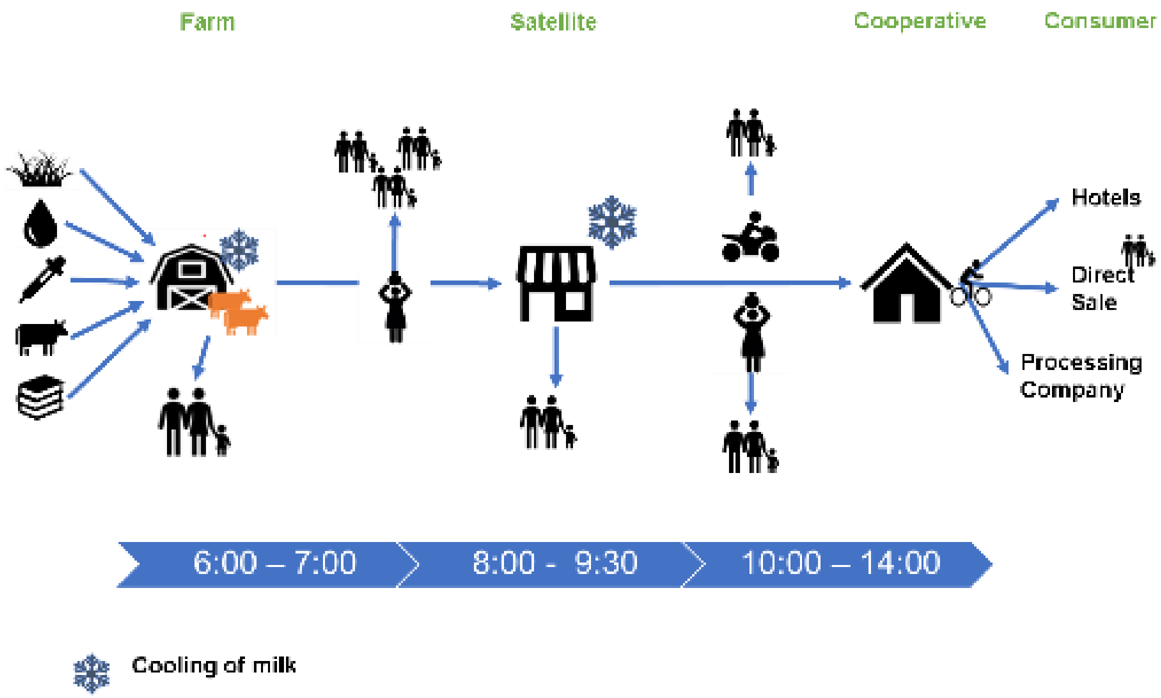
2.1 Socioeconomic impacts of solar milk cooling systems

The introduction of the technology needed a socio-economical assessment in order to identify conditions that may help implementation on a large scale to improve the livelihoods of small-holder farmers or to generate strategies to further increase the economic feasibility of the technology. Preliminary interviews were conducted with the farmers as shown in Figure 23.

Figure 23: Preliminary interviews to the cooperative members

The value chain was slightly modified after the introduction and adaptation of the solar milk cooling system, using the “Net Maps” Approach. Figure 24 shows the different milk channels along the value chain. At the farm stage, some cooperatives benefit from veterinary services and feed supply. Milk is usually sold directly to the neighbors before reaching the satellite. During the transportation from the satellite to the cooperative, milk is also informally sold along the way. Usually, when the milk reaches the cooperative, it is sold to hotels, direct sales or to processing companies. In general, the activities start at 6:00 a.m. and farmers have the chance to transport their milk to the satellite by 9:30 a.m. at the latest; at this time milk is transported to the cooperative and from there to the different consumers until 14:00 p.m.

