USE CASES AND COST BREAKDOWN OF OFF-GRID REFRIGERATION SYSTEMS

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EFFICIENCY FOR ACCESS COALITION

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About Us

Efficiency for Access

This report was commissioned by the Energy Saving Trust as part of the Low Energy Inclusive Appliances programme, a flagship programme of the Efficiency for Access Coalition. 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 Energy Saving Trust, which specialises in energy efficiency product verification, data and insight, advice and research.

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Executive Summary

Increased use of refrigeration can improve livelihoods and support development. Benefits associated with cooling include income generation, time saving, reduced food waste, and disease prevention. Realising these benefits depends on the uptake and continued use of refrigerators, which requires the design and delivery of affordable products that address the needs, desires, and constraints of consumers and markets.

Off-grid refrigeration systems (OGReS) have the potential to play an important role in providing cooling services for communities without access to a stable electrical grid. This report examines factors affecting the economic viability and affordability of refrigeration systems in off-grid settings in low- and middle-income countries. Our work is informed by stakeholder interviews and newly designed modelling tools, with inputs based on publicly available data.

The following analyses examine the economic potential for deploying refrigerators of less than 300 litres (sub-walk-in chillers) in off-grid settings primarily within domestic, and light and medium commercial use cases. Deployments in areas served by standalone power systems or weak utility grids are not examined as part of this report. The results identify:

a. Opportunities for improving the affordability of refrigeration systems.

b. Major knowledge gaps that affect our understanding of the economic viability of these systems in key markets.

We provide recommendations for activities to improve market intelligence and accelerate the scale-up of the off-grid refrigeration sector. While the modelling tools we developed apply to all geographies, this report focuses on countries in sub-Saharan Africa and India. This reflects the large populations that lack grid connection in these two regions.

Key findings:

- **We found sizable variation when comparing the economic viability of off-grid refrigeration systems across geographies and use cases.** Wide differences in regional factors including tax policies and environmental conditions make it challenging to prioritise strategies for the entire off-grid refrigeration sector. To provide more accurate estimates of market viability, careful field research is needed to examine the costs and benefits of refrigeration systems within specific geographies and for select use cases.
- **Developing a framework of best practice for field study design and reporting would increase the transparency and accuracy of market research.** At present, evidence for the productive benefits and viability of refrigeration in off-grid areas is limited, and the quality of existing studies varies.
- **Examining the entire value chain of the system, and not just the cost of the appliance can reveal opportunities for cost reduction.** In some countries, solar power systems are comparatively inexpensive, yet import taxes and duties on the refrigerator alone may exceed 30% of the total system cost. In India, where some refrigerators are manufactured, taxes and duties can account for slightly less (20 – 25%) of the total system cost. In this case, savings associated with energy efficiency may be outweighed by the initial purchase of the refrigerator. In contrast, for those countries where solar power systems are less affordable and/or taxes and duties on refrigerator appliances are low, refrigerator efficiency may be the most effective tool to reduce overall expenses.

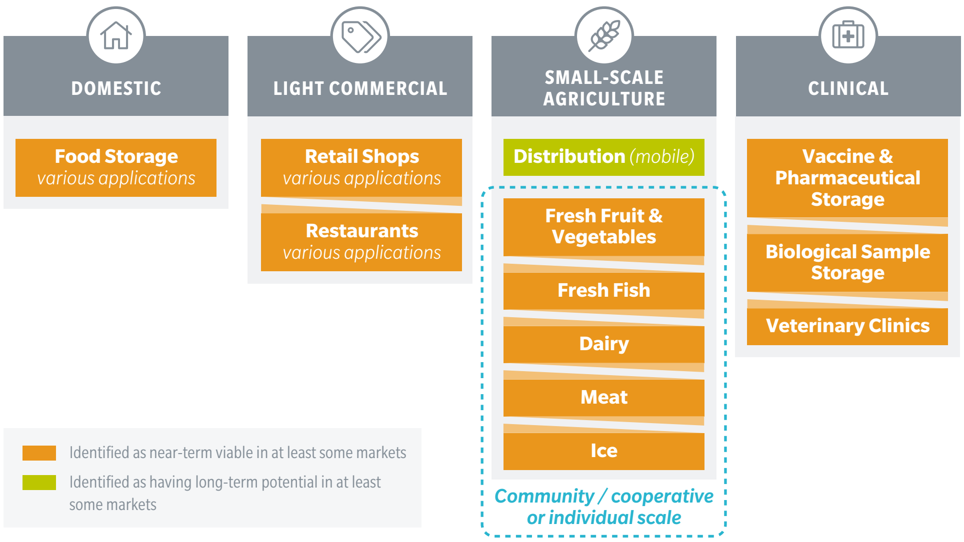
[1] In this report, we use the term “standalone” for independent power systems that do not connect to a utility grid.

- **Flexible financing mechanisms that align system payments with customer cash flows will likely be needed.** Aligning payment schedules to match when customers typically see financial gains from refrigeration could make purchasing an appliance more feasible. This alignment would require a closer understanding of use case income patterns (productive benefit) following refrigerator procurement.
- **Cold chain distribution technologies, market infrastructure, and after-sales support are needed for off-grid refrigeration to reach economic viability.** The majority of stakeholders interviewed identified the lack of aggregation/distribution entities as a major barrier affecting the scale-up of refrigeration for fresh fruit, dairy, and other near-term viable use cases. Support for this sector should include efforts to identify and address barriers to market access and provide after-sales maintenance.

General Use Case Segmentation

Figure 0.1 shows the use cases that manufacturers and distributors believe to have viability within the sector, if not necessarily in all markets. Most interviewees agreed that these cases reflect refrigeration opportunities. Specific use cases that were viewed as promising in the near future, three to five years by some, were viewed sceptically by others. It is important to note that documentation of the productive potential of off-grid refrigeration across use cases is limited. Both the robustness of the study designs used and reporting of results vary. Therefore, while use case segmentations are a valuable market assessment step, extrapolation to all geographies is discouraged.

Figure 0.1. Use case segmentation of off-grid refrigeration systems



- Domestic and light commercial applications are already viable in many markets, but the high cost of refrigeration systems and the potential for low productive benefit in some settings could create critical barriers to uptake.
- Small-scale agricultural applications were among the most promising, but in many markets, they remain unproven. The realisation of productive benefit under these cases can be affected by institutional factors such as access to distribution and aggregation networks. The importance of these local market factors and risk landscapes on productive potential underscores the need for field-based assessments. The impact of distribution systems on achieving productive potential may also signal a critical need for strategies that increase the near-term viability of cold chain distribution.
- Clinical applications are currently viable for off-grid refrigeration, but these markets are heavily driven by donor funding as opposed to local financial resources. Given the sensitivity of medicines and vaccines, clinical uses are also subject to performance standards that are not necessarily applicable to other sectors (clinical applications have been included in our mapping analysis but are not examined in depth as part of this work).

