SOLARCHILL

Market Study and GHG Emission Reduction Estimation

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Authors: Dr. Simon Mischel, Miquel Pitarch Mocholí, Britta Paetzold, Martin Brown-Santirso, Nancy Finger

This report had been prepared by HEAT GmbH.

HEAT GmbH, Seilerbahnweg 14, 61462 Königstein, Germany
Phone: +49 (0) 61 74 - 969 47 0, e-mail: kontakt@heat-international.de

SolarChill Development, Testing and Technology Transfer Outreach Project (GEF ID: 4682)

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ABBREVIATIONS

CHAI	Clinton Health Access Initiative
CO2e	Carbon dioxide equivalent
DD	Direct Drive
EEI	Energy Efficiency Index
EHC	Energy Harvest Control
GAVI	The Global Alliance for Vaccines and Immunization
GEF	Global Environment Facility
GHG	Greenhouse Gas
GWP	Global Warming Potential
HC	Hydrocarbons
HEAT	HEAT GmbH
IEA	International Energy Agency
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
LCC	Life cycle cost
LDCs	Least developed countries
LED	Light-emitting diode
MoU	Memorandum of Understanding
PATH	Programs for Appropriate Technologies in Health
REREC	Rural Electrification and Renewable Energy Corporation
SC-A	SolarChill A (medical coolers)
SC-B	SolarChill B (food / beverage refrigerators)
SDD	Solar Direct Drive
SHS	Solar Home Systems
SME	Small Medium Enterprise
UNEP	United Nations Environmental Program
UNICEF	United Nations Children´s Emergency Fund
VAT	Value Added Tax
WHO	World Health Organization

1 INTRODUCTION OF SOLARCHILL

Until recently, the market for vaccine refrigerators in remote areas without reliable electricity has been dominated by kerosene operated units. These refrigerators possess several problems such as operating costs, effectiveness in maintaining appropriate temperatures, and environmental impact. In remote areas, obtaining kerosene on a timely and consistent basis has proven to be challenging and expensive. In addition, fossil fuel (mostly kerosene but also propane gas or diesel) driven vaccine refrigerators result in greenhouse gas (GHG) emissions through normal operation and emit toxic fumes that are dangerous to humans when situated in enclosed spaces. These refrigerators are also more susceptible to catch fire as compared to electric and solar refrigerators.

SolarChill provides a climate-friendly alternative to remote areas with limited or no access to electricity: Solar Direct Drive (SDD) refrigerators. These refrigeration systems are climate friendly as they use natural refrigerants and therefore don´t cause any direct greenhouse gas emissions and further, have no battery for energy storage as the generated solar power is directly converted and consumed in the refrigeration systems.

In the market, there are currently two main versions of SolarChill coolers available, one for medical use to store vaccines and other medication, and one for commercial use to store food and beverages.

2 GLOBAL MARKET FOR SOLAR REFRIGERATION

According to *The Energy Progress Report 2019*, the global electrification rate rose from 83% in 2010 to 89% in 2017 which resulted in a decrease from 1.2 billion people in 2010 without access to electricity to 840 in 2017. According to latest projections, the electrification rate could reach 92% by 2030 which would still leave 650 million people globally without access to electricity whereat most of them will be in Sub-Saharan Africa.[1]

A recent IEA report on electricity access in Sub-Saharan Africa indicates that the energy gap will persist in the future, estimating that by 2040, while 1 billion people will have access, 540 million will remain unelectrified[2]. Further, even when electricity reaches communities, it is often not reliable enough for certain uses such as keeping medicines cool.

The Global LEAP *State of the Global Off-Grid Appliance Market Report* 2016 claims that the global off-grid appliance market will experience significant growth in the next years with the potential to become a USD 4.7 billion market by 2020[3]. The authors identified increasing energy efficiency as the key driver behind this development. Based on country-level data and surveys in key markets, the 2015 Global LEAP *Off-Grid Appliance Market Survey* identified TVs, cooling and refrigeration as the upcoming priorities for households after satisfying basic lighting and communication needs.[4]

These findings were confirmed by the 2018 *Efficiency for Access Coalition Market Survey*[5], showing that refrigerator/ freezer units had moved up to rank 4 (after LEDs, TVs and mobile phones) in terms of anticipated

[1] International Bank for Reconstruction and Development / The World Bank (2019). *Tracking SDG7: The Energy Progress Report*
[2] International Energy Agency (2014). Africa Energy Outlook.
[3] Global LEAP (2016). The State of the Global Off-Grid Appliance Market.
[4] Global LEAP (2015). Off-Grid Appliance Market Survey.
[5] Efficiency for Access Coalition (2018). Off-Grid Appliance Market Survey: Perceived Demand and Impact Potential of Household, Productive Use and Healthcare Technologies (third edition).

consumer demand and impact potential, with little deviation between female and male user perspectives. Looking at this product sector in more detail revealed that, across regions refrigeration equipment, for both agricultural cold chain and light commercial/SME applications, were ranked second and third in both consumer demand and potential impacts. Milk chilling units ranked fifth in terms of potential impact, strengthening the consistent focus on refrigeration products across the board. While refrigeration and cooling seem to be gaining importance, the rankings for smaller business appliances (LED lighting, mobile/smart phones) undergo significant changes. According to the authors underlying causes might be the increasingly saturated market for phone charging and lighting as a business, or a general shift of the off-grid sector towards larger business/productive use appliances.

The Efficiency for Access report also investigated sales data. While radios, solar water pumps and TVs provided the mayor share, only 12% of reported sales related to refrigeration/cold chain technologies, fans, and Information and Communication Technology (ICT) equipment. With less than 1% of the total reported units sold, the sales volumes for milk chilling units, refrigeration for light commercial/SME or household uses, and health/medical devices were comparatively small. The authors state a critical difference between the theoretical needs that were reflected by a high ranking in terms of demand and potential impact by the survey participants, versus market realities (reflected by little or no reported sales). There is still a lack of commercial availability and viability of larger appliances in off-grid markets. Cost reductions and efficiency improvements for these appliances were pointed out as the main challenges ahead. Continued support from investors for R&D and enterprise financing to overcome these barriers is also be seen as critical. [6]

According to the authors of the Solar Appliance Snapshot: refrigerators published by the Efficiency for Access Coalition in June 2021, the market potential for off-grid refrigerators was estimated to be USD 4.4 billion in 2018 and has to potential to grow up to USD 14.3 billion by 2030.[7]

Demand for off-grid refrigerators is high as refrigeration can help to significantly reduce the amount of food waste in warm climates and can provide new income opportunities in rural areas, especially in agro-processing. But affordability continues to be a challenge and overall market penetration remains low with less than 40% in Nigeria, 30% in India and even lower percentages in rural areas at just 6% in Bangladesh and 1% in Kenya. Underlying causes are mainly logistic problems and costs coming along with delivery to remote areas, high upfront costs for refrigerators, high cost of energy supply and the lack of consumer financing mechanisms/programs. The absence of well-established distribution, sales and maintenance networks is also seen critical[8].

Off- and weak-grid consumers, the target group for these appliances, are very price-sensitive making refrigerators a substantial financial investment. Of high importance are the durability and the quality of the equipment as off-grid consumers often live in remote areas with almost no access to repair technicians or replacement components. If products fail or users have bad experiences, they are likely to lose confidence in certain products or brands quickly. Problematic in this context is that a higher price not always comes along with better energy performance or quality. Data indicate that among products that perform similarly in terms of energy efficiency (with EEI values around 130 m^2/kWh), the retail price ranges from roughly 360 to 1300 USD. This, together with the lack of clear performance specifications, makes it challenging for consumers and

[6] Efficiency for Access Coalition (2018). Off-Grid Appliance Market Survey: Perceived Demand and Impact Potential of Household, Productive Use and Healthcare Technologies (third edition).

[7] Efficiency for Access (2021). REFRIGERATORS Solar Appliance Snapshot.

