EFFICIENCY FOR ACCESS

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PHASING DOWN HFCS IN OFF- AND WEAK-GRID REFRIGERATION:

AN OPPORTUNITY TO REDUCE GREENHOUSE GAS EMISSIONS

FEBRUARY 2021

ABOUT

Access to cooling and refrigerators is one of the primary focus areas of energy access efforts, and a significant number of off-grid refrigerators continue to use hydrofluorocarbon (HFC) gases as refrigerants, which have high global warming potential (GWP). This research note has been developed to raise further awareness around this issue within the energy access community.

About Efficiency for Access

Efficiency for Access is a global coalition working to promote high performing appliances that enable access to clean energy for the world's poorest people. It is a catalyst for change, accelerating the growth of off-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life and support sustainable development.

Efficiency for Access consists of 15 Donor Roundtable Members, 10 Programme Partners, and more than 30 Investor Network members. Current Efficiency for Access Coalition members have programmes and initiatives spanning 44 countries and 22 key technologies. The Efficiency for Access Coalition is coordinated jointly by CLASP, an international appliance energy efficiency and market development specialist not for-profit organisation, and UK's Energy Saving Trust, which specialises in energy efficiency product verification, data and insight, advice and research.

The Low Energy Inclusive Appliances programme is Efficiency for Access' flagship initiative.

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ACRONYMS

AC	Alternating Current
CFC	Chlorofluorocarbon
CO_2	Carbon Dioxide
CAGR	Compound annual growth rate
DC	Direct Current
EU	European Union
GHG	Greenhouse gas
Gm	Gram
GWP	Global warming potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
HFC	Hydrofluorocarbons
HFO	Hydroflouroolefins
IPCC	Intergovernmental Panel on Climate Change
Kg	Kilogram
L	Litre
LEIA Programme	Low Energy Inclusive Appliances Programme
ODS	Ozone Depleting Substance
PV	Photovoltaic
RAC	Refrigeration & Air Conditioning
UN	United Nations
UNEP	United Nations Environment Programme

Introduction

Alongside implementing purposeful interventions that expand access to off-grid appropriate appliances[1], it is also important to undertake research to investigate any undesired and unintended environmental consequences of these interventions. Access to cooling and refrigerators is one of the primary focus areas of energy access efforts, and a significant number of off-grid refrigerators continue to use hydrofluorocarbon (HFC) gases as refrigerants[2], which have high global warming potential (GWP)[3]. This research note has been developed to raise further awareness of this issue within the energy access community. In addition to this research note, the Low Energy Inclusive Appliances (LEIA) programme will be undertaking other research projects to investigate other unintended environmental consequences and broader environmental sustainability issues in the off- and weak-grid appliance sector.

About the report

As highlighted above, this research note aims to raise awareness around the harmful environmental effects of using fluorinated gases in refrigerators under 600 litres (L) in the energy access community. It also helps develop an argument to prioritise the development of low GWP refrigerant and high-performing off-grid refrigerator technologies. To this end, this note has the following additional objectives:

1. To raise awareness around the Kigali Amendment and what it means for developing countries.
2. To investigate the penetration of natural refrigerant-based systems in the off-grid refrigerator market.
3. To propose an impact metric for estimating refrigerant emissions for refrigerators with a capacity of 600 litres or lower.
4. To estimate the climate change mitigation potential in using natural refrigerants in small refrigerators in the off- and weak-grid market.
5. To provide a set of actionable recommendations for the energy access stakeholder community to phase out the use of HFCs.

1 For the purposes of this report, off-grid appropriate appliances refer to appliances that are designed to optimise energy performance, service delivery, and quality. This definition was first proposed in the 2019 State of the Off-Grid Appliance Market Report available at https://efficiencyforaccess.org/publications/2019-state-of-the-off-grid-appliance-market-report

2 See section 'Distribution of HC vs HFC systems in off-grid refrigerator market: trends and opportunities'.

3 The global warming potential (GWP) of a certain greenhouse gas is the heat absorbed by one tonne of the gas relative to the amount of heat absorbed by one tonne of CO_2 over a certain period. CO_2 was established as the reference gas for comparing warming potentials for various gases by the Intergovernmental Panel on Climate Change (IPCC) and its GWP is defined by 1. This helps provide a standard scale for comparing emissions of different gases.

What is the Kigali Amendment, and its implications for developing countries?

Global environmental treaty regulating use of HFCs: The Montreal Protocol on Substances that Deplete the Ozone Layer, known simply as the Montreal Protocol, banned the use of ozone depleting substances, leading to widespread adoption of HFC gases, which have high global warming potential when compared with CO_2. If the current growth in HFC use is not controlled, efforts to keep global temperatures at or below 2°C by the end of this century will be at risk. To address this, the Parties to the Montreal Protocol adopted the Kigali Amendment which brings the future production and consumption of HFCs within the Protocol's remit.

The Kigali Amendment came into force on 1 January 2019 and requires parties to gradually phase down their use of HFCs to 80– 85% by the late 2040s. Developed countries were expected to start their first reductions in 2019.

Penetration of natural refrigerant-based systems in the off-grid market

Share of refrigerators using HFCs in off- and weak-grid refrigerator markets: The most striking observation that emerged from the authors' analysis of refrigerator models was that off-grid refrigerator manufacturers are using only three types of refrigerants in off-grid refrigerators under 600 litres. These are propane (R290) and isobutane (R600a) among natural refrigerants, and 1,1,1,2-tetrafluoroethane (R134a) among hydrofluorocarbons or HFCs. H-134a is a potent greenhouse gas with a global warming potential (GWP) of 1430 on a 100-year timescale.

This trend is different from on-grid markets in developing countries where many manufacturers are transitioning to using an intermediate refrigerant technology called hydrofluoroolefins (HFOs) first instead of adopting natural refrigerants. According to interview data with off-grid manufacturers and other anecdotal data, off-grid manufacturers showed high levels of receptiveness to transitioning directly from HFCs to natural refrigerants.

A second observation that emerged from this analysis was that vapour compression systems dominated the off-grid refrigerator market.. This reflects a global trend where vapour compression systems are expected to remain the primary technology of the future, which makes it even more pertinent to swiftly transition the off-grid sector to low-GWP refrigerant use.

The off-grid refrigerator market is dominated by the use of R134a and R600a. 40% of the analysed refrigerator models use R600a and 47% models use hydrocarbons (R600a or R290). More than 50% of manufacturers are still using the HFC R134a. This significantly lags behind the trend in Europe where there is a total penetration of R600a refrigerant systems in the household refrigerator and freezer markets.

Calculating emissions from refrigerants

It is vital for energy access stakeholders working to enhance access to refrigeration to understand how emissions from refrigerants are calculated. This will enable them to standardise reporting of emissions from refrigerants across companies and quantify how emissions from different refrigerant gases contribute to climate change. Making emissions savings from the avoided use of fluorinated gases visible in impact reporting would reward companies that are already working with HC systems.

This research note recommends using the following formula which is adapted from the formula illustrated in the OzonAction Kigali Fact Sheet 3, published by the OzonAction, UN Environment Programme (UNEP) for estimating refrigerant emissions.

Total kilograms (kg) CO_2 equivalent = $S \times (R_M + R_S - R_D) \times GWP_R$

Number of refrigerator units x (Refrigerant charge mass at manufacturing stage in kg (R_M)+ Refrigerant charge mass used to service refrigerators during use phase in kg (R_S) – Refrigerant recovered during disposal in kg (R_D) x Global Warming Potential of Refrigerant (GWP_R)

This note also recommends formulas for estimating the mass of R134a and natural refrigerants like R600a and R290 to improve the ability to compute refrigerant emissions.

These formulas can be used in instances where refrigerant mass information is not available. See sub-section 'Assumptions for refrigerant charge size for off-grid DC refrigerators under 600L'.