Based on discussions with manufacturers and distributors, there is a clear overlap between domestic and light commercial product applications and moderate overlap between light commercial and small-scale agricultural uses.

Refrigeration System Cost Modelling

The majority of a refrigeration system's cost comes from its power components and duties and taxes, regardless of geography or model (Figure 0.2). Some key markets have high duty rates on refrigerator appliances, but a relatively low cost and low duties on the associated power components. In these environments, the most affordable system is not necessarily the one with the most efficient refrigerator. These dynamics underscore the importance of considering the entire value chain of the system components when assessing cost and affordability. They also suggest that increased access to refrigeration will not be achieved through improvements to appliance efficiency alone.

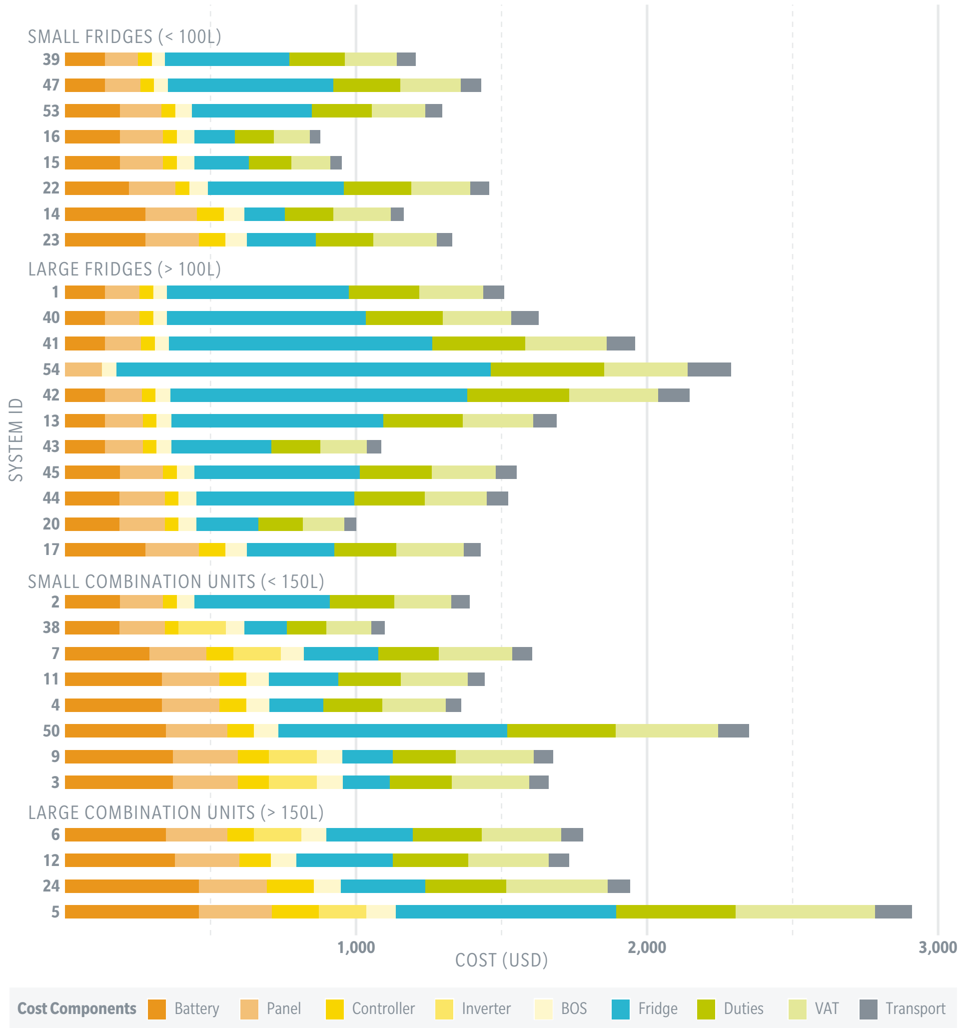


Figure 0.2. Modelled cost breakdowns of off-grid refrigeration systems assuming identical environmental and use case conditions. The blue bars correspond to the appliance, red bars the power system, and green bars duties and freight. Modelled estimates are for drink chilling in Kenya.

Duty regimes vary widely, so considering local market conditions is important. Figure 0.3 illustrates the contribution of each cost component category, for an average refrigeration system under both current and alternate tax, and duty regimes.

Figure 0.3. Average refrigeration system costs under different duty and tax regimens. Under "full duties and taxes" taxes are applied to all system components (i.e. there are no tax/duty exemptions for solar products). In some countries, duties on some solar power system components are reduced or eliminated to increase access, but similar reductions are usually not available for refrigeration equipment. The "typical" scenario uses average duty and tax rates in selected East and West African countries. "No Duties and Taxes: All" applies zero duties on all components with the exception of batteries, as batteries rarely receive exemptions. Achievable reductions in individual countries will differ due to variation in factors affecting system design and duty/tax rates.

Price Sensitivities and System Resilience

The resilience of a system is measured by how well it adapts to deviations from those norms assumed during the product's design phase. Increased resilience might protect against use behaviour, e.g. higher cooling loads, or environmental factors such as ambient temperature. Measuring energy consumed during actual business operation has shown that laboratory predictions can underestimate refrigerator power needs by a factor of two or more. Using our cost model, we tested the sensitivity to system price to various factors known to affect system performance. Our results indicate that environmental conditions (specifically ambient temperature) can significantly affect the power consumption of a refrigerator. Based on modelled scenarios, refrigeration system designs aiming for the most robust product should size power systems to handle the hottest season, as opposed to the period with the least solar resource. Moreover, some refrigerators may be unable to achieve cabinet temperatures of 5°C when ambient temperatures exceed 32°C, increasing the risk of compressor failure.

User interactions also affect performance. Refrigerators that are repeatedly opened, like a drink chiller, might require an appliance with a faster drawdown, or a larger power system to allow the compressor to run more frequently. In our sensitivity analyses, we found that doubling the baseline cooling load resulted in a 15% average increase in the daily energy requirement, and an overall system price increase of 0.5% –17%. These results highlight the importance of use behaviour and should be refined as more on system utilisation is discovered.

Our results suggest that current laboratory test procedures need revision to better reflect actual system use. Given the implications for affordability and reliability, links between system performance, environmental factors, and use behaviour should be examined as part of field assessments. Results from these efforts should, in turn, inform revisions to laboratory testing protocols for off-grid refrigeration systems.

[2] See for example: https://www.who.int/immunization_standards/vaccine_quality/pis_e3/en/.

Programme Recommendations

1. **Facilitate data collection to address critical knowledge gaps surrounding refrigerator use, performance, and productive benefit, and conduct market research on consumer preferences.** Although regional and global assessments are important to identify the scale of the opportunity, our results suggest that the factors governing the economic viability of refrigerators are highly variable across geographies and use cases. As a result, effective strategies will need to consider local-level data and insight.