[8] Global LEAP (2016). The State of the Global Off-Grid Appliance Market.

distributors to pick the appropriate appliance. Based on insights from off-grid suppliers in Africa and Asia, the report estimates that small off-grid refrigerators would need to decrease in price to approximately 200 USD and work on less than 40 watts to be viable for the rural, off-grid customer. [9]

The 2016 *State of the Global Off-Grid Appliance Market* report concludes that due to high purchase costs and energy consumption the demand for refrigerators in off-grid areas will be triggered at least partly by its potential contribution to additional income-generating opportunities rather than for household use only. Appliances must deliver value to off-grid consumers to ensure the long-run viability of the market. Experiences from Africa and India showed that small enterprises as roadside kiosks and small grocery stores selling chilled water, milk, drinkable yoghurt, soft drinks, or chocolates were the main user groups for off-grid refrigerators. In Bangladesh fishermen use refrigerators to cool the fish catch. Industry sees the highest demand for small refrigerators of 50–80-liter size for the off-grid segment. This is because stocking needs of target households and small shops are relatively low due to limited financial resources. In addition, small shops often have little space and favor appliances that can be moved around.[10]

The same report also points out that there is still a need to better understand the heterogeneous and evolving needs of off-grid consumers to inform investments in both innovation and design of off-grid appliances. It is very difficult for manufacturers to estimate the size of the potential market because robust ground-level consumer data, including demand for off-grid appliances, customer preferences, affordability, and willingness to pay are not available. On the other hand, there is only little information available on off-grid appliance products themselves, which makes it difficult for producers to get an overview of potential competitors.

3 GLOBAL MARKET FOR SC-A REFRIGERATORS

In the 2018 *Efficiency for Access Coalition Market Survey* of the healthcare sector, refrigeration (including vaccine and blood bank refrigeration) ranked first in terms of perceived demand across all regions. From this survey, the authors concluded that despite the efforts of numerous initiatives to equip clinics and healthcare institutions in developing countries with options for vaccine refrigeration there is still a significant need. [11]

According to GAVI up to 90% of health facilities in developing countries lack proper equipment to adequately store and transport vaccines[12].

A 2014 WHO report [13] indicated that reliable data on electricity access in health facilities is limited. In a global review led by WHO, nationally representative data could only be found for 14 developing countries, 11 of them in Sub-Saharan Africa. It was shown that on average, one in four Sub-Saharan health facilities had no access to electricity and only 28% of health facilities and 34% of hospitals had more or less “reliable” access to electricity (Adair-Rohani et al, 2013). The same report states a steady increase in investments by intergovernmental agencies working in the health sector in solar-powered vaccine refrigeration, giving the example of UNICEF, which as of December 2014 had purchased close to 10,000 solar refrigerators for over 24 countries, with numbers more than doubling in the past three years. According to the report, solar direct-

[9] Efficiency for Access (2018). APPLIANCE DATA TRENDS.
[10] Global LEAP (2016). The State of the Global Off-Grid Appliance Market.
[11] Efficiency for Access (2018). APPLIANCE DATA TRENDS.
[12] https://www.gavi.org/about/ghd/sdg/
[13] World Health Organization (2014). Access to modern energy services for health facilities in resource-constrained settings: a review of status, significance, challenges and measurement.

drive (SDD) refrigeration procurement represented 13% of all refrigerators and freezers procured by UNICEF in 2013 with this market share projected to increase further as the agency pressed industry to step up production (UNICEF, 2013).

As a result of the GAVI initiative towards securing the vaccine cold chain, it is estimated that by the end of 2021 80,000 solar direct drive (SDD) vaccine cooler units have been installed in 82 countries supported by UNICEF (direct communication with UNICEF, January 2022). This is in track to achieve the 100,000 units targeted by the Clinton Health Access Initiative (CHAI) and its partners (WHO, GAVI, Bill& Melinda Gates Foundation, UNICEF) by 2021-2022[14].

Energy Harvest Control (EHC) units can increase the benefits of SDD Refrigerators by safely providing surplus electricity to power secondary electrical loads.[15] This will probably increase the attractiveness of SC-A units to potential users as health care centers and shall be highlighted in discussions with potential partners/users.

3.1 MARKET FOR SC-A REFRIGERATORS IN THE PROJECT COUNTRIES AND GHG EMISSION SCENARIOS

As per the analysis above, the market for these appliances is focused on areas that remain off-grid or have unreliable electricity availability. While there is little data on the actual number of facilities that fall in this category, it is possible to approximate the number based on the proportion of the population that is off-grid or under-serviced by the electricity grid and using assumptions on the average number of people serviced by medical facilities that would require reliable refrigeration.

It is also important to consider that some electrification statistics are starting to include access to electricity services through the implementation of micro solar systems. This is improving the lives of many, especially in rural areas, however these systems are not capable of supporting domestic or commercial refrigeration appliances. As such, wherever possible, the assessment has excluded these statistics.

This analysis provides an approximation of the size of demand for SC-A products, although it should be considered that not all these locations will have the financial options for purchase and servicing, making the intervention of international organizations essential to deploy these units in meaningful numbers. Also, it is important to consider that the countries in the study have adopted development strategies that aim to improve electricity coverage for the population.

Besides looking into the demand for SC-A coolers for each project country in the following sub-chapters, an estimation of the potential GHG emission reduction is given for indirect emissions, those emissions that occur during the operation of kerosene and solar direct drive refrigerators. Direct emissions, emissions that can occur due to leakage of refrigerants, are not included in this analysis. Direct emissions for SDD refrigerators were initially assumed to be 0 because the industry seems to be moving to R600a as refrigerant for smaller refrigerating units. However, this assumption is rather positive as there are some SDD refrigerators in the market that use R134a. To provide an emissions reduction counterfactual, it can be assumed that all the kerosene-powered units are using R134a. To estimate emissions in this case, standard GHG emissions inventory practice for units this size is as follows:

- All emissions take place in one event at the end of the life of the unit as it is unlikely that there is recycling capacity for the left-over gas.

[14] Efficiency for Access (2018). Refrigerator Industry Bulletin 2018.
[15] Path (2016). Energy Harvesting Controls for Solar Direct-Drive Cooling Systems: Laboratory Testing Report.

- Charge for an SCA unit is assumed at 50mg per unit.
- According to the 6th Assessment Report from IPCC R134a has a GWP of 1,530 and for R600a has a GWP of 0.006.

Based on the above, one unit of SC-A charged with 50mg of R134 will have direct emissions of 76.5 kg CO_2e over its lifetime, compared to an SC-A unit charged with 50mg of R600a which would have negligible direct emissions of 0.0003 kg CO_2e. The difference is significant, especially at larger scale.

3.1.1 Kenya

Kenya's level of electrification is increasing fast, and the National Electrification Strategy is aiming at universal access by 2022[16]. While this target is ambitious, it does count with significant international donor backing to progress as fast as possible. On the other hand, recent fiscal policy changes are effectively instituting a VAT tax of 14% on supplies imported for the construction of power plants and off-grid power equipment.

Electrification rates rose to 73% in 2018, up from 26% in 2013, with the support of the Rural Electrification and Renewable Energy Corporation (REREC) they aim to continue this process to complete universal (or near universal) by 2022. However, a significant proportion of this access is on the bases of diesel powered mini-grids or solar mini-grids that may not have the capacity to support larger appliances[17]. Similarly, the reliability of a grid expansion that proceeds at such rapid pace may be limited to basic applications in the early years as the economy develops requiring more robust infrastructure. According to Afro-Barometer[18] around 37% of the population in Kenya enjoys reliable electricity access, and off-grid refrigeration solutions are still a necessity for 63% of the population.

It is assumed for this analysis that electrification rates will continue to improve, however not at the pace stated in national policy, as "last mile[19]" electrification experience in many countries proves to be challenging even in developed countries. As such, it has been assumed that universal access is reached by 2050 although still making use of solar microsystems and with some proportions of the electrical grid remaining underserved. With this in mind, a 65% access to reliable electricity supply from the grid is assumed, with the remaining 35% having electricity with lower reliability or from off-grid solutions.