Climate change mitigation potential in using natural refrigerants in small refrigerators in the off- and weak-grid market

The author argues that the off-grid refrigeration sector presents a unique opportunity for additional climate change mitigation that can be achieved with minimal effort. This is because Europe has already demonstrated a penetration of 100% HC-based domestic refrigeration systems, and feedback from off-grid manufacturers demonstrates a high receptiveness to move to HC-based systems given a set of market enablers.

The net greenhouse gas mitigation potential that a 50L hydrocarbon-based fridge can claim is approximately 89.9 kg of CO_2e avoided emissions.

A market sizing model proposed by Dalberg and set out in the State of the Off-Grid Appliance Market Report (2019) estimates that the obtainable market for refrigerators would be 11 million households. If all 11 million refrigerator sales were realised by the end of 2030, which would need to occur at a compound annual growth rate (CAGR) of about 95%, and the current market share of natural refrigerant based fridge models in the off-grid market remained stable at 47%, at least 5.83 million fridges could be sold with HFC refrigerants. In a simplistic calculation, assuming all of these refrigerators have a 50 litre capacity, this sector could result in emissions of nearly 0.5 million tonnes of CO_2e.

Recommendations and next steps

The report suggests that transitioning to a near 100% natural refrigerant based off- and weak-grid market is achievable in the run up to 2030, and the energy access sector is uniquely positioned to show its leadership on this topic. To help achieve this, it makes the following recommendations:

Impact reporting and enabling easier access to data on the types of refrigerants used by off-grid refrigerators companies:

Energy access stakeholders, such as the Low Energy Inclusive Appliances (LEIA) programme, should add avoided emissions from hydrocarbon use to impact metrics; estimate emissions from the use of HFC gases in refrigerants in cold rooms and as blowing agents; and enhance access to data on the types of refrigerants used by off-grid refrigerator companies. This note will feed into the wider impact assessment framework for off-grid appliances that the LEIA programme is currently developing as a response to the growing need to robustly capture the socio-economic and environmental impact of off-grid technologies. Making emissions savings from avoided use of fluorinated gases visible as part of this impact reporting are expected to encourage companies to transition to natural refrigerants and will reward those that are already working with HC systems.

The role of 'nudges' and continued awareness building on this topic:

Given the existing high levels of environmental awareness in the off-grid refrigeration sector, donors, investors and policy makers can 'nudge' manufacturers to adopt more pro-environmental behaviour. Some manufacturers that currently use HFCs have shown a great level of receptiveness to move to natural refrigerants particularly R600a in the near term. This indicates that the off-grid refrigerator market, with the right guidance, shows great promise to follow practices in Europe, where HFC gases have been phased out completely in the domestic refrigerator and freezer market.

Green procurement policies:

Institutional customers such as governments and international agencies are encouraged to add the use of HCs as refrigerants as one of the criteria in their procurement policies and procedures for domestic refrigerators.

Building repair and technical capacity for handling hydrocarbons:

A lack of trained technicians who can handle HCs is one of the biggest obstacles to greater levels of adoption of hydrocarbon systems in the off-grid world. To enhance technical capacity in off-grid areas, it is crucial to leverage the efforts of programmes such as the UK's Department for Environment, Food and Rural Affairs (Defra), the Multilateral Fund for the Implementation of the Montreal Protocol, GIZ's Proklima programme, Kigali Cooling Efficiency Programme, Cool Coalition, and others.

Promote alternative refrigeration technologies:

The author calls on key energy access stakeholders, notably aid agencies and foundations, to support the development of alternative cooling methodologies alongside vapour compression technologies. For example, Efficiency for Access Research & Development awardee, Fosera's Peltier-based solar refrigerator avoids the use of refrigerants. The technology also has other important benefits such as fewer moving parts, greater repairability and portability.

The role of policy:

The note recommends that tax incentives for HC refrigeration systems should be provided to help encourage the industry to avoid the additional financial implications of using HCs. Policy makers can also maintain duties on low global warming potential (GWP) refrigeration technologies; reduce or eliminate VAT on repair services for such technologies; and ease restrictions on the importation of spare parts for refrigerators using HCs.

Labelling for off-grid refrigerators:

The note recommends that off-grid refrigerator manufacturers using HFC refrigerants should label their products and provide this information on their website, which will help ensure transparent reporting on the type and quantity of refrigerant used. Refrigeration & Air Conditioning (RAC) equipment using HFC refrigerants placed on the European Union (EU) market must be labelled to a format specified in the EU F-Gas regulation. This includes the refrigerant type, its GWP value and the refrigerant mass charge. A requirement for off-grid refrigerator manufacturers to label their products and provide this information on their websites will help tremendously in emissions reporting and will provide another soft 'nudge' for them to transition to use of HCs.

What are refrigerants, and why should we care about them?

The Montreal Protocol on Substances that Deplete the Ozone Layer, was adopted in 1987 and regulates the production and consumption of man-made chemicals that are referred to as ozone depleting substances (ODS). When released into the atmosphere, these chemicals, which are also known as chlorofluorocarbons (CFCs) and other fluorinated gases, damage the stratospheric ozone layer. The protocol is the most successful multilateral environmental treaty, as it is the only United Nations (UN) treaty that has been ratified by every country in the world. The protocol has not only averted the threat to the ozone layer, but also significantly contributed to positive climate impacts as fluorinated gases are powerful greenhouse gases. Efforts under the Montreal Protocol led to the widespread adoption of HFCs, which have been used as the primary substitutes for ozone depleting substances controlled under the treaty[4]. While HFCs do not deplete the ozone layer, many of these chemicals are potent greenhouse gases (GHGs) and are widely used as cooling agents or refrigerants in refrigeration and air conditioning technologies.

The Kigali Amendment to the Montreal Protocol: Phase down of HFCs

According to UNEP OzonAction[5], "Overall HFC emissions are growing at a rate of 8% per year and annual emissions are projected to rise to 19% of global carbon dioxide (CO_2) emissions by 2050." If the current growth in HFC use is not controlled, efforts to keep global temperatures at or below 2°C[6] by the end of this century will be at risk. To circumvent the climate threat posed by HFCs, in October 2016, the Parties to the Montreal Protocol adopted the Kigali Amendment which brings future production and consumption of HFCs within the Protocol's remit.

The Kigali Amendment's implications for developing countries: The Kigali Amendment came into force on 1 January 2019 and requires parties to gradually phase down their use of HFCs to 80– 85% by the late 2040s. Developed countries were expected to start their first reductions in 2019. The first group of developing countries, which includes African countries, will start by freezing HFC consumption levels in 2014, and the second set of developing countries which includes India will start in 2028[7]. Natural refrigerants, especially hydrocarbons (HCs), make a minimal impact on global warming.
They have also emerged as a very popular alternative to synthetic refrigerants such as HFCs especially for the domestic refrigeration sector. See Table 2 for an illustration of global warming potential values for some of these gases.

Distribution of HC vs HFC systems in off-grid refrigerator market: trends and opportunities

Desk based manufacturer research: An initial internet-based search generated a comprehensive list of approximately 140 off-grid refrigerator manufacturers and distributors.
Where available, details about their products including refrigerant type, refrigerant charge in grams, capacity of unit in litres and information about the location of manufacturing and distribution were compiled. The search constraint was for refrigerator units based on vapour compression systems that were less than 600 litres in volume and could be used in domestic, small commercial and health use cases. An aim of the search was to gather information about the volume of the fridge and the amount of refrigerant in each model to derive a correlation. Very few companies publish the refrigerant gas used in the refrigerator and even fewer provide information on the weight of the refrigerant in each unit. This information may only be available to specialists and repair teams.
To bridge this data gap, an outreach to a select group of off-grid refrigerator manufacturers, formal e-waste recyclers and refrigerant experts was undertaken via email-based surveys and telephone interviews. Please refer to the interviewee list in Annex I. Data collected in this manner helped analyse the distribution of the market by various refrigerant types and create a numerical relationship between the amount of refrigerant gas used per litre of refrigeration capacity.