   We recommend the following field activities to target key knowledge gaps:

   a. **Measure the potential and determinants of productive benefit.** Quantify the effect of refrigeration on revenue for specific use cases. Identify areas and conditions with high productive potential, as well as strategies to help customers maximise revenue.

   b. **Evaluate and map technical and non-technical market access barriers (risk landscapes).** Realising the productive potential of refrigeration requires more than just good appliance technology. Refrigeration technologies capable of moving goods from farms to markets and distribution centres will be critical for realising productive benefit. Entities that coordinate distribution and aggregation of goods will likely be important for enabling dairy, fish, and fresh produce in many markets.

   c. **Assess customer preferences and needs across key use cases.** Market analyses that focus on the end-user including measurements that link use characteristics such as load fraction and reloading frequency to refrigerator performance in kWh/day will help inform product design and can lead to more affordable systems. This investigation should begin with goods described as having the greatest near-term potential, including fresh fruit, vegetables, and meat.

   d. **Measure in-field performance of refrigeration systems and update laboratory testing procedures accordingly.** Laboratory test procedures are critical for benchmarking the quality and performance of a product, but do not always reflect how refrigerators are used in actual homes and businesses. Using field observations and measurements to help identify and address gaps in current laboratory testing procedures will help programmes (such as Global LEAP) identify models that best satisfy the needs of users and help distributors and manufactures right size their products.

   e. **Measure the long-term performance of refrigerators and user experience to inform quality testing and servicing strategies.** Enrolment of customer cohorts and regular visitations to characterise user experiences across the lifetime of the refrigerator would provide insights to inform system design modifications, after-sales support, and lab testing procedures.

   f. **Map in-country value chains.** Gather information on the cost and logistics associated with in-country supply chain steps, including maintenance. These cost components are not well understood but might have large impacts on total system expense.

   g. **Measure the willingness and ability to pay for refrigeration.** Using robust study designs, measure willingness and ability to pay for refrigeration systems in key markets and use cases.

2. **Develop a framework document that describes best practices for field studies and related reporting, to improve the quality and comparability of market research efforts.** Early field research is critical to inform governments, development agencies, and donors of the value and market potential of refrigeration. At present, evidence of productive benefit and other factors affecting the viability of off-grid refrigeration systems is limited, and study quality varies. Studies reporting the change in income characteristics following refrigerator procurement exist for several use cases. However, measurement approaches and reporting methods are inconsistent, making a comparison across studies difficult. This framework can be designed specifically for refrigeration market studies but should be developed in collaboration with other appliance working groups given the potential for overlap. It should describe best practices for assessment design, review, analysis, and reporting. Emphasis should be placed on how measurements impact complementary programme efforts including lab testing, performance metrics, and desk-based market assessments.

3. **Characterise the potential trade-offs of proposed measures for reducing system cost and improving affordability in specific geographies.** While there exists a critical need for in-field assessments, there are also desk-based efforts that could help distributors and manufacturers identify and prioritise geographies and use cases. These activities include:

    a. Estimating the costs and trade-offs associated with in-country assembly of refrigeration systems.

    b. Examining potential policy levers that could help reduce duty and VAT in all major markets.

    c. Improving estimates of in-country mark-ups and transportation costs.

    d. Applying the off-grid refrigeration cost model to test opportunities for cost reduction in local geographies.

    e. Synthesising geospatial data on grid access, grid reliability, and potential customer characteristics in key markets.

4. **Conduct pilot deployments that examine refrigeration within standalone power and weak-grid environments.** Power components represent a high fraction of the cost of an off-grid refrigeration system. Customers with weak-grid access or standalone power generation may value refrigerator efficiency and energy storage, which could yield productive return, but may have fewer power supply needs than an off-grid customer.

5. **Consolidate the existing data on local markets and make this information easily accessible to distributors and manufacturers.** Rightsizing refrigeration systems to reflect user needs and productive potential is key to improving affordability and requires straightforward access to relevant data. Many stakeholders expressed a need to acquire data that is technically available, but difficult to process in its current form. This includes information on import duties and regulations, refrigerator performance under specific conditions, and central grid access and reliability measures within regions of interest.

01 Introduction and Background

Increased use and access to cooling services has the potential to improve livelihoods and support development broadly. Observed benefits are wide ranging but include positive effects on income and savings potential, time allocation, reduced food waste, and disease prevention. In weak- and off-grid areas of the world, off-grid refrigeration systems (OGReS) may be able to play an important role in enabling these populations to access cooling services and benefits.

Realisation of the benefits of refrigeration is dependent on their uptake and use, which means designing and delivering affordable, market-ready products that consider the needs, desires, and constraints of potential consumers and markets[3]. For industry leaders and market stakeholders, a step in this process is identifying promising product applications and providing market ready products to these consumer groups.

Use case mapping is a process of classifying potential customer groups by characteristics of market readiness. One critical component of market readiness is the economic viability of products, which relates to the affordability and productive benefits of products to users in a given context. For stakeholders, such information can serve as guidance for identifying and prioritising customer groups and product sectors, informing product design, and focusing resources to address critical knowledge gaps affecting viability and risk in specific contexts. This can be especially useful during nascent stages of market development, early traction can help establish a pathway for achieving economies of scale. Use case mapping can also provide a high level view of market opportunities and potential.

While sector-scale assessments are useful for identifying market potential, they are rarely generalisable to all markets. Factors affecting viability can vary at the local (national and subnational) scale. It is the understanding of the potential for deployment at this more local scale, however, that is often more important for programme implementers and stakeholders. Greater understanding of these locally varying factors can also help development programme strategy by identifying the extent to which policy and technological "levers" could influence factors affecting viability.

1.1 Study Overview

At the Efficiency for Access Off- and Weak-Grid Refrigeration Market Development Roundtable in Amsterdam in June 2018, industry leaders and stakeholders identified consumer and market intelligence as a major challenge affecting growth of the market. Specifically, they expressed a need to better understand the use cases for refrigeration and strategies to characterise potential consumers. Access to information to help identify use cases and contexts that were most "market ready" was expressed as a major need.

[3] Successful uptake extends beyond the upfront cost of a system. Other important factors affecting sustained use of these systems also include, for example, proper use by the customer and access to reliable and affordable maintenance and repair services.

In response to these expressed needs, this study broadly explores the economic viability of off-grid refrigeration at the sectoral and local market scale. We map the landscape of economically viable use cases for off-grid refrigeration for the sector, then examine value chain factors driving system costs in specific markets. We also consider opportunities for improving affordability in light of these results.

We apply several techniques to examine the viability of refrigeration. A mapping of off-grid refrigeration use cases is developed, representing applications currently perceived as having near- or long-term viability across markets in the sector. We then develop and apply a cost model to examine the costs associated with various steps along the value chain in order to identify sensitivities and cost reduction opportunities. The output of this effort is a consistent and repeatable approach for generating initial estimates of refrigeration systems costs and cost breakdowns, accounting for the effects of user-appliance interaction and local environmental and policy conditions.