From this analysis, it can be concluded that the implementation of DD SC-A units in medical facilities in Kenya will still provide a number of significant benefits including:

1. Essential services for medical facilities servicing around 63% of the population where reliable electricity access has not been established to date. Further, while connection rates are increasing, so is rural population ensuring significant demand for SC-A units.

2. Providing security (and lower operating costs) for the medical facilities where the connection still relies on diesel mini grids that are usually accompanies by high electricity costs and reliability issues.

3. Reliability for medical facilities recently connected to the grid in areas where demand may outstrip supply limiting activity to basic uses. This also frees available grid resource to service other needful activities.

[16] https://www.trade.gov/country-commercial-guides/kenya-electrical-power-systems

[17] World Resource Institute (2021). Integrated Planning Helps Kenya Close its Energy Access Gap.

[18] Afrobarometer (2019). Progress toward 'reliable energy for all' stalls across Africa, Afrobarometer survey finds.

[19] The last mile refers to achieving electrification to the last segments of isolated population.

Combined with a strong solar resource[20], issues of grid reliability and investment costs, there is a strong case for the continued implementation of SC-A appliances in Kenya.

Assuming a current level of medical facilities to provide vaccinations and other basic services of around one per 27,000 population in off-grid areas of underdeveloped countries, increasing to one per 10,000 by 2050, and based on the electrification rates above, there is a current need for around 1,800 direct drive coolers in Kenya, rising to 3,200 by 2050 as deployment increases to 1 per 10,000 population. This assumes a single refrigeration unit per facility, which could underestimate the demand for DD appliances.

According to WHO, Kenya has been installing SDD refrigerators at health facilities without reliable electricity since 2009. Several hundred SDD refrigerators have already been installed it is expected to continue with this process in the coming years (WHO, 2017).[21] Considering the need for replacement over time, this market will have steady demand into the future.

Aside from the off-grid reliability benefits, SC-A units benefits the owners and operators from the near-zero operating costs compared to the fossil fuel operated units which require a steady supply of LPG or kerosene. At the same time, the SC-A units have zero GHG emissions supporting national climate action goals.

Figure 1 illustrates emissions from DD coolers based on the market size estimates from above and assuming different rates of the SC-A penetration rates compared to a baseline where all the units are kerosene operated. While it is understood that some of the market is already solar, the margins of error in the estimates make accurate emissions reductions analysis less relevant. Each fossil fueled unit emits approximately 800 kg CO_2e per year of operation, not including the emissions from supplying the fuel to the units.

It is of note that the GHG emissions reductions analysis does not represent a cumulative assessment reduction of the life of the solar DD units and their accumulation in the market over time. Rather, each point in the timeline represents an available GHG reduction potential from the implementation of SolarChill units compared to a baseline where all the units demanded from the market are kerosene powered. This cross-sectional view provides an over immediate potential for each year, but it should be considered that the deployment of the units will be gradual and that units stay operational for around 10 years, increasing the total cumulative abatement potential.

[20] World Resource Institute (2021). Integrated Planning Helps Kenya Close its Energy Access Gap.

[21] World Health Organization (2017). Evidence Brief: Solar direct-drive vaccine refrigerators and freezers (WHO/IVB/17.01).

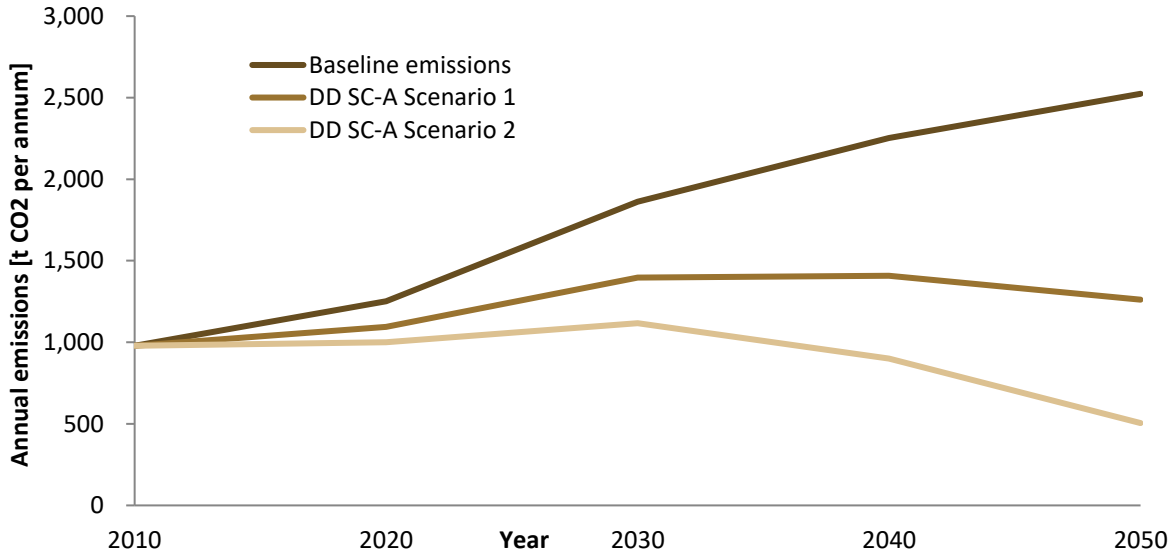

Figure 1 GHG emissions of different SC-A implementation scenarios, Kenya (Source: HEAT).

In the baseline scenario, emissions form DD coolers in 2020 is 1,407 tCO_2e and continue to climb reaching 2,524 tCO_2e by 2050 as population increases and health coverage for the off-grid population improves. These number are very sensitive to changes in the rates at which electrification progresses. In Scenario 1, a 50% penetration rate of SC-A units in 2050 replacing the kerosene units effectively reducing emissions by half. This is a reduction of 1,262 tCO_2e compared to the baseline scenario. Scenario 2 assumes an 80% penetration rate in 2050, and consequently achieves 80% reductions in emissions.

Within the SolarChill project 36 SCA units were installed in Kenya which translates to a GHG emission reduction of indirect emissions of 28 tCO_2e/ year assuming the installation of such units avoided the installation of the same number of kerosene off-grid vaccine coolers.

It is important to note, that all of these emissions are cost effective, as the operating costs of supplying kerosene to these units over their lifetime far outweighs the high purchase costs of the SC-A units in this study.

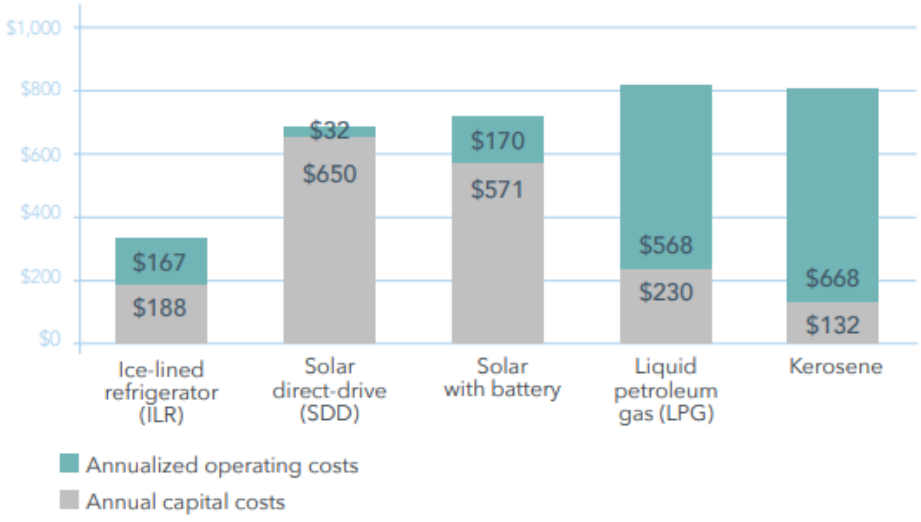

Figure 2 Estimated annualized cost of ownership of off-grid coolers. (Source: WHO, 2017[22])

[22] World Health Organization (2017). Evidence Brief: Solar direct-drive vaccine refrigerators and freezers (WHO/IVB/17.01).