4 Purohit et al., Electricity savings and greenhouse gas emission reductions from global phase-down of hydrofluorocarbons. 2020. https://doi.org/10.5194/acp-20-11305-2020, 2020

5 UNEP OzonAction, About Montreal Protocol, n.d. https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol

6 Ibid.

7 See OzonAction Kigali Fact Sheet 5 for a summary of the phase down schedule by country: OzonAction, UN Environment Programme, HFC Baselines and Phase-down Timetable, n.d. http://www.unep.fr/ozonaction/information/mmcfiles/7880-e-Kigali_FS05_Baselines_&_Timetable.pdf

Distribution of the off-grid refrigerator market by refrigerant types: Table 1 shows the distribution of vapour compression based off-grid DC refrigerator models available in the Sub-Saharan African and South Asian rural markets that are within 600L in volume. The author and the contributor to this report compiled refrigerant type by refrigerator model information for off-grid Sub-Saharan African and South Asian markets, across more than 50 companies and 66 unique refrigerator models.

The most striking observation about the refrigerant type and charge data collected where available, was that all off-grid refrigerator manufacturers used only three types of refrigerants, propane (R290) and isobutane (R600a) among natural refrigerants, and 1,1,1,2-tetrafluoroethane (R134a) among hydrofluorocarbons or HFCs. H-134a is a potent greenhouse gas with a global warming potential (GWP) of 1430 on a 100-year timescale. See Table 2 for GWP values for these gases.

From interview data with off-grid manufacturers and other anecdotal data, off-grid manufacturers have shown high levels of receptiveness to transitioning directly from HFCs to natural refrigerants. They are also willing to forego the adoption of hydroflouroolefins (HFOs) or their blends with HFCs altogether. According to one manufacturer, adopting HFOs was undesirable, as it would only delay the inevitable adoption of natural refrigerants, as regulations to phase out HFCs will tighten globally in coming years[8].

A second observation that emerged from this analysis was that the off-grid refrigerator market is dominated by vapour compression systems. All companies submitting refrigeration sales under GOGLA's sales data collection efforts use vapour compression technologies, apart from two companies that made submissions in the Global LEAP awards and one Efficiency for Access Research and Development awardee. This aligns with a global trend where vapour compression systems are expected to remain the primary technology of the future[9], which makes it even more pertinent to swiftly transition the off-grid sector to low-GWP refrigerant use.

Table 1: Proportion of off-grid DC refrigerator companies using HFCs in Sub-Saharan Africa and South Asia
Note: This data is correct as of 2019. It is possible that a slightly greater number of companies may now use natural refrigerants

	ABSOLUTE VALUES				PERCENTAGE SHARE			
Company category	**R134a**	**R290**	**R600a**	**● Total Companies**	**R134a**	**R290**	**R600a**	**Natural refrigerant share**
● **Submissions under Global LEAP Awards competitions**	24	2	12	35	63%	5%	32%	37%
● **Efficiency for Access R&D Grantees**	2	1	4	7	29%	14%	57%	71%
Other companies	6	0	6	10	50%	0%	50%	50%
● **Overall**	30	4	23	52	53%	7%	40%	47%

● *Off-grid refrigerators that were submitted to Global LEAP Awards competitions for off-grid refrigerators in 2017 and 2019. The Global LEAP Awards is an international competition that identifies and promotes the best-performing off-grid appropriate appliances and productive use equipment.*

● *Off-grid refrigerator companies with a compressor-based refrigerator model that received a grant via the Efficiency for Access Research and Development Fund. The companies represented here do not include companies that received grants for cold room technologies.*

● *Some companies have more than one type of association with the Efficiency for Access Coalition. E.g. they could have received an R&D grant, as well as submitted an entry in the Global LEAP awards. Duplicate entries have been removed in the 'Overall' category.*

● *Total number of companies may be smaller than the sum of the companies across the three types of refrigerant gases, as some companies have refrigeration models with more than one type of gas.*

8 Personal communication with SunDanzer. See Annex I: Interviewee / Stakeholder outreach list.

9 Danfoss, Refrigerant options now and in the future, 2020, https://assets.danfoss.com/documents/DOC351635909936/DOC351635909936.pdf

Overall

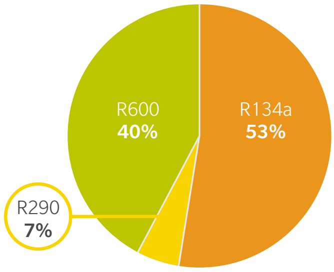


Figure 1: Proportion of off-grid refrigerator companies using HFCs and natural refrigerants in Sub-Saharan Africa and South Asia

REFRIGERANT TYPE	GWP VALUE
R134a, HFC	1430
R600a, HC	3
R290, HC	3

Table 2: GWP values for the main types of refrigerants used in DC refrigerators in off-grid settings[10]

The off-grid refrigerator market is dominated by the use of R134a and R600a. 40% of the analysed refrigerator models use R600a and 47% models use hydrocarbons (R600a or R290). More than 50% of manufacturers are still using the HFC, R134a. This significantly lags behind the trend in Europe where there is a total penetration of R600a refrigerant systems in the household fridge and freezer markets. It is more closely aligned, but still behind the trend in China where there is a 50% penetration of R600a systems in this segment[11]. Some manufacturers that still currently use HFCs have demonstrated strong receptiveness to move to natural refrigerants in the near term, particularly R600a. Some of this was motivated by the natural refrigerant-oriented conversations that arose during the development of this note, and other 'nudges' provided by various members of the LEIA team. This indicates that the off-grid refrigerator market, with the right guidance, could follow trends in Europe, where R600a has replaced R134a as the dominant refrigerant in the domestic refrigerator and freezer market[12].

Here are some of the reasons that off-grid refrigerator manufacturers gave for transitioning to hydrocarbons[13].

10 OzonAction, United Nations Environment Programme, GWP, CO_2(e) and the Basket of HFCs, n.d., https://wedocs.unep.org/bitstream/handle/20.500.11822/26866/7878FS03GWPCO_EN.pdf?sequence=1&isAllowed=y

11 SECOP, Natural Refrigerants, n.d., https://www.secop.com/solutions/natural-refrigerants

12 Cooling Post, Refrigerant blends to challenge hydrocarbon efficiencies, 2019, https://www.coolingpost.com/world-news/refrigerant-blends-to-challenge-hydrocarbon-efficiencies/

13 Author's interviews with off-grid refrigerator manufacturers.

1. The HC systems offer higher levels of energy efficiency compared to conventional HFC systems. One of the manufacturers reported that using thicker insulation materials in HC systems provides the best levels of energy efficiency.

2. The European ban on the use of HFCs with a GWP higher than 150 in domestic refrigeration systems naturally rules out the use of R-134a. Coupled with bans on the use of R134a in some US states, these regulations incentivise manufacturers to use hydrocarbon technologies for off-grid settings in developing countries.

3. The World Health Organization (WHO) encourages the use of hydrocarbon-based vaccine refrigerators, which led one manufacturer to shift its product line to HC systems. This indicates the strong influence that green procurement policies for cooling technologies can have on leading the energy access sector to transition to hydrocarbon use.

4. The adoption of HFOs and their blends with HFCs as an interim measure only delay the inevitable transition to HCs. HFOs are also more expensive.