The objective of this work is to provide insights for manufacturers, distributors, development agencies, and policy makers. For development agencies, our work aims to inform programme activities around refrigeration to help address critical aspects of affordability and establish healthy markets based on the evidence and knowledge resources that already exist. For distributors and manufacturers, we aim to provide insight into current and future refrigeration use cases and strategies that address gaps in market intelligence.

The analysis assesses the economic potential for deployment of refrigerators less than 300 litres (sub-walk-in chillers) in off-grid settings. The study excludes refrigeration applications in micro-grid and weak-grid applications. Although the modelling tools developed and applied as part of this effort are applicable to all geographies, results presented in this report focus on countries in Sub-Saharan Africa and India given the large population without access to grid connections in these areas.

1.2 Productive Benefit

A critical aspect of the viability of refrigeration within a sector or use case is the productive benefit it provides to the user. Understanding of productive benefit can help inform system designs and financing plans, thereby improving affordability.

Evidence on the productive benefit of refrigeration in off- and weak-grid areas is limited, and the quality of available information is varied. Studies reporting changes in income characteristics following refrigerator purchases/procurement exist for several use cases, but measurement approaches and reporting methods are varied, making comparability across studies conducted in different contexts difficult.

There remains a critical need for field-based evaluations that quantify productive benefits within key markets and use cases. To maximise the value of individual studies, measurement and reporting should, to the extent possible, follow consistent frameworks and procedures. In addition, emphasis on examining factors affecting productive potential should be considered as important as quantifying the productive benefit itself.

Domestic

Refrigeration in the domestic sector is believed to enable some productive benefits though factors arising from time savings and bulk purchases. As far as we are aware, however, there remains limited field-based evidence to support this.

A household study conducted in Nairobi, Kenya found that after controlling for income, ownership of a refrigerator was the best indicator for whether a household purchased fresh fruits and vegetables at a supermarket (Neven et al. 2006). Participants owning refrigerators were 30% more likely to purchase fresh fruits and vegetables in supermarkets. It is important to note, however, that this study examined where fruits and vegetables were purchased from, as opposed to whether homes purchased them. Focus groups conducted in the same study revealed that households without refrigeration generally work with more fixed budgets for fruits and vegetables, and purchased fresh food items in smaller quantities, but at a higher frequency. This result supports theories that refrigeration could free time for more productive activities and reduce food expenditures by enabling storage of bulk purchases. These effects, however, were not measured as part of the study nor any other studies identified as part of the review.

A study conducted in rural Uganda found that refrigerators were valued by rural households but not necessarily a high priority purchase. Among 119 respondents surveyed only 7% selected a refrigerator within their top 20 preferred items to own out of a list of 46 (Hirmer and Guthrie, 2017). It is important to note that respondents were not educated on the potential benefits or trade-offs of these items prior to selection. Among those who selected refrigeration, perceived benefits included preservation of food (78%), improvement in taste (56%), and business opportunity (44%).

Phone surveys conducted among off-grid refrigeration users as part of Global LEAP user surveys found that most customers did not experience changes in time savings or purchase volume. The surveyed population was not exclusively focused on domestic applications, however, and the refrigerators they owned were predominantly being used for retail applications or a combination of retail and domestic uses.

Light Commercial (Retail)

Refrigeration in retail settings allows shops to provide new services and expand product offerings. To-date, most examinations of off-grid refrigeration systems have been performed in these settings, specifically small businesses using their refrigerators to store cold drinks and dairy products.

From a pilot study of 45 stand-alone solar refrigerators in India conducted by a product distributor, more than 70% of participants reported increased profit of more than Rs. 4000 per month ($57 per month); the average customer reported a profit increase of Rs. 8000 ($114 per month) (Selco, 2019). Factors driving the variability in profits were not examined, nor selection criteria used for including/excluding participants from analysis.

Several end user assessments have been performed as part of the Global LEAP Results Based Financing programme[4]. Phone surveys of 214 off-grid refrigerator users primarily from Uganda (approximately 90% Uganda, 10% Tanzania) identified that most were being used for retail purposes, or a combination of retail and domestic applications.

[4] Based on discussions with the study team, unpublished results

As these trials were focused on deployments of refrigerator units and companies under Global LEAP, use cases may be more reflective of product offerings than of sectoral demand. Regardless, 75% of respondents noted using the refrigerator for both dairy and/or drinks. Roughly half reported use for fruits and vegetables, and a quarter reported storage of pre-cooked food. The majority of customers did not perceive changes in indicators of time savings, purchasing quantity, or diet. However, it was unclear whether customers were aware of the potential benefits of refrigeration in these regards. Education and awareness programmes were not a component of these assessments.

Customers surveyed as part of the Global LEAP programme in Kenya and Uganda reported average gross sales increases in the range of $20 – 28 per week. After adjusting for costs, profits are estimated to be in the range of $5 – 15 per week, depending on profit margins in the area and for the items[5]. An important consideration for interpreting these values was the potential effect of selection bias. Questions around income can be sensitive, and roughly half of the respondents chose not to report changes in income in Uganda. It is unclear whether this low response rate would lead to a high or low bias in the results. Moving forward, questions regarding income might be framed around unit sales to provide a sense of appliance application and to use a less sensitive metric for approximating changes in income.

Businesses with larger-scale refrigeration (i.e., walk-in fridges) could provide new cooling services to nearby farmers and create co-benefits, as demonstrated in a case study in Bali, Indonesia (USAID, 2009). In this case, the facility owner could generate additional profit from fully utilising their facility, and the farmers could receive a higher farm gate price for their produce.

Small and Medium Commercial (Fresh Produce)

Off-grid refrigeration presents substantial economic opportunity for sales of fresh produce at both small and large scales. The ability to store produce at cooler temperatures can reduce potential spoilage losses, expand produce sellers' access beyond local markets, and help lead to higher financial returns. This is not an issue exclusive to developing regions of the world, but a lack of access to refrigeration has exacerbated food spoilage issues in these areas (Coulomb, Dupont, and Pichard, 2015). Estimates of loss in Sub-Saharan Africa and India from field to the local market are as high as 50 % (Timmermans, Ambuko, Belik, and Huang, 2014).

Farmers without cold storage often have to sell below their optimal price to prevent spoilage or leave crops unharvested altogether (Puri, 2016). With adequate postharvest cooling, farmers would be able to reduce the losses by extending the shelf life of the produce. Based on estimates by USAID, cooling produce from 35°C to 15°C during the handling and storage phases can extend the shelf lives by a factor of four relative to storage at ambient temperature (USAID, 2009). The rise of supermarkets in developing countries may also increase demand for better quality products, creating greater market opportunity if issues around storage can be addressed (Neven et al., 2006).

Refrigeration is especially critical for dairy products and consequently could have larger productive impacts than other fresh produce. With solar direct drive milk chillers, off-grid dairy farmers in Kenya were able to store larger quantities of milk overnight, resulting in a 30% increase in income (Foster et al., 2017).