3.1.2 Colombia

While access to electricity in Colombia is nearly universal, the geography of the country presents great difficulties to reach isolated communities in the jungle regions and the heavily mountainous regions. To date, around 1.9 million people in over 1,700 communities remain off-grid or with limited electricity access largely provided by the limited operations of small diesel operated mini-grids. Furthermore, the supply of diesel, maintenance, and the reliability of the grid have been a constant problem for municipalities that run these mini grids, mostly subsidized from central government[23,24].

More than a decade ago, Colombia achieved a 95% electrification rate, but the last 5% has not proceeded as planned in national policy strategies and action plans due to difficulties of terrain, policy, infrastructure, etc. The government intends to provide access to the remaining isolated and marginalized communities, however the persistent difficulties indicated above will continue to hamper efforts. For this analysis, it is assumed that the universal access target will be achieved by 2050.

For this analysis, it is assumed that each of the 1,700 off-grid and isolated communities will have its own, if limited, medical facility requiring cooling for medicine and vaccines. Given its current state of development, population growth is expected to be slow and will be a lesser driver than in other countries. At the same time, the general size of the isolated communities is less that the 10,000 people per facility assumed for other countries, and as such, population growth has not been considered for the SC-A analysis, although it will play a role in the SC-B analysis.

Based on the assumptions above, the demand for SC-A begins at 1,700 units in 2020, assuming a single unit for each community medical facility. From this a continuous effort to provide electricity to communities is assumed to continually reduce the number of communities needing this service. As such the demand for units decreases over time. Based on these assumptions, demand for the SC-A will decrease to near zero with only the most difficult-to-reach communities remaining and no further off-grid solutions needed.

In terms of emissions, assuming 800 $kgCO_2e$ level per unit, the total for 2020 is around 1,043 tCO_2e and continually reduce total emissions to near zero by 2050. As considered above, the reduction is due to progress in electrification in Colombia while population growth is not considered. However, SDD units deployed early will continue to provide GHG reduction savings during their lifetime, so prompt action is recommended.

[23] El Tiempo. El mapa de 1.710 poblados que aún se alumbran con velas en Colombia.

[24] Estefany Garces, Julia Tomei, Carlos J Franco, Isaac Dyner (2021). Lessons from last mile electrification in Colombia: Examining the policy framework and outcomes for sustainability.

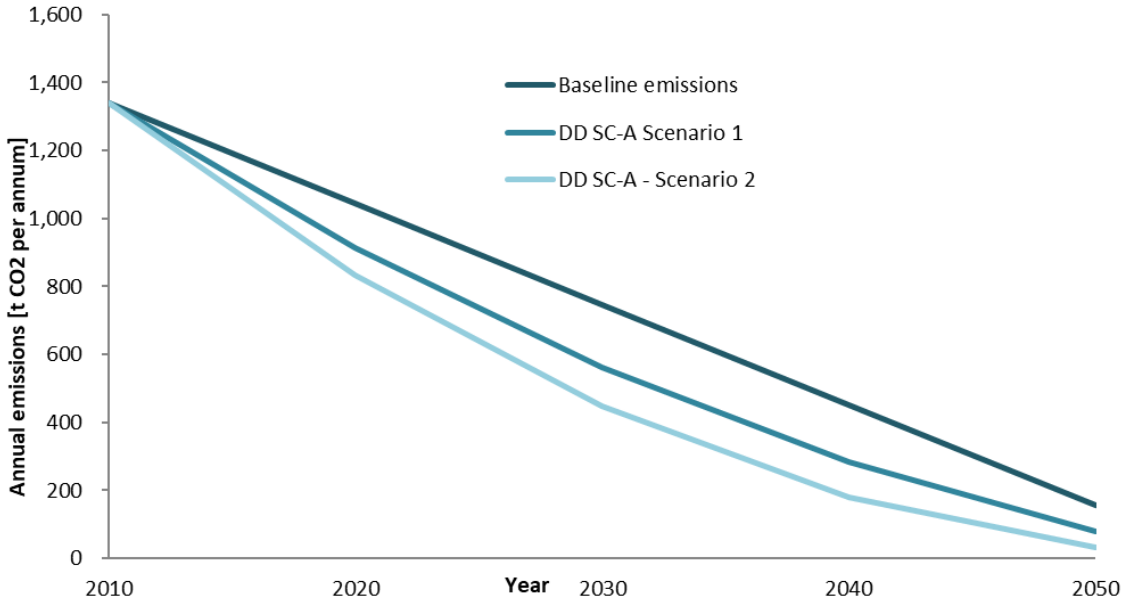

Figure 3 GHG emissions of different SC-A implementation scenarios, Colombia (Source: HEAT)

Within the SolarChill project 37 SCA units were installed in Colombia which translates to a GHG emission reduction of indirect emissions of 29 tCO_2e/ year assuming the installation of such units avoided the installation of the same number of kerosene off-grid vaccine coolers.

3.1.3 Eswatini

Eswatini is small landlocked country surrounded by South Africa and Mozambique with a population of less than 1.2 million people. As with other developing countries, electrification rates have seen a rapid improvement in the last decade and the government's policy is to achieve universal access by 2022. However, considering that around 75% of the population lives in rural areas practicing subsistence agriculture, they are generally unable to cover the cost of extending the grid.

Similarly, electricity peak demand in the Eswatini is around 232 MW compared to the 70 MW peak supply capacity owned by the state utility. Local electricity demand is largely met with imports from the shared Southern Africa Power Pool market but the increase in the electrification is exacerbating the existing deficit.

Currently, around 70% of the population is reported to have electricity access an increase from 51% just a decade earlier. As with Kenya, part of the rapid electrification rate includes a proportion achieved through micro-solar systems for basic electricity services, and a proportion of communities connected to the grid have limited reliability.

The Ministry of Health estimated the future demand of SC-A units at 382 units, to cover the remote health center locations in the country (SolarChillMidTerm Evaluation report). This estimate is higher than the assessed using the assumptions for all least developed countries at large. The market assessment for SC-A was subsequently adjusted to account for this assessment and an average number of units per million population was assessed and kept constant throughout the period.

With this in mind, the overall demand for off-grid chiller units in eSwatini goes from 382 currently, decreasing to 309 by 2050 as electrification improvements reach more communities. Figure 4 shows the GHG emissions

generated from these units from a baseline path that assumes 100% kerosene powered units, to scenarios 1 (assuming 50% solar units penetration by 2050) and 2 (assuming 80% solar unit penetration by 2050). Each kerosene unit would emit around 800 kgCO_2e per year, and about 8 tones CO_2e over a 10-year lifetime.