5. The feedback on the incremental cost associated with using a hydrocarbon compatible Direct Current (DC) compressor was mixed. While one manufacturer reported a modest increase in cost associated with using a different compressor, another manufacturer reported a cost increase of more than US$100 per refrigerator from switching to a HC system. It should be noted that AC compressors used in domestic on-grid units are manufactured in massive volumes. As a result, a higher price parity is expected between AC compressors that are compatible with hydrocarbons and those that are compatible with R134a.

   On the flipside, as well as an increase in cost given the requirement of a hydrocarbon compatible compressor, there are additional costs associated with making ventilation upgrades in the assembly area where refrigerators are filled with gases, or where refrigerants may be stored. Given that these are one-time costs, this was not perceived as a major deterrent. The lack of skilled technicians who can handle natural refrigerants was the biggest reported barrier to increasing adoption of HC systems in off-grid settings. It is harder to find local services for hydrocarbon systems in rural off- and weak-grid regions in developing countries. One manufacturer based in India reported that while his company was eager to transition from the use of R134a to hydrocarbon systems, it was unable to do so given the lack of locally available technicians who could service HC systems.

Method for estimating emissions from refrigerant use

The following section describes the methodology used to estimate emissions from refrigerants per litre of refrigeration capacity for direct current (DC) solar refrigerators within 600 litre (L) of capacity, or those that are typically classified as domestic-household refrigerators.

Refrigerant emissions occur when refrigerant gases leak into the atmosphere. These leakages could occur during filling or re-filling of gases in refrigerators, due to tiny holes that may go undetected, improper handling of the refrigerator e.g. leaning the fridge too far or inverting it upside down[14], or during the disposal phase of the refrigerator (dismantling or recycling). Most off-grid manufacturers take great care while filling refrigerants during the assembly of the refrigerator[15]. Depending on the safety and handling precautions undertaken during refrigerant refilling, a small amount of leakage may also occur then. For the purposes of this analysis, it is assumed that emissions only occur during the refrigerator's use and disposal phases alone.

When estimating refrigerant emissions, it is necessary to know the refrigerant type, its global warming potential (GWP) and the mass of the refrigerant filled inside the refrigerator. Multiplying the mass of gas and its GWP value will yield the emissions. This note recommends using the following formula which is adapted from the formula illustrated in the OzonAction Kigali Fact Sheet 3, published by the OzonAction, United Nations Environment Programme (UNEP) for estimating refrigerant emissions. The formula proposed in this note helps unpack the various stages of refrigerant escape routes and refilling to estimate total refrigerant leakages more accurately, to the extent that data is available.

$$\text{Total kilograms (kg) } CO_2 \text{ equivalent} = S \times (R_M + R_S - R_D) \times GWP_R$$

	Number of refrigerator units
×	Refrigerant charge mass at manufacturing stage in kg (R_M)
+	Refrigerant charge mass used to service refrigerators during use phase in kg (R_S)
-	Refrigerant recovered during disposal in kg (R_D)
×	Global Warming Potential of Refrigerant (GWP_R)[16]
=	**Total kilograms (kg) CO_2 equivalent**

The rest of this sub-section proposes values for refrigerant mass that can be assumed if values for refrigerant charge masses used at manufacturing and servicing stages, and remaining mass at time of disposal are not available.

14 Author's interviews with off-grid refrigerator manufacturers.
15 Ibid.
16 This will be a weighted GWP value for a refrigerant blend, GWP values can be found in this fact sheet: OzonAction, United Nations Environment Programme, GWP, CO_2(e) and the Basket of HFCs, n.d., https://wedocs.unep.org/bitstream/handle/20.500.11822/26866/7878FS03GWPCO_EN.pdf?sequence=1&isAllowed=y

Assumptions for refrigerant charge size for off-grid DC refrigerators under 600L (R_M)

Often, the refrigerant charge mass used in a refrigerator is unknown. An obvious place to look for refrigerant mass assumption is technical data in a manufacturer's product specification sheets or their website. Inconsistent formatting when reporting the technical specifications represents a challenge in gathering information about off-grid refrigeration products. The websites often list basic information about the products, focusing instead on their potential social benefits. It is at the discretion of the manufacturer and distributors as to the level of detail they provide. Many websites encourage visitors to contact the company for further details. Refrigerant charge size information is omitted in the majority of cases. The following assumptions can be noted where charge size information is unavailable.

The size of the refrigerant charge used in a refrigerator can vary based on several factors. As a result, it is challenging to propose precise assumptions for estimating refrigerant charge. These factors can include design and safety considerations, the capacity of the refrigerator, type of compressor used, thickness of insulation and so on. Some manufacturers may simply use the recommendations on size limits provided by compressor manufacturers. Others may follow a more iterative design-based approach where they test refrigerator performance based on different design and refrigerant charge amount considerations while keeping within the practical limits[17] prescribed in the relevant standards in the case of natural refrigerants. It should be noted that refrigerators designed to be powered by solar photovoltaic (PV) panels will have different design characteristics than conventional alternating current (AC) refrigerators. For example, they will typically have thicker insulation materials to allow for greater levels of holdover time or autonomy periods and be designed to achieve higher efficiency levels when compared with their AC counterparts. This is so they remain affordable due to extra capital costs associated with solar power components. This made it necessary to investigate refrigerant charge size assumptions specifically for off-grid refrigerators.

From the data gathered from manufacturer websites, manufacturer interviews and other outreach, (section 'Distribution of off-grid refrigerator market by types of refrigerants used'), the author collected refrigerant charge mass of 25 unique models of off-grid DC refrigerators using natural refrigerants viz. R600a and R290 across 12 manufacturers and 5 models using R134a across 2 manufacturers. As expected, there is a moderately strong positive linear relationship between the refrigeration volume in L and the refrigerant mass used in each unit. It should be noted that the volume of refrigerators used for this calculation is the manufacturers' self-reported refrigerator volume. Please refer to the scatter plots in figures 2 and 3. Thus, we can conclude the following linear relationship for approximating refrigerant mass. While this is an imperfect model, it is useful in estimating first order approximations of refrigerant emissions where this data is unavailable.

Refrigerant mass for fridges with HCs:

Refrigerant mass for fridges with HCs (R600s or R290) in gms = 0.1881 x C_L + 27.437 or 150 gms whichever is lesser where, C_L is the capacity of the refrigerator in L.

The requirement of 150 grams as the practical limit for category A3 (highly flammable) refrigerants such as R600a and R290 was set out in IEC norm IEC 60335-2-24, which covers domestic appliances. This note recommends using the 150-gram limit for this impact calculation.

17 The practical limit is used as the maximum allowable refrigerant charge and is prescribed in various standards relevant to refrigerant use.

Refrigerant mass for fridges with R134a:
The relationship between refrigerant mass and fridge volume for R134a, albeit the strong correlation value, is based on only five refrigerator models. (Please refer to Figure 3). In general, the charge of R600a or R290 is approximately 40–50% by weight compared to HFCs[18]. We find that the estimated refrigerant masses for natural refrigerants, which is shown in Figure 2, closely follows the 40–50% by weight of estimated charge of R134a from the relationship derived in Figure 3 for refrigerators with capacities of 100L or more. This gives confidence in the derived results in Figures 2 and 3.
The estimated refrigerant mass for natural refrigerants based on the linear regression relationship in Figure 2 is between 51%–46% of refrigerant mass for R134a based on the relationship in Figure 3 for refrigerators with capacities between 100–500L. For fridges that are less than 100L, the estimated charge range gets wider.

This is because for refrigerators with very small capacities, the refrigerant per unit L required is relatively higher than refrigerators with larger capacities. For example, a DC refrigerator of 50L volume was reported to be using 55gms of R600a while a refrigerator with 65L of volume was reported to use 65 grams of R600a, only 10 grams more for a capacity increase of 10L.