[5] Author approximation

Clinical

In the clinical sector, the productive impacts of solar vaccine refrigeration depends on the quality of the grid servicing the clinic. In locations with stable grid connection, the cost per dose is higher for solar vaccine refrigerators than grid-electric refrigerators (Leila et al., 2017; WHO and PATH, 2013). In locations with an unstable grid, however, the cost per dose of solar vaccine refrigeration can become lower than a grid-powered refrigerator after considering the avoided cost of the spoiled vaccines and patients turned away (Haidari et al., 2017).

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02 Strategy and Approach

This section describes the scope of the study and provides a brief overview of activities and methods.

2.1 Study Scope

Given the breadth of potential off-grid refrigeration applications and market, it was necessary to restrict activities to examine specific components of the market. For modelling, only refrigeration systems less than 250 litres were considered (no walk-ins). Vaccine refrigerators were also not examined beyond incorporation into the case segmentation mapping. Our assessments of cost and cost breakdown focus on units tested under Global LEAP Off-Grid Refrigeration Competition in 2017. We assume that each system is paired with a stand-alone solar power system that alone can run the appliance. As a result, the results are not necessarily reflective of mini-grid or weak-grid situations. The developed modelling procedures, however, are flexible to expand to other refrigerators contingent on the availability of necessary performance data.

2.2 Leveraging Complementary Activities

This study benefited from several complementary efforts for information and feedback.

- **LEIA Refrigeration Technical Working Group –** Refrigerator classification frameworks, performance metrics.
- **Global LEAP Results Based Financing End-User Surveys –** Information on application of refrigerators and effects of refrigeration on sales.
- **Global LEAP Competition Test Results (Equip Database) –** Performance characteristics of refrigerators.
- **2019 Efficiency for Access Forum Market Insights Roundtable –** Initial feedback from industry leaders and stakeholders on both the use case segmentation update and cost model approach.
- **IFC Study on Impacts of Backup Generators –** Global and national trade of products, applied in this case to refrigerators.

2.3 Methods and Approach

Several strategies were used to separate refrigerator use cases and assess their economic viability within global and local markets.

- **Stakeholder Interviews** were used to provide a qualitative assessment of market sectors and use cases currently seen as near- and long-term viable for the sector as a whole. Insights are based on the experiences, market analyses, and perceptions of a subset of manufacturers and distributors active in Africa and South Asia.
- **Cost Modelling** was used to operationalise the cost components of a refrigeration system and provide a framework for evaluating economic viability under specific markets and use case conditions. This tool was designed to leverage existing knowledge on viability of use cases to estimate viability in other geographies and for other use cases for which field trials and verifications do not yet exist. Results inform first order approximations of economic viability, identify important data gaps and opportunities for improving affordability, and develop recommendations for programme activities.

2.3.1 Stakeholder Interviews

Distributors and manufacturers of refrigeration systems were interviewed at the beginning and end of the study. An effort was made to provide a mix of appliance types and sector roles, and, to the extent possible, geographies (Table 2.1). Interviews were conducted via online conference calls and recorded with the permission of the interviewee. Most calls lasted between 20–30min. Prior to phone interviews, a screening survey was administered to introduce them to the types of questions they would be asked. It also provided an opportunity to gather background information on their organisation and initial impressions of the early use case segmentation. Table 2.2 provides an overview of the backgrounds of distributors and stakeholders interviewed as part of this effort.

The initial round of interviews conducted in May 2019 focused around three core themes: near- and long-term viable use cases, barriers to scale up, and understanding of welfare impacts of refrigeration on users. A total of nine interviews were conducted and a Roundtable discussion was performed as part of the 2019 Efficiency for Access Off- and Weak-Grid Refrigeration Market Development Roundtable in Amsterdam.

The second round of interviews conducted in August of 2019 focused primarily on gathering feedback on results to the use case mapping and cost model. It also included discussions with four development agencies and NGOs who benefit from or use off-grid refrigeration, but are not themselves involved in design or distribution. A total of five interviews were conducted as part of the second phase, including two development agencies.

Table 2.1. Stakeholder classifications.

Stakeholder Type	Description
Manufacturers	Involved in the manufacturing and engineering of refrigerator appliances. Knowledgeable about appliance components, performance, material/component costs, and importation costs and procedures.
Distributors	Involved in in-country distribution and after-sales support. Includes some decentralised energy service providers and companies with experience with financing and the impacts/benefits of refrigeration.
Development Agencies	Involved in programme implementation and piloting of refrigeration and non-refrigeration programmes in which cold chain plays a critical component (i.e. nutrition). Could have activities related to refrigeration programme monitoring and evaluation.

Table 2.2. Manufacturer and distributor characteristics.

	Category	Number of Interviewed Distributors (of 9)
Sector	Small commercial	6
	Household	3
	Medical	2
	Large-scale commercial	1
Use Case	Fresh fruit and vegetables	7
	Dairy storage	5
	Milk chilling	5
	Retail shop	5
	Fish storage	4
	Restaurant	4
	Meat storage	3
	Ice making	2
Regions	South Asia	2
	Southeast Asia	1
	North Africa	2
	South Africa	2
	East Africa	8
	West Africa	2
	South America	2

2.3.2 Cost Modelling

The following section provides a high-level overview of the cost model and corresponding output. A more detailed description of underlying model assumptions and estimation procedures is provided in Appendix A.1.