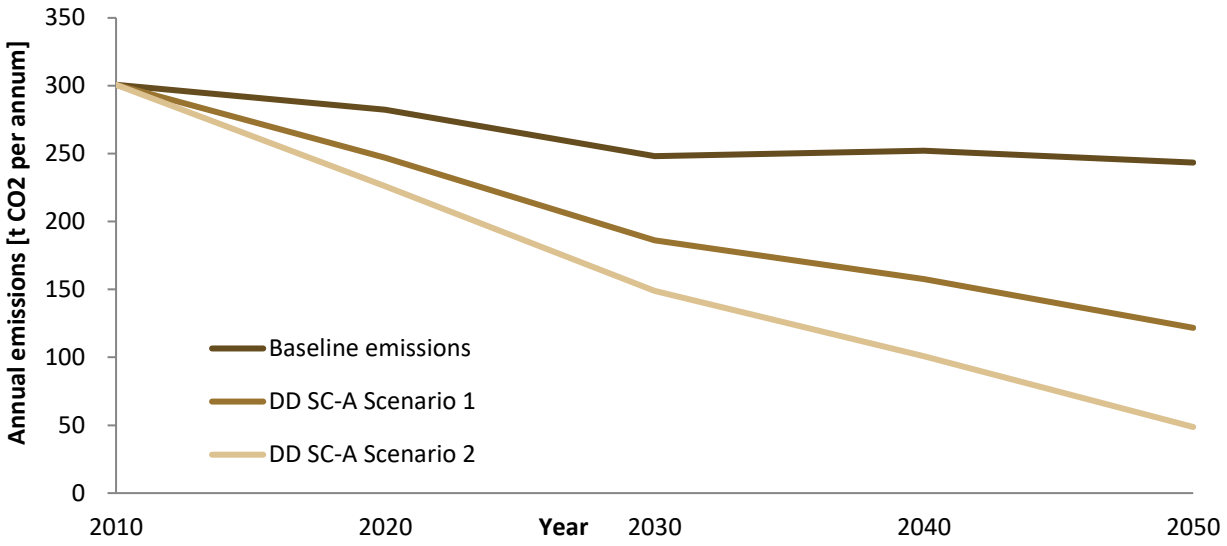

Figure 4 GHG emissions of different SC-A implementation scenarios, Eswatini (Source: HEAT)

Within the SolarChill project 40 SCA units were installed in Eswatini which translates to a GHG emission reduction of indirect emissions of 31 tCO_2e/ year assuming the installation of such units avoided the installation of the same number of kerosene off-grid vaccine coolers.

3.2 MANUFACTURERS FOR SC-A REFRIGERATORS

The SolarChill project has partnered with various manufacturers, with those who are already in the market and agreed to participate with some of their models in the field monitoring study, and with manufacturers who showed interest to develop SDD refrigerators for their local markets (see chapter 5).

SDD vaccine refrigerators (SC-A refrigerators) are tested and certified according to WHO standards and need to comply with the WHO Performance, Quality and Safety (PQS) process before being used in immunization programs. Products that passed the WHO PQS requirements can be found in a product list which includes the manufacturer, the name of the model, a short product description and a pdf with more specific product details that can be downloaded on the following WHO website:
https://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/categorypage.aspx?id_cat=17.
To field test certain SC-A models within the SolarChill project Vestfrost Solutions, Zero Appliances (Pty) Ltd, Godrej & Boyce MFG. Co. Ltd., B Medical Systems Sarl and Qingdao Haier Biomedical Co., Ltd. became SolarChill project partners.

4 GLOBAL MARKET FOR SC-B REFRIGERATORS

As outlined in chapter 2, the global market for off-grid solar refrigeration is expected to increase significantly over the next years.

Of potential interest to the SolarChill project in the context of future commercialization/uptake of SC-B units are especially countries with a large off-grid/weak-grid population. Sub-Saharan countries are therefore important to consider (see chapter 2). The report *Chilling Prospects: Providing Sustainable Cooling for All,* published by SE4ALL in 2018, provides a list of countries that in the coming years are projected to have the biggest populations facing significant cooling risks. These countries across Asia, Africa and Latin America include India, Bangladesh, Brazil, Pakistan, Nigeria, Indonesia, China, Mozambique and Sudan[25].

A study undertaken by Energy4Impact in 2017 in Uganda[26] interviewed 172 micro-enterprises to understand how decisions on acquisition and use of refrigerators were made. In this case an on-grid situation was selected as off-grid refrigeration is nascent and therefore does not provide a sensible baseline. Background of this activity was that the winner of 2016-2017 Global LEAP Award off-grid refrigerator competition will be field tested to determine appropriate design and user experience. Main outcomes of the study include:

- There is a clear business case for energy efficient refrigerators for on-grid enterprises as well as for off-grid users incl. retail micro-businesses selling beverages.
- There was keen interest in the potential of solar fridges.
- Many business lines are around new/additional types of cold drinks and production /sale of ice.
- Fridges enable diversification of products sold and improve business' competitiveness.
- Most important and valued for the micro-enterprises are energy efficiency and autonomy.
- Also important: appropriateness of the products for the business needs: robustness, design features.
- The desired size range seems to be between 100-150L for a fridge and slightly smaller for a freezer (which reflects the sizes of the businesses interviewed - small retail shop run by a couple or family).
- The average product cost was 250 USD.
- Fridges need to be long-lasting. If they require expensive repairs of replacements are frustrating.
- Fridges currently provided by beverage firms have high energy demand (Coca Cola and Pepsi).
- User feedback: Interviewees value appliances with a display to show what is on sale. The ability to partition products in the fridge compartments was also seen as a positive characteristic.

Based on fridge characteristics from this study, solar refrigerators (i.e., refrigerators designed only to be compatible with solar home systems (SHS) or DC grids) at their current cost are not economic for micro-businesses. However, the technology trajectory looks promising with, at best, a 3-year payback period for the power supply of a 170L fridge that costs 546 USD.

The study identified micro-enterprises running retail shops that have an element of selling drinks, preferably located in towns/trading centers along busy roads, as target groups for further tests.

While small businesses are identified as the key target group for this type of initiative given their economic interest and possible community development benefits, recent reports from SolarFreeze in Kenya indicate that there is also significant interest from the residential sector that may look to add refrigeration to other services they already get on a pay-as-you-go basis through PayGo such as lighting and televisions.

[25] Sustainable Energy for All (2018). Chilling Prospects: Providing sustainable cooling for all.

[26] Energy4Impact (2017). GRID POWERED REFRIGERATION FOR PRODUCTIVE USE Study of 172 micro-enterprises in Uganda to understand the case for off-grid appliances.

Lighting Global undertook 2019 a detailed market assessment on the productive use of solar in Kenya, Zimbabwe and Cote d'Ivoire, including milk chillers and refrigerators for fish preservation. Amongst others, some key findings are i) a shift in off-grid solar powered applications towards communication, entertainment, and refrigeration, ii) limited knowledge about solar refrigeration in horticulture, dairy, and fish cold chains despite a high demand for refrigeration due to losses up to 33% without adequate cold chain, and iii) high refrigerator costs still hinder the uptake. [27]

	Severity of constraint:	**PULSE use cases / product groups**			
	High **Medium** **Low**	**Irrigation**	**Cold storage**	**Agro-processing**	**Refriger-ation**
A	**Upfront investment costs***				
M	Limited financing for users especially SHF				
E	Distribution challenges				
K	Limited financing for local PULSE innovators				
B	**VC structure & aggregation points***				
C	**Lack of precedents***				
G	**Limited tailored product design in PULSE use cases***				
D	Insufficient investment in R&D activities / quality				
J	Lack of policy support targeting PULSE				
H	Limited post-sales support				
I	Poor market linkages for SHF				
L	Lack of co-ordination at country level programming				
F	**Capacity building of SHF/microenterprises***				

Figure 5 Constraints for different product segments (Source: Lighting Global 2019[28])

Confirmed by various studies, high upfront costs of solar powered refrigerators hinder the market uptake despite a high demand especially for micro-business. In chapter 4.2.2 we will therefore further elaborate on how to overcome this barrier and outline a few possible generic business models.

4.1 MARKET FOR SC-B IN THE PROJECT COUNTRIES AND GHG EMISSION SCENARIOS

Following the approach taken in chapter 3.1 the demand for SC-B coolers for each project country and an estimation of the potential GHG emission reduction for indirect emissions will be assessed in the following sub-chapters. The GHG emission reduction potential for direct emissions is not analysed on country level yet rather indicatively estimated based on the same assumptions like in chapter 3.1:

- There is only one set of emissions at the end of life of the unit as it is unlikely that there is recycling capacity for the left-over gas.
- According to the 6th Assessment Report from IPCC R134a has a GWP of 1,530 and for R600a has a GWP of 0.006.