Therefore, the following relationship is proposed:

Refrigerant mass for fridges with R134a in gms = 0.5282xC_L + 36.518

where C_L is the capacity of the refrigerator in L.

It should be noted that this relationship needs strengthening with additional data and should be used only where the precise refrigerant charge amounts are not known.

Figure 2: Refrigerant mass & refrigerator volume relationship for R600a and R290

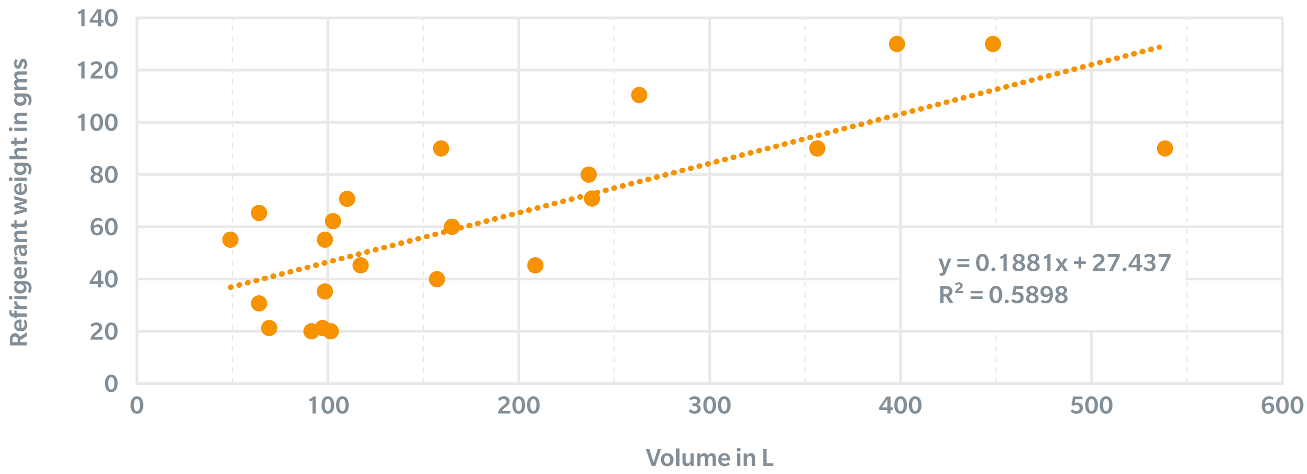
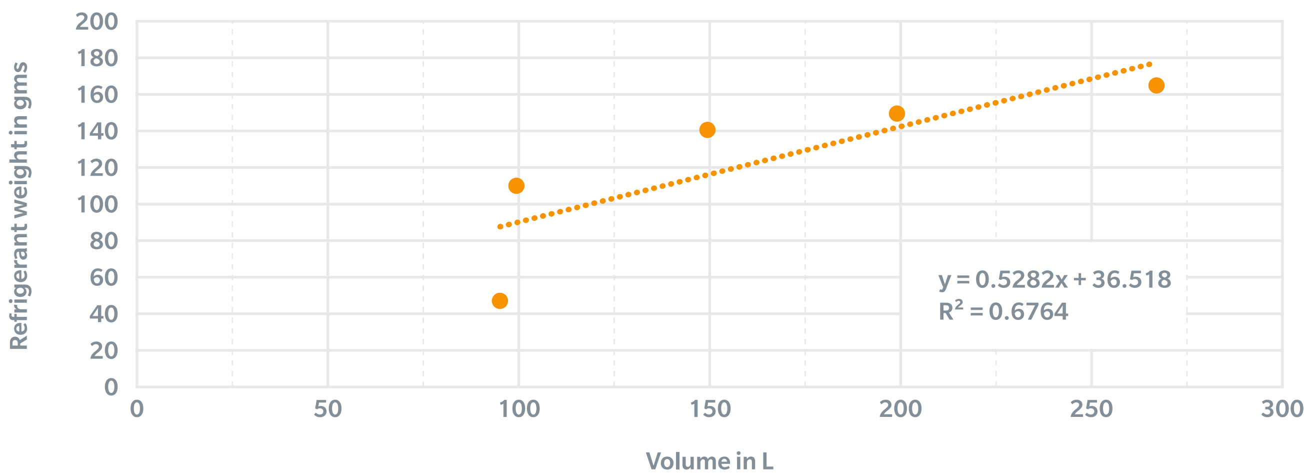


Figure 3: Refrigerant mass & refrigerator volume relationship for R134a



18 Danfoss, Hermetic Compressors for DC Voltage, 2020, https://assets.danfoss.com/documents/DOC143086415696/DOC143086415696.pdf

Refrigerant charge mass used to service refrigerators during use phase (R_S)

The off-grid refrigerator market is nascent, and many refrigerators installed for small commercial use cases are yet to reach their end of life. As a result, it is difficult to make a definitive assumption on the gas refilling rate, which is defined as the number of times that a refrigerator requires topping up or refilling of refrigerant gas during its technical life. However, early data suggests that the refilling rate is expected to be small. According to one manufacturer, three refrigerators required the topping up of a small amount of gas out of more than 200 systems within two years of their installation. There may have been one – two other systems that were refilled without the manufacturers' knowledge. This leads to a re-fill rate of approximately 2%. However, this assumption requires further strengthening, as the installed refrigeration inventory becomes older and more data becomes available. Given that all of these instances related to small top-ups of gas, and field-level data of exact amount of gas top-up is unavailable, this note assumes a conservative average top-up estimate of 10% of gas filled at manufacturing stage over the life of the unit. It is suspected that these gas top-ups were required due to gas leakages that occurred due to improper handling of refrigerators, which if were avoided the refill rates would have been even lower.

Refrigerant recovered during disposal (R_D)

If the refrigerator in question is expected to be de-gassed at the end of its life, such that the refrigerant will be destroyed, recycled or stored, the recovered mass of gas at the end of life can be subtracted from the mass in the emissions calculation formula above. The rate of formal recycling in Africa is extremely low. According to data from the 2017 Global E-Waste Monitor, less than 1% of e-waste is collected and recycled in Africa annually. Within the formal recycling sector, most recyclers cannot recycle refrigerators and do not capture and recover the refrigerant. The gas is released immediately and quickly as the compressor is cut during the manual dismantling of refrigerators[19]. Most refrigerators that were officially not reported as recycled may get recycled by informal recyclers on landfill sites in unsafe conditions. The much-investigated e-waste processing site in Abogbloshie, Accra, Ghana, illustrates working conditions. However, it is important to note that this is an extreme case of informal recycling under hazardous conditions on a continent that already has the highest levels of harmful informal recycling[20].

19 Interviews with formal recyclers in Africa. See Interviewee List in Annex I.

20 While the recycling situation in Ghana looks dismal, other efforts by Ghanian government to reduce emissions in the refrigeration sector such as ban on imports of used refrigerators and a rebate scheme for replacing old refrigerators with more energy efficient ones are laudable. See UNDP, In Ghana, new refrigerators save energy for thousands of households, 2013, https://www.gh.undp.org/content/ghana/en/home/ourwork/crisispreventionandrecovery/successstories/savoring-the-gains-from-the-refrigerator-rebate-scheme-in-ghana.html

According to one formal recycler based in Nigeria interviewed during this research, approximately 60% refrigerators received for recycling are so close to the end of life that their gases have already been released. Consequently, only a small amount of gas recovery is possible in the remaining cases. According to another recycler based in Kenya, in the absence of any regulation to capture and recover gases, refrigerants are simply let out. The recycler said that he had not met anyone capturing gas in Kenya for refrigerators. This points to a 100% refrigerant leakage in the substantial number of cases unless there is a specific known arrangement between a manufacturer and a recycler to capture gases at a product's end of life. Given the low rate of recycling and small number of gases in the refrigerator remaining at the recycling stage, it is recommended to make an assumption of 0 kgs of refrigerant recovered during disposal. This is recommended unless there is a known arrangement between an off-grid refrigerator manufacturer and a recycler to capture gases at disposal.