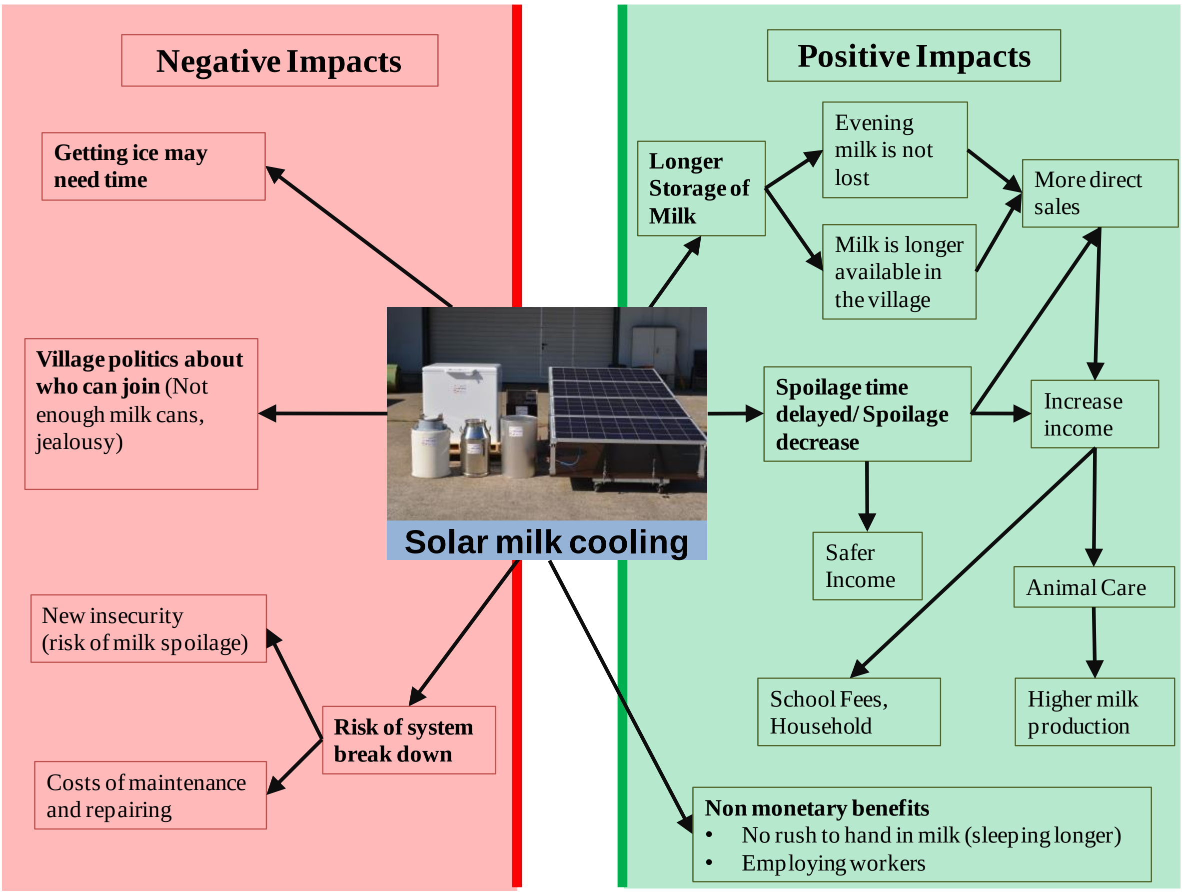
Figure 24: Schematic view of the milk value chain indicating the possibility to cool milk already at the farm or at the satellite



The Net Maps also helped identify the potential challenges of the value chain and were accompanied by impact diagrams in order to collect information on the social impact of introducing the milk cooling system. Figure 25 shows farmers' remarks on the impacts that they experienced due to the technology. On the positive side, farmers were quick to mention the storage of the milk for longer periods which implies a reduction of the evening milk losses. The villagers furthermore found it very advantageous that the milk cooling system made milk available at the village for a longer time. It also increased the direct sales for which the producers could get a better price. A second finding was linked to the delay of spoilage, offering farmers more time to deliver the milk to the cooperative and giving them the opportunity to sell more milk on the direct market, consequently securing or even increasing their income.