[27] Lighting Global (2019). The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa.
[28] Lighting Global (2019). The Market Opportunity for Productive Use Leveraging Solar Energy (PULSE) in Sub-Saharan Africa.

The refrigerant charge is assumed to be approximately 100mg per unit as SC-B refrigerators are usually bigger in size and storage capacity than SC-A refrigerators. Based on these assumptions, one unit of SC-B charged with 100mg of R134 will have direct emissions of 153 kg CO_2e over its lifetime, compared to an SC-B unit charged with 100mg of R600a which would have negligible direct emissions of 0.0006 kg CO_2e. The difference is significant, especially at larger scale.

4.1.1 Kenya

The SolarChill team conducted 2018 a survey to evaluate the potential market for SC-B units in Kenya with the result that there is significant interest in the market for the SDD technology. Considering that still over half of the country is not connected to electricity grids or is underserved by existing grids, this leaves many businesses and households to look for alternatives.

Based on the preliminary market modelling for SC-A (Chapter 3.1.1), only 44% of the country's households and respective small businesses in those geographic areas are reliably serviced by electricity grids, leaving over 56% and growing population to find alternatives. As such, solar solutions have become very popular in Kenya with over 20% of households meeting some of their electrical needs through solar solutions (e.g. through SHS). SHS usually involve very small solar collectors capable to provide sufficient power for lighting, phone charging, and televisions for the larger systems. This makes Kenya one of the largest markets for off-grid solar applications.

According to the survey, nearly 60% of households that purchased an SHS want additional systems and 20% of the customers are interested to add a fridge to their current module (based on a GOGLA survey of 2,300 customers in Kenya, Mozambique, Uganda, Rwanda and Tanzania). Turkana, Samburu, and West Pokot are likely the best counties for new solar product adoption with more than 50% of households currently using some off-grid solar systems. The survey identified a total cost of ownership of ranging between 500 to 1500 USD to be the most suitable SC-B systems in Kenya.

Making conservative assumptions about affordability and ability to pay for SC-B refrigerators, the demand to deploy SDD units is increasing from 1 in 75 off-grid households currently (based on global deployment of off-grid refrigerators) to around 1 in 25 off-grid households in 2050 as economics improve. As a result, the demand for SC-B units in Kenya is currently around 100,000 units and is expected to increase to over 350,000 units by 2050. This is both a result of increasing proportion of households demanding units, but also of population increase, meaning that while electrification improves, the overall number of off-grid households in Kenya still increases between 2020 and 2050.

In terms of emissions, if all this demand for off-grid appliances was met with kerosene appliances, GHG emissions would be over 80,000 tCO2e in 2020 increasing to 288,000 tCO2e by 2050. This is a very significant increase in emissions which Kenya could avoid through the use of SC-B units. What's more, this could be achieved at a negative cost to the country as the life cycle cost (LCC) of direct drive solar units has been proven to be less costly (Figure 2) than fossil fuel powered units due to the high (and increasing) cost of petroleum fuels. Further, solar technologies continue to improve, producing lower costs and better technical operational results over time.

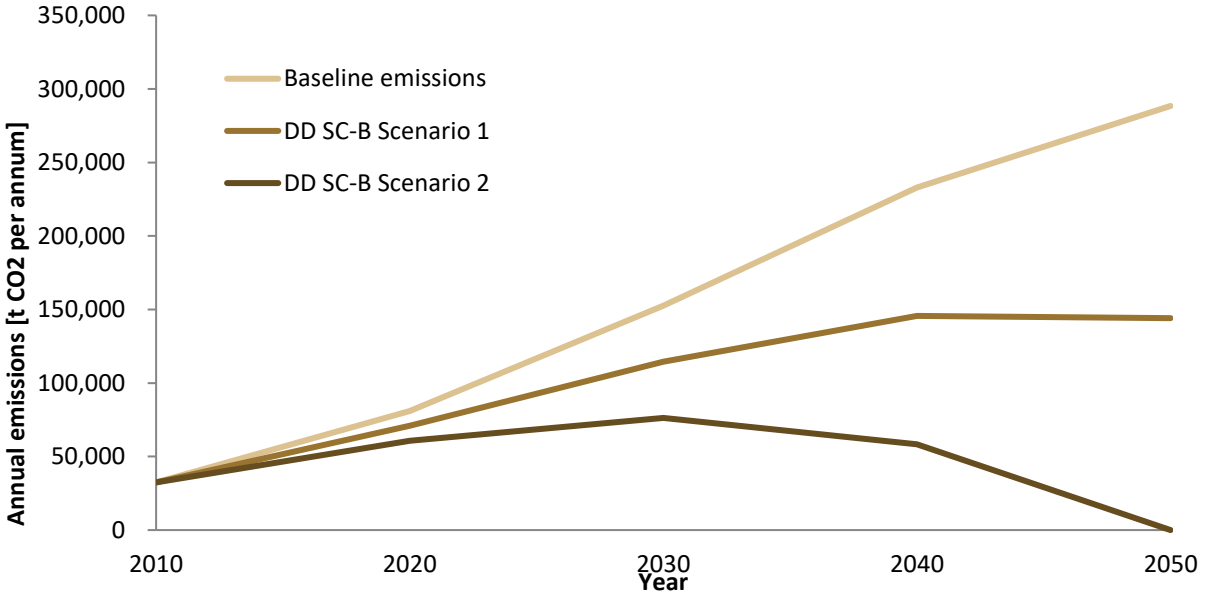

Figure 6 GHG emissions of different SC-B implementation scenarios, Kenya (Source: HEAT)

Within the SolarChill project 14 SCB units were installed in Kenya which translates to a GHG emission reduction of indirect emissions of 11 tCO_2e/ year assuming the installation of such units avoided the installation of the same number of kerosene off-grid commercial coolers.

Companies consulted in Kenya to deploy this technology expressed interest and there are pilot projects underway, despite some key concerns regarding some practical consideration, businesses models, and technical implementation including:

- **Incorporation of SDD refrigerators into the PayGo system**: PayGo customers pay for days of service such as lighting or TV usage. In this system, a lack of payment results in the system shutting down until the next payment is received. In the case of a refrigeration, this could result in losing the goods (largely perishable food products) causing further damage to poor households. Alternatives include just locking the device, but further research may be needed.
- **Training of the users:** Rural people often live without a fridge and would most likely need proper training before they can handle the unit. Giving responsibilities for the unit and ownership is important.
- **After-sales agreements:** What happens in case of warranty, unit-failure etc?
- **Match the demand:** Product needs to meet the needs and expectations of the users, including an affordable price, design (upright version).

4.1.1.1 SolarFreeze

SolarFreeze started its business in 2016, focusing on cold storage units for rural smallholder farmers. In central locations that are accessible for several farmers cold storage units were installed. There, farmers pay for the usage of a defined storage area over a defined period by the PayGo model, a payment method that allows payments on daily, weekly or monthly basis. In a market research study conducted by SolarFreeze it was concluded that there was a considerable market for smaller cold storage units as only 15% of rural households have access to a refrigerator. As SolarFreeze had an interest in increasing their portfolio and offering smaller refrigerators based on solar power to their customers, they became a SolarChill project partner for SC-B field testing and installed 6 SC-B units from two different manufacturers between August

and October 2019 which allowed them to receive field test results and customer feedback, as well as to develop their business model further before placing bigger orders for SolarChill refrigerators.

Feedback from SolarFreeze: Customers who use SolarChill units are quite satisfied, no technical issues had been reported. As a result, SolarFreeze has been receiving overwhelming customer inquiries from customers who would like to purchase such units, mainly small businesses such as shops and kiosks, as well as healthcare facilities in rural areas. As of September 2021, SolarFreeze had at least 250 pending sales requests from customers interested in purchasing such units by paying 30% of the total costs upfront and the remaining 70% over a 12-month-period. SolarFreeze plans to further uptake the technology in the market by optimizing their business model and collaborating with banks and micro-finance organisations that issue loans to the customers to allow them paying the upfront costs.