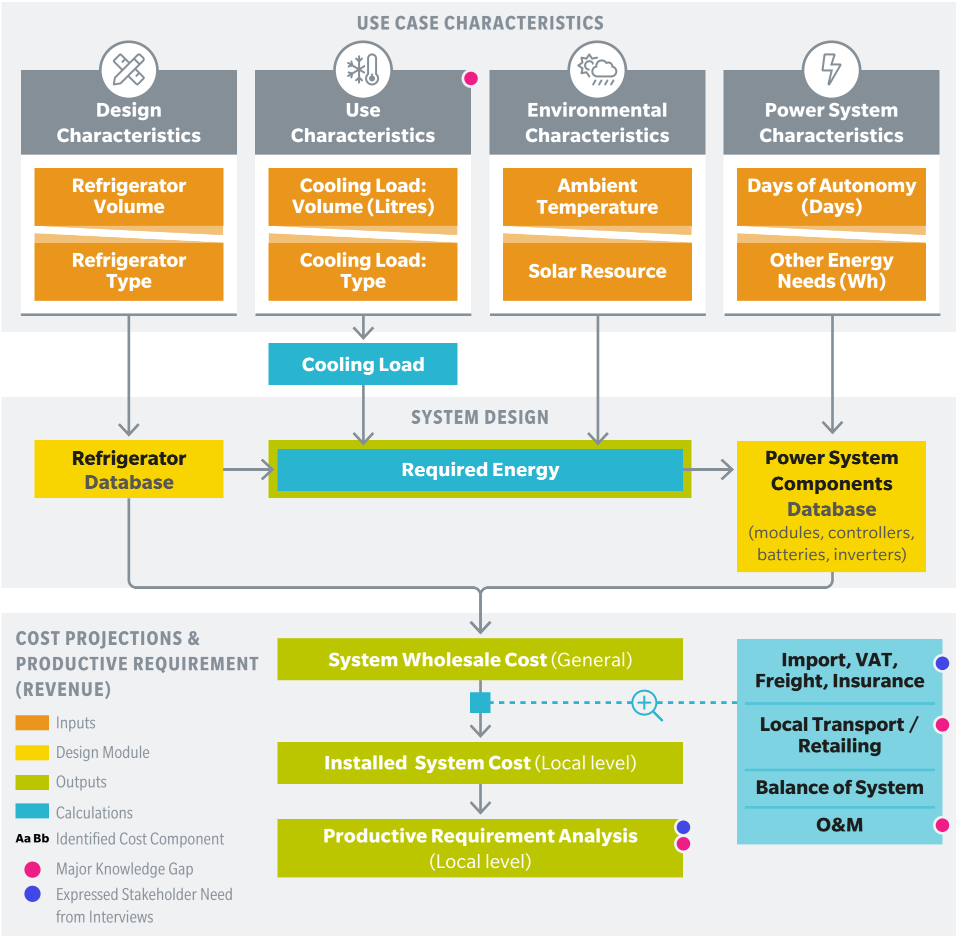
Model strategy overview

The cost model developed for off-grid refrigeration operationalises the components of a refrigeration system with respect to cost under specific market and use case conditions. Our modelling approach and procedures attempt to provide cost estimates that account for local conditions that influence system performance and design. Figure 2.1 is a general schematic of the cost model developed and applied in this study. The schematic highlights the process of connecting use case characteristics with performance and cost. It also highlights cost components that are considered in the model. A more detailed description of the model design characteristics are located in Appendix A.

Results from the model provide a first approximation of system cost and a breakdown of costs. This approach allows for consistent comparisons of the same refrigerator unit under different market conditions and for different productive applications. Cost breakdowns can also be used to identify potential cost reduction strategies. A modelling approach like the one used in this study is not a replacement for field measurements, but is akin to performing a lab test before trialling in-field. It may help to identify potential sensitivities and knowledge gaps affecting cost estimates and justifications for field activities. The model also provides a platform/framework in which new knowledge can be incorporated and stored.

It is important to note that not all factors affecting the viability of refrigeration are considered in a cost model. Institutional factors such as aggregators and distribution networks, for example, can be critical for realising productive benefit but are not captured as part of system costs. Thus, addressing gaps identified in the cost model exercise are important but not sufficient for a complete assessment of viability. We identify next steps and recommendations which help to address these additional factors and complement the output of this work.

Figure 2.1. Schematic of the off-grid refrigeration cost model.



What is a cost model?

A techno-economic model (cost model) is an analytical technique often used at early stages of product development to identify opportunities for cost reduction. In this work, we apply a cost model to “break apart”, or operationalise, the cost of a refrigeration system and provide a more granular view of how price is affected by various stages of the supply chain, user behaviour, and environmental conditions.

The price of a refrigeration system observed by a customer includes the manufacturing cost of the appliance, as well as freight, import duties, and local distribution; the refrigerator also requires a power system to accommodate local conditions and intended use. For example, a refrigerator operating in a warmer climate will require more power to maintain temperature than one in a cooler climate. Similarly, a refrigerator being used to cool 50 drinks per day will require more energy than one that cools fewer. All these factors add to the price and in theory can be reduced through a variety of mechanisms not limited to improvement of the appliance. As noted by several stakeholders, these non-appliance costs can be equal to or greater than the cost of the appliance alone[6].

[6] This point was raised by the Technical Working Group (TWG) Roadmap document (Pg. 23, “Prioritising affordability rather than cost reductions”). This working group was tasked with developing a Technology Roadmap to identify and coordinate the activities, resources, and technology investments needed to improve off-grid refrigeration products. The TWG Roadmap can be downloaded from https://efficiencyforaccess.org/publications/off-grid-refrigeration-technology-roadmap

In the model, a "use case" is defined through the characteristics that affect system design, performance, and cost. This includes factors such a local ambient temperature, import duties and value added tax applied to system components, and freight. It also includes aspects of user interaction and service, such as the type and amount (load) of material being cooled. This generalised approach maintains flexibility to accommodate new use cases also allows for fairer comparison of systems across different markets and conditions.

Using a cost model to assess economic viability

For many stakeholders, the productive benefit and resulting payback time are critical benchmarks for viability. The cost model approach allows us to compare the cost of the system to the productive return in a specific context.

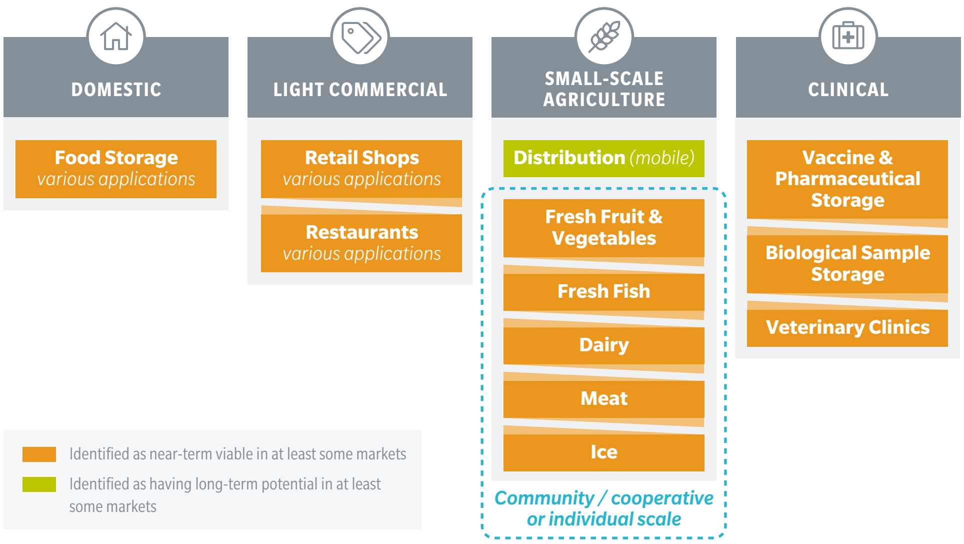
Given the limited data on the productive benefit of refrigerators to users, we apply the cost model to derive first order approximations of the revenue required (productive return) to meet payback objectives. This required revenue is the profit or savings level experienced by the refrigerator owner so that the net present value (NPV) at a specified payback period (i.e. two years) and interest rate (i.e. 7%) is zero - indicating the refrigerator has "paid itself off" (equivalent to the rate of return of the refrigerator being equal to the interest rate).
We provide estimates of the revenue required under various possible payback windows and interest rates.