GWP value of refrigerant (GWPR)

The GWP values for different gases can differ based on the time scale chosen[21] and the source of GWP data. Under the Kigali Amendment, a standard set of values of refrigerant gases has been proposed and is based on the 100-year GWPs proposed in the Intergovernmental Panel on Climate Change (IPCC)'s fourth Assessment Report. These values can be found in the OzonAction Kigali Fact Sheet 3[22] and the Kigali Amendment treaty text. Refrigerants could also be a blend of two or more gases, in which case the GWP of the final blend will be the weighted average of the GWPs of the individual gases.

21 Gas concentrations decay in the atmosphere over time and therefore their GWP will vary and decline with the increase in time horizon assumed in emissions calculations.

22 OzonAction, United Nations Environment Programme, GWP, CO_2(e) and the Basket of HFCs, n.d., https://wedocs.unep.org/bitstream/handle/20.500.11822/26866/7878FS03GWPCO_EN.pdf?sequence=1&isAllowed=y

Mitigation potential

Off-grid refrigerators for domestic and small commercial use are almost a new off-grid appliance segment; in the past most of the refrigerator sales had been for specialised uses such as vaccine storage. This is also reflected in the low levels of refrigerator sales captured in the GOGLA sales data collection[23]. For example, in 2019, GOGLA sales data reported the sales of fewer than 7000 off- and weak-grid DC refrigerators in Sub-Saharan Africa and South Asia combined[24]. While GOGLA sales data does not reflect all the sales that occur in a given time period, and total off-grid refrigerator sales are unknown, they are unlikely to exceed tens of thousands based on known sales data[25]. Given the small refrigerant charge in the order of grams in domestic refrigerators and low sales volumes, the current level of emissions from current installed base of off-grid refrigerators is expected to be low.

Mitigation potential per refrigerator unit

An example calculation of the mitigation potential offered by replacing HFC with an HC refrigerant in a typical DC refrigerator for off- or weak-grid use:

Based on the submissions made by refrigerator manufacturers in the GLOBAL LEAP awards, the most submitted refrigerator capacity was around 50L. Using the refrigerant emissions assumptions and formula proposed in the 'Method for estimating emissions from refrigerant use' section, a 50L fridge is expected to have a charge mass of 36.8 grams if a hydrocarbon like R600a or R290, and 62.9 grams of charge mass of HFC, R134a. This yields emissions equivalent to approximately 0.1 kg CO_2e for a HC based refrigerator and 90 kg CO_2e for an R134a based refrigerator. This calculation assumes that there was no refrigerant top up requirement during the life of the refrigerator and a 100% leakage of the refrigerant by the disposal stage of the refrigerator.
Thus, the net GHG mitigation potential that a 50L fridge can claim is approximately 89.9 kg of CO_2e avoided emissions.

Mitigation potential offered by small refrigerators in the off- and weak-grid sector

While the current installed base of off-grid refrigerators in developing countries is low, sales levels for domestic and small commercial use are expected to rise significantly in the run up to 2030, alongside sales for vaccine and medicine storage, and broader cold chain. In high-income countries, nearly 100% of households own refrigerators compared to 17% of households in in Sub-Saharan Africa[26]. The penetration of refrigerators is similar in low-income South Asian countries such as Bangladesh and Myanmar. These ownership levels are lower when household refrigerator ownership is considered in rural areas alone. The average rural penetration of refrigerators is 4% after excluding the middle-income outlier of South Africa in the top 19 countries by area in Sub-Saharan Africa.
In a middle-income country like India, 16% of households in rural areas own refrigerators[27]. The low installation base indicates substantial latent demand for appliance ownership.

23 Every 6 months, GOGLA, as part of an effort funded by the LEIA Programme collects sales data of key appliance categories, and publishes a market intelligence series based on this data.

24 GOGLA, IFC and Efficiency for Access, Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data July – December 2019, Public Report, 2020, https://www.gogla.org/sites/default/files/resource_docs/global_off_grid_solar_market_report_h22019.pdf

25 Efficiency for Access, State of the Off-Grid Appliance Market Report, 2019, https://efficiencyforaccess.org/publications/2019-state-of-the-off-grid-appliance-market-report

26 Ibid.

27 Ibid.

According to Dalberg's market-sizing model in the State of the Off-Grid Appliance Market Report (2019), there are 475 million off or weak-grid households. This model defines two types of markets 'addressable market' and 'obtainable market', which exist within the total estimated off or weak-grid households. The addressable market is defined as the subset of these 475 million households that could afford an off-grid appliance provided they had financing. The obtainable market is defined as a small sub-set of the addressable market taking into consideration areas where solar off-grid companies can deliver a service, such that both end-user appliance financing and proximity of road infrastructure are available. The addressable market for off- and weak-grid refrigerators is estimated to be 68 million while the obtainable market is estimated at 11 million households. If all the 11 million refrigerator sales within the obtainable market were realised by the end of 2030, which would need to occur at a compound annual growth rate (CAGR) of about 95%, and the current market share of natural refrigerant-based fridge models in the off-grid market remained stable at 47% (Table 1), then at least 5.83 million fridges could be sold with HFC refrigerants. In a simplistic calculation, assuming all of these refrigerators had a capacity of 50L, this sector could result in emissions of nearly 0.5 million tonnes of CO_2e.

There is a lot of variability in these estimates. As an example, if the market grew substantially to more than 11 million refrigerator systems, the typical capacity of refrigerators preferred could increase much beyond 50L determined by how technology improvement and affordability gains are realised. This could lead to a much larger mitigation potential. Conversely, as the rest of the world beyond the European markets enhances their market share of HC based domestic refrigerators in compliance with the Kigali Amendment phase down schedule, some of this will have trickle down effects in the off-grid sector as well. As a result, the current share of 47% of HC based systems in off-grid small refrigerators market will improve to some extent on its own and offset some of the emissions as estimated above.

Either way, the off-grid refrigeration sector presents a unique opportunity for additional climate change mitigation that can be achieved with minimal effort. This is because Europe has already demonstrated a penetration of 100% HC based domestic refrigeration systems, and feedback from off-grid manufacturers demonstrates a high receptiveness to move to HC based systems given a set of market enablers. The current levels of 47% penetration of HC refrigeration systems in the off- and weak-grid market is a promising start. Furthermore, most of these households will be purchasing refrigerators for the first time, which provides an avenue for this sector to leapfrog directly to natural refrigerant-based technologies.

Recommendations and next steps

This section highlights key strategies that the LEIA programme and other energy access stakeholders working towards the expansion of sustainable refrigeration technologies could consider in the short to medium term. Transitioning to a near 100% natural refrigerant based off- and weak-grid market is achievable in the run up to 2030 and the energy access sector is uniquely positioned to show its leadership on this topic.

1. **Strategies specific to the LEIA programme:**

   Impact reporting & enabling easier access to data on types of refrigerants being used by off-grid refrigerator companies.

   1.1. Adding avoided emissions from HC use to impact metrics: One of the objectives of this note was to develop an impact metric for easy reporting of avoided emissions from refrigerant use for off-grid DC vapour compression cooling technologies. This note will feed into the wider impact assessment framework for off-grid appliances that the LEIA programme is developing in response to the growing need to capture the socio-economic and environmental impact of off-grid technologies robustly. Making emissions savings from avoided use of fluorinated gases visible in the impact reporting will help encourage companies to transition to natural refrigerants and will reward those that are already working with HC systems. Furthermore, this step will help provide a clearer distinction between green and less green cooling technologies to investors and donors who prioritise green and sustainability criteria in their investments.