4.1.1.2 Pawame

Pawame was chosen as a partner in the pre-commercialization phase and for the further uptake of the SC-B technology in the market in Kenya and other countries and signed the Memorandum of Understanding (MoU) with the SolarChill project team in March 2019. Like SolarFreeze, they as well apply PayGo as business model. Within the SolarChill project, they installed 5 SC-B units from three different manufacturers.

User feedback: By January 2021, Pawame conducted interviews with two of their beneficiaries. Both are very satisfied with the refrigerator, had no technical issues, have been cleaning the refrigerator at least two times per week if not daily, and would recommend the product to others. While one beneficiary has been using the refrigerator for personal use, the other beneficiary had been using it in addition for her business and could increase her sales and number of customers by offering chilled products such as soda and milk.

Feedback from Pawame: To further uptake the SolarChill technology in the market, Pawame recommends a maximum price for SDD refrigerators depending on the size of 500 – 800 EUR.

Figure 7 Installation of a SC-B unit by Pawame (Source: Pawame)

4.1.2 Colombia

Assuming the electrification rates described in Chapter 3.1.2 indicating that access to electricity in Colombia is nearly universal, the geography of the country presents great difficulties to reach isolated communities in the jungle regions and the heavily mountainous regions. To date, around 1.9 million people in over 1,700 communities remain off-grid or with limited electricity access largely provided by the limited operations of small diesel operated mini-grids. Furthermore, the supply of diesel, maintenance, and the reliability of the grid have been a constant problem for municipalities that run these mini grids, mostly subsidized from central government[29,30].

Based on these assumptions, demand for off-grid chillers in Colombia was estimated at around 6,600 units for 2020 using assumptions based on global deployment of off-grip appliances. This number might be an underestimation as the global average assumption includes figures from least developed countries (LDCs) which are not representative of Colombia. However, considering that population growth is slowing down, and that 'last-mile' electrification efforts are underway, the market for off-grid appliances is projected to peak around 2030 with 8,300 units to decrease rapidly to under 3,000 by 2050.

There is another potential market in the agricultural sector, especially the small and medium farms. This type of activity does not have a stable income that allows them to pay the monthly cost of electricity. Some farmers restrict their production and/or do not process it due to the high cooling costs and the dependency on unreliable electricity. Solar cooling could be a solution for farmers looking for independence from electricity supply issues and wish to process their products or increase their production with a reliable cooling solution.

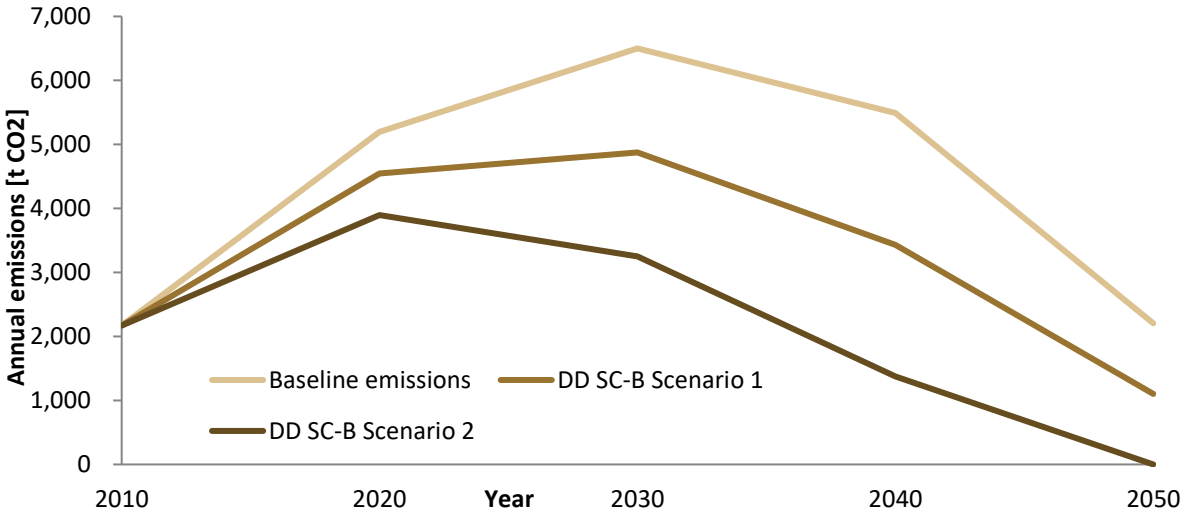

Figure 8 GHG emissions of different SC-B implementation scenarios, Colombia (Source: HEAT)

In terms of emissions reductions from the deployment of SC-B units, Colombia's more limited market presents a smaller yet still worthwhile emissions reductions as units remain operational for over 10 years, reducing emissions for a long time. The is the potential for solar direct drive units to replace the entire

[29] El Tiempo. El mapa de 1.710 poblados que aún se alumbran con velas en Colombia.

[30] Estefany Garces, Julia Tomei, Carlos J Franco, Isaac Dyner (2021). Lessons from last mile electrification in Colombia: Examining the policy framework and outcomes for sustainability.

market, reducing emissions to 0 from a possible high of 6,500 tCO_2e in 2030 if all of the off-grid refrigerator demand is met with fossil fueled units.

In Colombia there is a potential that many of the users that already have electrical coverage could switch to a SDD solution, first of all because electrical services are not regular in many places, second because in the long run they will save resources by using alternative power sources and third some are already sensitive about environmental issues.

4.1.3 Eswatini

As described in section 3.1.3, Eswatini's population is around 1.2 million with the great majority living in rural areas (approximately 75%), and with a general access to electricity of around 70%. However, a significant proportion of the access to electricity services is in the form of micro solar units and a proportion of grid connections are unreliable and/or expensive for many. Based on these assumptions, it is estimated that over 50% of the population in the country is underserved and would benefit from the SDD domestic units of SC-B.

This study considers an initial rate of deployment of off-grid refrigerators of 1,225 units per million population in 2010 from the global assessment and increases to around 10,000 per million population (in line with the assessment for the other countries) as the country develops economically and the economies of scale (or international support increases) improve for these appliances.

Based on these assumptions, demand for off-grid refrigerators in Eswatini is around 2,000 units in 2020, increasing to over 5,000 units by 2050. The increase takes place despite improvements in the electricity grid that see reliable access increase from 49% in 2020 to 70% in 2050. The growth is a factor of increase demand from the sector that remains underserved by the electricity system as refrigeration is increasingly a necessity to increase quality of life.

In terms of emissions, the baseline scenario sees emissions increase from 1,600 tCO_2e in 2020 to around 4,000 tCO_2e by 2050 if 100% of the off-grid units are fossil fueled. In Scenario 2, SC-B units account for 100% of the market by 2050 resulting in zero GHG emissions or such SC-B units in operation in 2050.