03 Off-Grid Refrigeration Use Case Segmentation

3.1 Use Case Segmentation Map

Based on review of existing literature and discussions with stakeholders, use cases for off-grid refrigeration were segmented into sectors and classified as either near-term (three–four years) or long-term (four+ years) viable (Figure 3.1). The time window selected to represent "near" and "long" are subjective, but were generally viewed as acceptable by distributors interviewed. This mapping is a broad representation of the sector as a whole and is almost certainly not representative of every country market. This mapping should be considered an aggregation of promising use cases reported as being near- or long-term viable in at least some areas of Sub-Saharan Africa or South Asia. It is important to note that even among use cases reported below, there was disagreement on viability due to differing experiences with pilot deployments, particularly around use cases indicated as near-term viable. This mapping also does not reflect the ecosystem or institutional modifiers which are sometimes necessary to realise the productive benefit of a use case. Some of the local-level factors and local barriers are described in greater detail in subsequent subsections.

Figure 3.1. General use case segmentation of off-grid refrigeration systems. Thickness of the "product overlap" lines corresponds to the degree of product overlap, with thicker corresponding to greater overlap.



3.1.1 Sectoral Classifications

Four distinct sectors are identified for the off-grid refrigeration sector:

- Domestic (Household).
- Light Commercial.
- Small-scale Agriculture.
- Clinical.

Many stakeholders viewed the domestic sector as promising but being affected heavily in the near-term by affordability barriers. Most early adopters of these systems tend to use them for both domestic and light commercial applications. It is possible that users are benefiting from the use of these systems through an ability to bulk purchase and by realising nutritional benefits and fuel savings, but there is little in-field evidence to confirm this. Flexible financing mechanisms may be especially critical for scale-up in this sector given limited opportunities for increasing productive potential.

Light commercial applications had the most near-term promise based on stakeholder feedback. While the productive benefit potential in the light commercial area is likely smaller than for small-scale agriculture, the productive potential of light commercial applications are also less likely to be affected by institutional factors such as access to agricultural distribution networks and existence of product aggregators.

Small-scale agriculture was considered an area with the largest productive potential, but it is also an area that is unproven in many markets and subject to institutional barriers at the local level. Many use cases are dependent on the existence of local markets and aggregator networks to secure pricing and distribution. This was noted by several stakeholders as being a critical barrier for scale up. Cold chain distribution is a critical mediator for productive potential, and especially so for the inclusion of off-grid households which are typically more remote and further from markets.

Clinical applications were viewed as the most distinct product group. Determination of product design and viability are currently dictated by factors that differ from other sectors due to the composition of funders and high cost of failure. The sensitivity of vaccine efficacy to storage temperature also dictates more stringent requirements for certification and design, affecting cost. Beyond vaccines and other pharmaceuticals, clinical applications may also include veterinary applications, although deployments for this use case appear to be limited.

3.1.2 Product Overlap

Based on feedback from stakeholders, significant product overlap was noted for domestic and light commercial sector appliances. The units that are currently sold in off-grid markets are generally refrigerators sized less than 150 litres. The Global LEAP RBF End-User surveys suggest that many owners use their refrigerator for both domestic and small commercial applications. Walk-in chillers are not common for small commercial applications, but they are critical at the co-operative level and as part of aggregation and distribution chains. New financing mechanisms may expand use of walk-in chillers by allowing farmers to lease space from an aggregator or co-op rather than purchasing individual units.

3.2 Factors Affecting Productive Benefit

Numerous barriers affecting market scale up were noted by manufacturers and distributors. Some of these barriers were specific to use cases and markets, while others were relevant to the sector as a whole. Implementing solutions to overcome these barriers will span different timescales. Policy-related barriers can begin to be addressed, but will likely require effort that extends beyond the LEIA initiative.

3.2.1 Affordability

Improving affordability requires addressing factors along the entire value chain of the refrigeration system, not just the appliance. These need to be complemented with flexible financing mechanisms that better align system payments with customer cash flow.

For many customers, a refrigeration system will be the most expensive and energy intensive appliance they will own to date. Helping customers overcome the "sticker shock" of high upfront costs was noted as a critical barrier, as was the need for financing mechanisms that help align payments to cash flows and productive benefit. Flexible financing alone, however, may not be sufficient for making refrigerators market viable in some use cases and should be explored in parallel with efforts aimed at reducing total system cost and maximising productive benefit (in turn informing terms of finance plans). Examining non-appliance cost components will likely be critical to this increasing affordability (i.e. see "trade barriers").

Issues of affordability are also not exclusive to customers. Several distributors noted the logistics and associated cost of providing after-sales support as a potential concern affecting their ability to scale. In the absence of trained local staff capable of providing in-field repairs, refrigerators must be shipped back to major cities at the expense of the distributor or retailer. While challenges associated with maintaining after sales support is not unique to the refrigeration sector, logistics and costs are amplified as a result of their size. While customers may not have to bear the cost of repairs, refrigerator downtime does impact productive benefit, and the inability for distributors and retailers to provide support can compromise reputations (most local distributors do not deal exclusively with refrigeration) and damage public perception.

3.2.2 Market Intelligence

In-field evaluations focused on specific use cases in key markets are critically needed to address knowledge gaps around productive potential, risk landscapes, and user preference and needs.

Numerous stakeholders expressed a need for more reliable local market intelligence around a range of factors including productive benefit, risk landscapes, and user needs/preferences. Performing such assessments are often outside the expertise of the distributors or manufacturers, but are decision factors for scaling. While effects on income growth and stability were areas mentioned most frequently, other interests included transformative effects on behaviour and welfare (i.e. time savings, fuel savings, preferences, etc.).

The effect of grid access and grid quality on the economics and competitiveness of off-grid refrigeration products remains a critical gap affecting our understanding of viability.

Several stakeholders mentioned the importance of knowing the characteristics of the utility grid for making business decisions, but they lacked the knowledge and resources to do so. Most distributors acknowledged needing to serve customers in both off- and weak-grid areas. From the perspective of productive benefit, it was noted that customers in weak-grid areas are likely to benefit more from cold chain and refrigeration in the near-term than customers currently living off-grid. Reasons for this include differences in access to markets, distribution networks, and capital for expanding.

Some stakeholders mentioned that they also struggle to make business decisions on the basis of unreliable and anecdotal market intelligence. One stakeholder mentioned that information he had received from a local NGO on milk chilling was inaccurate, but that he would not have known if he had not visited himself. Variation in the way intelligence is collected and presented can make it difficult to extrapolate results collected in a particular context to a new one.

3.2.3 Trade Barriers

High duties are a critical barrier to affordability that, if addressed, could have potentially greater benefit on increasing affordability than near-term technological improvements.