   1.2. Estimate emissions from use of HFCs as refrigerants in cold rooms and as blowing agents[28].

   - This note proposes an impact methodology for estimating emissions from the use of refrigerants in refrigerators within 600L capacity. These refrigerators have low amounts of refrigerant charge, which are in the order of 10s or 100s of grams. However, food cold chain infrastructure is expected to expand substantially in developing countries in the coming years when GHG emissions are expected to grow significantly. In these countries, there are risks of locking in use of refrigerants with high GWP values[29]. In cold room technologies, much larger quantities of refrigerants are used.
   - Similarly, using high GWP HFCs in blowing foams used in insulation in refrigeration technologies is another HFCs related emission hotspot whose impact in off-grid settings needs to be understood better.

   The LEIA programme is undertaking a life cycle assessment (LCA) research that will perform a cradle to grave emissions analysis of key refrigerator and cold room technologies. As part of this research, the GHG emission impacts related to refrigerant use in cold rooms and HFCs used in blowing foams will be analysed and these results will be published.

   1.3. Enhancing access to data on types of refrigerants used by off-grid refrigerator companies: Often, the type of refrigerant used and the refrigerant charge mass in a refrigerator is unknown. An obvious place to look for refrigerant mass assumption is in a manufacturer's production specification sheet or on their websites. The websites often list basic information about the products; it is at the discretion of the manufacturer and distributors as to the level of detail they provide. Refrigerant charge size information is omitted in most cases. The LEIA programme is in a unique position to bridge this data transparency gap. GOGLA, in an effort funded by the LEIA programme, collects sales data of off-grid appliances every six months and publishes the Global Off-Grid Solar Market Report based on the collected data. In the 2021 rounds of data collection, the LEIA programme will seek to include questions related to refrigerant types and their charge mass amounts in the sales data questionnaire used in the bi-annual surveys undertaken with refrigerator manufacturers. This will improve transparency and availability of data related to types of refrigerants used, and act as a 'reputational' nudge to incentivise companies still using HFCs to consider transitioning to HC systems. This data will also help estimate emissions from the use of refrigerants in the off-grid sector with greater accuracy. (Please refer to the section 'Method for estimating emissions from refrigerant use').
   The VeraSol Product Database for standalone fridges includes information on refrigerant type and is an important first step in the direction of making this data visible.

28 Note that while retail refrigeration in supermarkets and shops remain a key issue to be considered while greening cold chains, they are largely on-grid applications and less relevant for off- and weak-grid applications in the developing world.

29 Carbon Trust, Kigali Cooling Efficiency Program and Cool Coalition, Net zero cold chains for food, 2020, https://www.carbontrust.com/resources/net-zero-cold-chains-for-food

2. **Role of 'nudges' and continued awareness building on this topic**

The off-grid solar energy sector is one of the most responsible and conscientious sectors when it comes to environmental sustainability practices[30]. This may be partly because many investors and donors are environmentally driven. Part of this is because it is inherently a clean technology sector in which stakeholders have higher levels of awareness around climate issues and greenhouse gas mitigation measures compared to other sectors. Since companies want to be perceived as environmentally driven and sustainable, the challenge in implementation arises not from a lack of willingness but from financial constraints. Therefore, this is also a sector where the role of 'nudges' for pro-environment behaviour from the donors, investors and policy makers can be particularly powerful. Some manufacturers that currently use HFCs have shown a great level of receptiveness to move to natural refrigerants particularly R600a in the near term. This was motivated by the natural refrigerant oriented conversations that arose during the creation of this note and other 'nudges' provided by various members of the LEIA team. This indicates that the off-grid refrigerator market, with the right guidance, shows great promise to follow practices in Europe, where R600a has replaced R134a as the dominant refrigerant in the domestic refrigerator and freezer market[31].

3. **Green procurement policies**

A related recommendation is for institutional customers such as governments and international agencies to add the use of HCs as refrigerants as one of the criteria in their procurement policies and procedures for domestic refrigerators. It should be noted that for bigger refrigeration systems, like cold rooms, an approach of technology neutrality may be required whilst setting a maximum GWP limit. However, for small systems under 600L that are within the scope of this note, using natural refrigerants does not represent a technological challenge, as very small amounts of refrigerant charge are used. Likewise, energy access programmes that focus on cooling can prioritise the use of HCs alongside other important goals such as efficiency and affordability in interventions such as R&D grants, bulk procurements, and so on. Investors and development agencies will be important drivers of change in the off-grid solar sector.

4. **Building repair and technical capacity for handling hydrocarbons**

While many factors including supply chain issues, regulatory environments, affordability and return on investment will determine the accessibility of refrigeration[32] equipment with low GWP refrigerants, one of the biggest obstacles to greater levels of adoption of hydrocarbon systems in the off-grid world is the lack of trained technicians that can handle hydrocarbons. While the lack of trained technicians is a wider issue, this problem is compounded in remote rural regions. While wider efforts in pursuit of Kigali amendment goals will lead to improved technical capacity in handling hydrocarbons, most of this is likely to occur in urban regions and off-grid energy access stakeholders would need to to undertake capacity building for rural areas. To expand technical capacity in off-grid areas, it would be crucial to leverage the efforts from programmes such as the UK's Department for Environment, Food and Rural Affairs (Defra), the Multilateral Fund for the Implementation of the Montreal Protocol, GIZ's Proklima programme, Kigali Cooling Efficiency Programme, Cool Coalition and others.

One area that can be explored is working with local universities to provide short training programmes for third party repair technicians on handling hydrocarbons. The GiZ Proklima Programme is developing a training, certification and registration approach for cooling technicians that includes conducting 'Train the Trainer' sessions. They have created a training programme under their 'Fit for Green Cooling Initiative'[33]. Existing collaborations with universities of energy access stakeholders can be leveraged to offer such courses. This will also lead to local job creation or increase in income opportunities for existing repair technicians.

30 Anecdotal evidence and interviews with formal e-waste recyclers based in Africa.

31 Cooling Post, Refrigerant blends to challenge hydrocarbon efficiencies, 2019, https://www.coolingpost.com/world-news/refrigerant-blends-to-challenge-hydrocarbon-efficiencies/

32 United Nations Environment Programme, Report of the Technology and Economic Assessment Panel September 2020. Volume 2: Decision XXXI/7 - Continued Provision of Information on Energy-Efficient and Low-Global-Warming-Potential-Technologies, 2020, https://ozone.unep.org/sites/default/files/assessment_panels/TEAP_dec-XXXI-7-TFEE-report-september2020.pdf

33 Green Cooling Initiative, Fit for Green Cooling, 2020, https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2020/07/01/fit-for-green-cooling-1

5. **Promote alternative refrigeration technologies**
It is important to support the development of alternative cooling technologies alongside vapour compression technologies. For example, Fosera's Peltier-based solar refrigerrator[34] avoids the use of refrigerants and has important co-benefits such as fewer moving parts, greater repairability and portability.

6. **Role of policy: Fiscal measures and role of 'labelling'**

6.1. Fiscal measures: Usually the argument for introducing tax benefits for off-grid technology is to improve appliance affordability. Tax incentives for HC based refrigeration systems could be provided to help encourage the industry to overcome the additional cost implications of using HCs. One such tax rebate could be on DC compressors. It should be noted that AC compressors used in domestic on-grid units are manufactured in massive volumes and a higher price parity is expected between HC compatible AC compressors and those that are compatible with R134a when compared with their DC counterparts. However, due to small manufacturing and sales volumes for DC compressors, tax rebates on HC compatible DC compressors could provide further incentives for an improved HC transition. With the Kigali amendment, there is growing international attention to the policies and regulatory incentives that can support low GWP refrigerant technologies. These will also be important in off-grid refrigerator markets, and links will have to made between incentives for HC systems and sustainable cooling access goals. Policy makers can reduce duties on low GWP refrigeration technologies, reduce or eliminate value added tax (VAT) on repair services for such technologies, and ease restrictions on the importation of spare parts for refrigerators using HCs.