Farmers indicated that they could invest the income in the payment of school fees and use the money to improve the animal care conditions which are strongly correlated to higher milk production. Non-monetary benefits were also identified, such as being able to sleep longer since there would be no need to rush in the delivery of milk; some of the farmers also reported that they were able to employ more workers.

Figure 25: Preliminary findings: Impact of small-scale solar milk cooling



Negative aspects were also identified as shown in Figure 25. Examples are the extra time necessary for getting the ice. Farmers furthermore reported possible impacts on village politics regarding the modified milk cans provided with the different version of the solar milk cooling system introduced in the region as well as the possibility of jealousy arising towards those who got equipped with the technology. At the beginning of the technology assessment, it was also reported that there was a risk of breakdown and the posing of new insecurity if the solar cooling system needed fixing but was not able to be repaired immediately.

Farmers were also asked to rate the different impacts on a scale from 0 to 6 (low to high). Getting the ice was rated as 1, village politics was given an importance of 2 and the risk of breakdown was very important and rated with the value of 6. The non-monetary benefits were rated with 2 and the delay of storage time was given an importance of 6. This preliminary information was valuable for understanding the influence of the solar milk cooling system installed at the farm, and the implications of handling ice for preserving milk quality from the farm to the market. The rating of the negative impacts could help allocate resources as there is a need for maintenance and repairs at the local level to make the introduction of the milk cooling system sustainable.

2.2 Business around the solar milk cooling system

There are several interpretations and definitions of business models. Among the most common understandings are that a business model is a holistic approach to explain how a company manages a business successfully and that a business model explains how a company creates value for its customers, the company itself, and its stakeholders and thus does business (Johnson, 2012; Lobbers et al., 2017).

A business model can be built based on the canvas model (Osterwalder and Pigneur, 2013). There are two elements (value proposition and costs) out of the nine elements (customer segments, channels/distribution, channels/marketing, revenue streams, partners, required resources, suppliers and strategic partners) proposed in the canvas model that can be defined with the information obtained within the scope of the design and introduction of the solar milk cooling system. Two potential business models are proposed: the **Cooperative Model** (the cooperative buys and invests in the system) and the **Farmers' Group Model** (the farmers' group buys and invests in the system). According to the scenarios proposed in section 1.2.2.3 - Figure 22, the cans with a milk capacity of 30l are usually handled at the satellites or cooperatives, while the cans of 7.5l are mostly managed by the farmers due to the low individual production volumes.

2.2.1 Value propositions for the investors

The value addition, according to the milk value chain assessment realized in Kenya, is basically derived from the sales of extra milk. Therefore, a good strategy to introduce the technology goes in the direction of supporting spoilage reduction and storage of milk. The solar milk cooling technology could offer a steady or increase milk volumes year around that will be reflected in a series of benefits already presented in section 2.1.

In respect of selling the morning milk when the technology is used, this brings the benefit of reducing the rejection and assuring the payment to the farmer. Furthermore, a greater benefit could be related to the direct sales and to profit from the higher price which is obtainable on the informal market: For example, in the study region, the cooling system permits the farmers to have more time for selling the milk, so that they are not forced to deliver their milk to the cooperative. Based on field assessment, it can be assumed that the system with the capacity of 60l is utilized at 80% (i.e. collection of 48l); 10l are usually sold directly to the villagers and 22l are sold on the way to the cooperative, while only the remaining 16l are delivered to the cooperative. This implies that a higher share of milk can be sold directly at a price of 70 KSH instead of selling at 50 KSH to the cooperative.