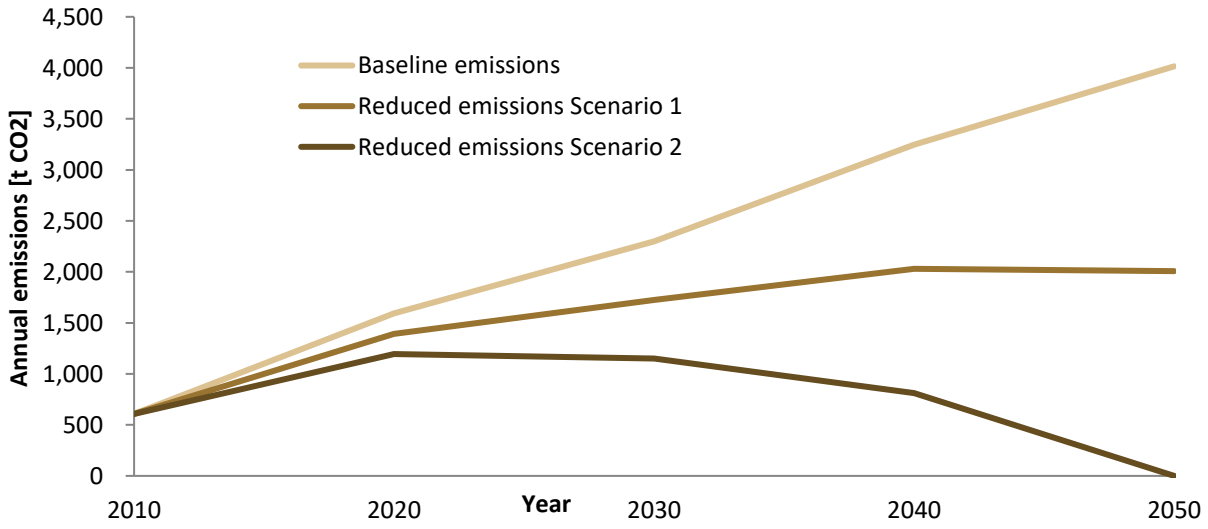

Figure 9 GHG emissions of different SC-B implementation scenarios, Eswatini (Source:HEAT)

Within the SolarChill project 15 SCB units were installed in Eswatini which translates to a GHG emission reduction of indirect emissions of 12 tCO_2e/ year assuming the installation of such units avoided the installation of the same number of kerosene off-grid commercial coolers.

The only national manufacturer of refrigerators, Palfridge Ltd. T/A The Fridge Factory (TFF), converted all production lines and foaming to natural refrigerants such as hydrocarbons (HC) and became a SolarChill project partner. For SC-B types, Palfridge Ltd. has three different sizes: 86, 192 and 286 liters. The unit with 86 liters is ready in production.

4.2 COMMERCIALISATION FOR SC-B REFRIGERATORS

Before products can be economically assessed and marketed, the technical development of the same needs to take place including designing and testing products as well as setting up robust production processes at manufacturers sites to ensure product quality. Part of the SolarChill project scope is the **technology transfer to local manufacturers** to encourage local developments, to strengthen developing and emerging economies and to promote environmentally friendly cooling technologies such as SDD refrigerators that neither require the usage of harmful batteries nor contain synthetic refrigerants with a high GWP. The SolarChill project team developed therefore a technical guide for manufacturers who are interested in taking up the technology.

This technical guide doesn´t intend to be a step-by-step instruction manual but rather an introduction into the SolarChill technology. The aim is to give an insight to refrigerator manufacturers into SDD refrigerators and help them to overcome and anticipate the difficulties that they might find during the design and manufacturing process. In this way, the technology can be spread and used for different applications. By informing manufacturers, the production of SDD refrigerators can be streamlined, increasing availability and promoting research and development, hence reducing cost.

In this context, local manufacturers such as Palfridge in Eswatini as well as Interhospitalaría, Martin Kas and Fricon in Colombia became SolarChill project partners for the technology transfer and started developing SC-A and SC-B refrigerators for their respective local market showing promising signs for the potential future commercialization and market uptake in the country.

4.2.1 A manufacturers perspective

When asked about their perception of the potential market for SC-B, Palfridge Ltd. responded that they believe there is a market worldwide. According to their view, probably there will be less off-grid areas in the future, but what is more relevant is the issue of paying to be connected. In Eswatini, users must pay for the transformer if they want to connect to the grid. For people with low income, the solution often is an illegal connection (like the South Africa context). At the same time worldwide the cost of living becomes more expensive. Compared to a few decades ago, the percentage of the household income that´s now spent on rent and electricity is much higher which makes life more challenging. Consequently, free electricity is attractive to all income bands.

As low-income households represent a huge percentage of households in Africa Palfridge continues its efforts beyond the SolarChill project to further optimize cost by building in cheaper compressors and PCMs into their SC-B unit. This will reduce the price of the units by a large portion and make it more of an option to the everyday person as an alternative to paying money to the electricity companies.

4.2.2 Generic business models

Connected to the potential market and commercialization of SC-B units is the question about adequate distribution channels and access to finance as many people in developing and emerging economies can´t afford paying high up-front cost. Before introducing various business models for solar powered off-grid applications such as SDD refrigerators, Table 1 provides an overview of all relevant stakeholders and their interests, followed by a paragraph about generic well-known business models.

Table 1 Stakeholder overview

Stakeholders	Objective
Manufacturers	To sell SDD refrigerators to expand their businesses and to increase revenue.
Distributers	To buy SDD refrigerators and to either resell SDD refrigerators to retailers and consumers, or offer cooling services (e.g. PayGo, cooling as a service)
Dealers / Retailers	To buy SDD refrigerators and to either resell SDD refrigerators to consumers, or offer cooling services (e.g. PayGo, cooling as a service)
Small Medium Enterprises	To expand product portfolio (e.g. kiosks that offer cold beverages) and/or to increase sales of their products (dairy products, beverages, fish, etc.).
Private households	To increase their quality of life by being able to cold store products such as dairy products, beverages, fish, etc..

The following business models are well known and established across different industries and are still applicable where access to finance on the consumer side is not a hurdle.

- **Integrated distribution:** A manufacturer offers a product through its own distribution channels which allows to incorporate other services such as transportation, installation etc. There are several advantages to this business model yet the most relevant to mention in the context of selling SDD refrigerators is that the sales revenue is maintained within one organisation which can help where manufacturers face the challenge to introduce their products into the market due to high product costs and consequently too high prices for consumers.
- **Traditional dealer-distributor network:** Distributors and dealers are independent firms. A distributer buys products from manufacturers and keeps maintenance and repair parts in stock whereas the dealer buys products from a distributer and provides in addition to the product technical services to the consumer. While every participating firm intends to create revenue through sales which results in higher prices for the consumers, the business model is appreciated, e.g. where manufacturers aim to enter a market abroad where they don´t necessarily have a technical support network but consumers request the same especially when they are not familiar with the technology.
- **Franchising /Micro-franchising:** Franchising firms are strongly influenced and controlled by their parent organisation. A franchisee needs to comply with the brand identity and needs to follow the parent organisations´ approach for pricing structures, marketing and sales activities and other operational businesses procedures. While there can be relatively high start-up costs, the advantage of this business model for franchisees is that they can benefit from an already established business in the market and an existing organisational structure that includes among others established supply chain processes.

The above-mentioned business models are proven concepts and work well in economies where consumers have own financial means or access to finance to purchase products. However, there are some other business models that have been evolving over the last years as especially in developing and emerging economies a

huge portion of people can´t afford pay for products such as refrigerators nor do they have access to bank institutions to potentially ask for a loan. In Sub-Saharan Africa alone 59% of adults have no access to a bank account or any other financial institution.[31] The following business models consider this aspect and play therefore a key role for the uptake of the SolarChill technology.

- **Pay-As-You-Go or the so called PayGo** model has been widely applied in rural, low-income areas and allowed people to have access to clean energy for lighting, televisions, fans, phone charging and refrigeration without having to pay for upfront costs. Instead, they are making daily, weekly or monthly payments for the use of the installed solar system at their homes. In order to make this business model work, it needs a few key players such as i) development banks or impact investors to provide funds, ii) operators or distributors like Pawame and SolarFreeze in Kenya who use these funds to provide SDD refrigerators to end users, and iii) cross country providers such as engie who provide SHS and solar mini grids across various African countries.
- **The rent-to-own model (microfinancing)** could be considered as a sub-model of the PayGo model as consumers pay a regular rate over a certain period as well. Mostly, it´s monthly rate with the aim to own the appliance(s) at the end of the payment period. In other words, the distributer / retailer who provides for example a SDD refrigerator won´t be any longer responsible for the appliance(s) once the ownership has been transferred with the last payment to the end user.

[31] EIB (2017). Banking in sub-Saharan Africa. Interim Report on Digital Financial Inclusion.

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