6.2. Role of labelling: Refrigeration & Air Conditioning (RAC) equipment using HFC refrigerants that are sold on the European Union (EU) market must be labelled in accordance with a format specified in the EU F-Gas regulation[35]. This includes the refrigerant type, its GWP value and the refrigerant mass charge. In addition to the recommendation in 1.3 above, taking inspiration from the EU F-Gas regulation, a requirement for off-grid refrigerator manufacturers to label their products and provide this information on their websites would improve emissions reporting and provide another soft 'nudge' for companies to transition to the use of HCs.

34 Efficiency for Access, Fosera wins funding for innovative Peltier-based Solar Cooler through Efficiency for Access, 2020, https://fosera.com/news/detail/fosera-wins-funding-for-innovative-peltier

35 Regulation (EU) 517/2014 (Art 12) and Commission Implementing Regulation (EU) 2015/2068 sets out the requirements and formatting for mandatory F-gas labelling in the EU and UK.

BIBLIOGRAPHY

Baldé, C.P., Forti V., Gray, V., Kuehr, R., Stegmann,P. : The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

CLASP (n.d.) Global LEAP Awards. Available at: https://globalleapawards.org/about.

Cooling Post (2019) 'Refrigerant blends to challenge hydrocarbon efficiencies'. Available at: https://www.coolingpost.com/world-news/refrigerant-blends-to-challenge-hydrocarbon-efficiencies/.

Danfoss (no date) Hermetic Compressors For DC Voltage. Available at: https://assets.danfoss.com/documents/DOC143086415696/DOC143086415696.pdf.

Danfoss (2020) Refrigerant options now and in the future. Available at: https://assets.danfoss.com/documents/DOC351635909936/DOC351635909936.pdf.

Efficiency for Access Coalition (2019) 2019 State of the Off-Grid Appliance Market Report. Available at: https://efficiencyforaccess.org/publications/2019-state-of-the-off-grid-appliance-market-report.

Efficiency for Access (2020) Fosera wins funding for innovative Peltier-based Solar Cooler through Efficiency for Access. Available at: https://fosera.com/news/detail/fosera-wins-funding-for-innovative-peltier.

Energia; Efficiency for Access Coalition (2020) The role of appliances in achieving gender equality and energy access for all. Available at: https://storage.googleapis.com/e4a-website-assets/Role-of-Appliances_Policy-Brief_FINAL.pdf.

EUR-Lex (2014) REGULATION (EU) No 517/2014 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 (Text with EEA relevance. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0517&rid=1.

EUR-Lex (2015) Commission Implementing Regulation (EU) 2015/2068 of 17 November 2015 establishing, pursuant to Regulation (EU) No 517/2014 of the European Parliament and of the Council, the format of labels for products and equipment containing fluorinated greenhouse gases (Text with EEA relevance). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=OJ%3AJOL_2015_301_R_0009.

GOGLA; International Finance Corporation; Efficiency for Access Coalition (2019) 'Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data Authors ' Note', (December), pp. 1–75. Available at: https://www.gogla.org/sites/default/files/resource_docs/global_off_grid_solar_market_report_h22019.pdf.

Green Cooling Initiative, G. P. (2020) Fit for Green Cooling. Available at: https://www.green-cooling-initiative.org/news-media/publications/publication-detail/2020/07/01/fit-for-green-cooling-1.

Intergovernmental Panel on Climate Change (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf.

OzonAction, U. (no date) About Montreal Protocol. Available at: https://www.unenvironment.org/ozonaction/who-we-are/about-montreal-protocol.

OzonAction, U. (no date) OzonAction Kigali Fact Sheet 5: HFC Baselines and Phase-down Timetable. Available at: http://www.unep.fr/ozonaction/information/mmcfiles/7880-e-Kigali_FS05_Baselines_&_Timetable.pdf.

OzonAction, United Nations Environment Programme (n.d.) OzonAction Kigali Fact Sheet 3: GWP, CO_2(e) and the Basket of HFCs. Available at: http://www.unep.fr/ozonaction/information/mmcfiles/7878-e-Kigali_FS03_Understanding_GWP&CO_2e.pdf.

Purohit, P., Höglund-Isaksson, L., Dulac, J., Shah, N., Wei, M., Rafaj, P., and Schöpp, W.: Electricity savings and greenhouse gas emission reductions from global phase-down of hydrofluorocarbons, Atmos. Chem. Phys., 20, 11305–11327, https://doi.org/10.5194/acp-20-11305-2020, 2020.

Ravishankar, M., Bordat, S. and Aitken, D. (2020) Net Zero Cold Chains for Food. Available at: https://prod-drupal-files.storage.googleapis.com/documents/resource/public/Net_zero_cold_chains_for_food.pdf.

Suri et al., Rural Incomes, Inequality and Poverty Dynamics in Kenya, Tegemeo Institute of Agricultural Policy and Development, 2008, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.161.8241&rep=rep1&type=pdf.

BIBLIOGRAPHY

United Nations Development Programme (no date) 'In Ghana, new refrigerators save energy for thousands of households'. Available at: https://www.gh.undp.org/content/ghana/en/home/ourwork/crisispreventionandrecovery/successstories/savoring-the-gains-from-the-refrigerator-rebate-scheme-in-ghana.html.

United Nations Environment Programme (2020) Report of the Technology and Economic Assessment Panel September 2020. Volume 2: Decision XXXI/7 - Continued Provision of Information on Energy-Efficient and Low-Global-Warming-Potential-Technologies. Available at: https://ozone.unep.org/sites/default/files/assessment_panels/TEAP_dec-XXXI-7-TFEE-report-september2020.pdf.

United Nations Industrial Development Organization (2017) Africa and the Kigali Amendment. Available at: https://ccacoalition.org/en/resources/africa-and-kigali-amendment.

USAID, Multi-tier framework for measuring energy access, USAID, 2018, https://www.usaid.gov/energy/mini-grids/economics/cost-effectiveness/tiers-of-service/.

World Bank Group. OFF GRID PV SYSTEMS - Array Size >1 kWp. System Design Guidelines, Draft Standard, World Bank, 2019, Uganda.

World Bank. Mini Grids in Kenya: A Case Study of a Market at a Turning Point, World Bank. 2017, http://documents1.worldbank.org/curated/en/792001512392701402/pdf/ESM-cKenyaMiniGridsCaseStudyConfEd-PUBLIC.pdf.

Annex I: Interviewee / Stakeholder outreach list

INFORMANT	ORGANISATION TYPE	ORGANISATION NAME	INTERVIEWEE/ PERSON CONTACTED
1	Manufacturers	BBOXX Ltd.	King Su & Christopher Baker Brian
2		Devidayal Solar Solutions Pvt. Ltd.	Tushar Devidayal
3		ISR – University of Coimbra	Nuno Quaresma
4		PCM Products	Zafer Ure
5		Phocos	Billy Amos
6		Steca, KATEK Memmingen GmbH	Müller Maximilian
7		SunDanzer	David Bergeron
8		SureChill	Duncan Kerridge
9	E-waste recyclers	City Waste Recycling, Ghana	Jurgen Meinel
10		Enviroserve, Kenya	Shaun Mumford
11		Enviroserve, Rwanda	Olivier Mbera
12		Hinckley, Nigeria	Adrian Clews
13	Other stakeholders	UK DEFRA	Alexander Adamson
14		GiZ Proklima	Nils Hansen
15		Tradewater	Tim Brown
16		PEG Africa	Rahul Jaisingh

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IKEA Foundation

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