With regards to the storage of milk, evening milk (second milking) is rarely transported to the cooperative as farmers sell this milk to their neighbors due to the lack of cooling systems. The solar milk cooling technology could allow for the storage of milk overnight maintaining good quality for up to 15 hours (including 12 hours of storage and 3 hours of transport to the cooperative). For instance, in the study area, from 5l of milk per cow (wet season), by average 2l can be sold; 1l is needed for the farmers' own consumption and the remaining 2l could be stored and sold to the cooperative, together with the morning milk. This would generate 100 KSH more income per day through the formal market (2 x 50 KSH/l).

The monetary benefits under the two scenarios of the two proposed business models are shown in Table 5. Assessing the figures, it seems that the cooperative model is more likely to be adopted. It is clear that under the first scenario, the farmers' group model seems more beneficial than the cooperative model. However, the second scenario shows a greater benefit due to the storage of evening milk. It is important, however, to highlight that the small milk cans of 7.5l capacity cannot be used for the storage of milk and can only be used for transporting the milk from the farm to the cooperative or market.

The challenge faced by following the **Farmers' Group Model** and the **Cooperative Model** is that both stakeholders profit less. When the work of farmers' groups is isolated from the cooperative, their profits only comes from selling the morning milk and there is a high risk of competing in the same market which would result in losses for the cooperative as it collects less milk. The Cooperative Model seems to be more beneficial due to the milk storage potential and may furthermore be favorable since it reinforces the formal value chain instead of encouraging informal channels.

Table 5: Benefits of the solar milk cooling system

<table>
<tr><th>Characteristic</th><th>Cooperative Model</th><th>Farmers' Group Model</th></tr>
<tr><td>Installation of the technology</td><td>Satellite or cooperative</td><td>Farm</td></tr>
<tr><td>Milk cans used</td><td>2 units of 30l capacity each</td><td>8 units of 7.5l capacity each</td></tr>
<tr><td>First scenario</td><td colspan="2">48l (morning milk)</td></tr>
<tr><td>Formal market
50 (KSH)</td><td>1,900 KSH/day (38l x 50 KSH)
693,500 KSH/year
(around 6,786 USD)</td><td>800 KSH/day (16l x 50 KSH)
292,000 KSH/year
(around 2,857 USD)</td></tr>
<tr><td>Informal market
70 (KSH)</td><td>700 KSH/day (10l x 70 KSH)
255,500 KSH/year
(around 2,500 USD)</td><td>2,240 KSH/day (32l x 70 KSH)
817,600 KSH/year
(around 8,000 USD)</td></tr>
<tr><td>Benefits</td><td>9,286 USD</td><td>10,857 USD</td></tr>
<tr><td>Second scenario</td><td colspan="2">48l (morning milk) plus 30l of evening milk</td></tr>
<tr><td>Formal market
50 (KSH)</td><td>2,900 KSH/day (58l x 50 KSH)
1,058,500 KSH/year
(around 10,357 USD)</td><td></td></tr>
<tr><td>Informal market
70 (KSH)</td><td>1,400 KSH/day (20l x 70 KSH)
511,000 KSH/year
(around 5,000 USD)</td><td></td></tr>
<tr><td>Benefits</td><td>15,357 USD</td><td></td></tr>
</table>

2.2.2 Costs of the system

There is a need to have a clear idea of the total cost, not only considering the technology cost but also fixed operation costs, the cost that could arise by involving private suppliers, overhead costs and the financial cost. A profit margin for the supplier also needs to be considered in order to cover the cost of sales (variable costs) per unit. Viable businesses should be able to breakeven (total revenues equal total costs) in the fifth year the latest. The first years of a business are not profitable and depend on the number of cooling systems sold. The initial cost of the technology is provided in Table 6. The price for the solar cooling system imported to Kenya is 2245 USD/unit and the price of the system via local supplier is 1560 USD/unit.

Table 6: Total cost of the technology imported or locally acquired in USD

Component	Investment (imported from Germany)	Investment (local supplier)	Depreciation period	Annual depreciation
Solar PV	600	480	20	24
Battery	250	180	5	36
Control unit	160	80	20	4
DC freezer	615	400	15	26.7
Cans	320	320	10	32
Others	300	100	20	5
Total	2,245	1,560		127.7

Additional costs that have to be considered in order to evaluate the investment are shown in Table 7. This preliminary information was collected from the system installed in Siaya County. The first cost derived from hiring a watchman. The cooperative mentioned that this was necessary for overnight security. The second cost was related to the maintenance of the technology. This is a very important cost to be covered as maintenance services assure the proper functioning of the technology for a longer period. The transportation cost of the milk from the farm to the cooperative is in most cases covered by the farmers linked to the satellite. Transport to the cooperative is a point to consider for ensuring prompt milk delivery.

Table 7: Additional costs

Detail	Costs of investor
Salary watchman	15 USD/month
Maintenance	50 USD/month
Transportation costs	75 USD/month
Total	1,680 USD/year

At this point, the investors should take a look at grants or concessionary loans as they will require access to finance or to arrange payment schemes through the supplier. Table 8 provides different options of payment schemes together with their advantages and disadvantages. This could serve as a guide to a proper setup of the revenue streams as it focuses not only on how the supplier gets paid, but also identifies whether the costumer is capable of paying for which reason a maintenance fee may be charged at the same time that the cost of the technology is covered.

Table 8: Overview of payment schemes

Payment scheme	Advantages	Disadvantages
Delivery model	Ownership transferred to customer upon payment, low need for working capital	
Supplier credit	Ownership is transferred to customer in the beginning	▪ risk of non-payment ▪ more working capital required ▪ monitoring of payments required ▪ high administrative workload, especially in upscaling phase
Lease-to-own/hire-to-purchase	In case of non-payment the system is shifted to another site	▪ more working capital required ▪ monitoring of payments required ▪ high administrative workload, especially in upscaling phase ▪ maintenance required until system is transferred (maintenance costs)

Within the framework of the demonstrated business models there is a need to further monitor the two scenarios proposed. This will include a feasibility analysis of the solar milk cooling system for which purpose more information needs to be obtained.

3 General Conclusions

Small-scale refrigeration systems powered by solar energy present a promising solution for assuring the preservation of milk quality on farm, satellite and transport to the cooperative/market. Microbial contamination of cooled milk was under the limits permitted by national standards in Tunisia and Kenya. This limit in food targets the prevention of foodborne illness from food containing hazardous levels of microorganisms. Moreover, if these guideline levels are exceeded, it generally indicates a problem in the handling of milk after milking or hygienic procedures that needs to be addressed, at the same time that a cooling system is introduced.

The results of the study clearly indicated that microbiological contamination was higher when no cooling was utilized at the different stages of the milk production in both countries. Also information on potential health hazards associated with the consumption of raw milk that was not cooled for more than 3 hours below 20°C should be extended to the public, so that consumption of this milk could be avoided.

The gradual introduction of the technology was carried out together with stakeholders as the success of the different interventions of the technology along the value chain depends on a strong and active collaboration with the farmer group and a strong commitment to the farm cooperative. Conducted this way, the introduction of the solar milk cooling system provided an important upgrade to the current value chain.

The scenarios established around the installation of the cooling systems provide different strategies to improve the economic viability of the new technology and the related business model implementation. As a first strategy, the reduction of the costs involved may be achieved by working with local manufacturers. At the same time a reduction in costs of maintenance and repairs can be covered by training local technicians. The payment schemes need to be well-established and should offer financing options with affordable interest rates. On the long run, once the farmers have the opportunity to commercialize all their milk (to the cooperative or to the local market), they would invest more in their dairy production, and therefore increasing milk production and productivity per farm.

The strategy followed for the introduction of an innovative technology in the milk value chain generated a series of reports, pictures, manuals, and protocols for assessing the technology and the socio-economic aspects of the intervention along the value chain. At the same time this report serves as a guideline towards the implementation of a business model.

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