Taxes and duties were noted as important and significant cost components of refrigerators (DC and AC) and are a primary policy roadblock to scale up. In Africa, duties for importing a fully assembled refrigerator can be as high as 50%, before applying VAT. Although reasonable argument could be made that refrigeration satisfies a basic service need, it is often classified as a luxury good, and subject to high import duties. Value added tax (VAT) often add an additional 15-20% on top of import duties. After factoring in freight, insurance, and distribution, the costs associated with transporting a unit from its place of manufacture to the point of retail sale is often comparable to the total cost of the refrigerator appliance itself (before factoring in power systems). One manufacturer interviewed noted that barring significant breakthroughs in technology, reductions in the capital cost of a refrigerator unit from possible changes in manufacturing would be small relative to the removal (or reduction) of import duties and VAT on the refrigerator.

Accessing information on local duty rates and certification requirements was also noted as an issue affecting scale up. As regulations around importation of refrigeration of appliances differ across countries and regions. These data are available, but often difficult and cumbersome to navigate for distributors.

3.2.4 Local Infrastructural to Support Markets

Agricultural produce aggregation and distribution will be important for the commercial viability of refrigeration for fresh produce applications (i.e. fruits, vegetables), but it is still lacking in many key markets.

Multiple stakeholders emphasised the importance of aggregation and distribution of agricultural produce for realising productive benefits under some use cases. These entities are collectives/cooperatives, processors, or commercial-scale enterprises that consolidate produce across multiple farms/producers, identify buyers, negotiate prices, and have the throughput to take on the financial risk of investing in refrigeration systems. For milk, this entity is the processor, but for other end-use applications that do not require processing (e.g. fruit, vegetables), these entities are often difficult to identify or absent in key markets. Several companies attributed an absence of this entity as a major reason for why markets in these areas have not expanded more rapidly. Given the market knowledge and effort required to maintain or establish these networks, one stakeholder mentioned that it was unlikely that a farmer could play this role while still meeting the needs of their own farm.

Identifying these aggregators will likely be important for the poorest farmers/producers who, in addition to lacking resources to scale and pay for refrigeration systems, are furthest from market hubs and have limited negotiation power. One observation by a company active in South Asia was that subsidies and other financial mechanisms are often available to farmers through government initiatives, and that it could make sense to extend similar assistance to support distribution and aggregation infrastructure.

3.2.5 Matching User Needs to Refrigeration Systems

For distributors and manufacturers, rightsizing refrigeration systems to user needs and is part of improving affordability, but requires more convenient access to the right kind of information.

Distributors, especially those dealing in multiple energy products, noted a lack of resources and expertise to identify suitable refrigeration systems for their customers and in-country supply chain partners. It is important to mention that some distributors may not have expertise with interpreting refrigerator performance metrics, yet they are trying to identify a product that is appropriate for a given context. This is especially true, for example, when the mini-grid operator is also the serving as a refrigerator distributor. As most distributors deliver products to both off- and weak-grid areas, it is often important for them to weigh the pros and cons of system designs with respect to cost and performance. For example, performance across end-uses representing very different user needs requires significant variation in system design (e.g. system designs differ for cooling applications that involve steady state refrigerator operation vs. applications that involve repeated drawdown). Likewise, distributors may need to consider whether it is more advantageous to specify a direct current (DC) or alternating current (AC) refrigerator for an off-grid energy system. One company highlighted its experience with the Global LEAP Buyers Guide and noted that they were discouraged by the lack of pricing data and the additional follow-up by distributors/customers required to answer basic performance and application trade off questions. This information has since been transferred to the Equip Database, potentially alleviating some of these barriers. Regardless, helping to translate raw performance metrics to values more reflective of stakeholder decision factors may be one way to reduce this barrier.

3.2.6 End-User Education

Educating customers can help improve affordability and maximise productive output, and it begins at the appliance selection stage.

Educating customers can help improve affordability and maximise productive output. To achieve good outcomes, this education process should begin with refrigeration product selection. Customer preferences may be for refrigerator designs that are less efficient – e.g., upright cabinet-style units as opposed to chest designs – that require larger and more expensive power systems, but they may change their views after understanding the implications of their original preferences.

Education can also be used to help customers identify uses of their refrigeration system that maximise economic productivity. Customers not currently engaged in markets may not be growing crops that have the most earning potential and thus would not immediately benefit from a refrigeration system. As noted by one stakeholder, many businesses have found ways to work around a lack of refrigeration through the way they operate their businesses or the geography in which markets have developed. For example, milk producers may not be active in the hottest areas of the country and butchers slaughter animals at a rate that is consistent with demand. People in some communities have grown accustomed to drinking sour milk and so it has become a cultural preference. To address some of these barriers, some stakeholders have begun conducting customer awareness campaigns.

3.3 Conclusions: Use Case Segmentation

- **In-field evaluations focused on specific use cases in key markets are critically needed to address knowledge gaps around productive potential, risk landscapes, and user preference and needs.**

- **Opportunities to improve affordability by reducing system cost should consider more than the refrigerator appliance itself.** Costs associated with other steps of the value chain can be critically important to overall cost.

- **Established aggregation and distribution networks will be important for realising productive benefit of many fresh food applications and are likely absent in key markets;** these institutional determinants should be examined as part of field studies and pilots affecting use cases dependent on access to larger markets.

- **There is no consensus on use case viability. Use cases that were viewed as promising by some were viewed sceptically by others, underscoring the need for local market assessments that are designed and reported using consistent approaches for comparability and transparency.** Factors affecting affordability and viability of off-grid refrigeration change across settings and potential markets. As a result, there is likely no single "mapping" of use case viability that accurately reflects all potential areas where off-grid refrigeration could have value. Most examinations/studies to date have focused on reporting on whether productive benefits exist, in a specific location, rather than the mechanisms and drivers that led to success in one situation and failure in another. To the extent possible, market intelligence gathering efforts and field studies should be designed to identify associations between application characteristics as well as whether productive benefit is occurring (get at the "why") in order to maximise their value.

- **Early support to distributors and manufacturers can be provided by consolidating existing data needed to access markets and making these resources more accessible.** Accessibility means not only making information easy to find, but potentially translating and connecting technical metrics so they are easier for stakeholders to apply in decision making.
- **Creating awareness among consumers and retailers to help optimise the service benefit they receive from their products can help reduce consumer risk;** this begins with product selection and "right sizing" systems so they are only as expensive as they need to be to meet expressed needs. This may involve tools and assessment guides that help with product selection and educate consumers as well as retailers.

04 Cost Modelling

This section presents results from a cost model developed to examine differences in refrigeration system cost and affordability when considering the entire product value chain and local market factors. The analysis and underlying framework and procedures can be used to:

- Identify important cost components of the refrigeration system and strategies for reducing total system cost.
- Compare system prices to estimates of productive benefit as an indicator of affordability.
- Estimate system price(s) accounting for local market and environmental conditions, and applications (use cases).

Characteristics of a use case affect system price through several pathways:

- **The refrigerator type and size –** Larger refrigerators tend to cost more, as do units with freezers.
- **Use profiles (application) –** The cooling load and material can affect the amount of energy required to cool contents to the target temperature, with corresponding implications for the size and cost of the energy system.
- **Environmental conditions (temperature, solar resource) –** The refrigerator compressor will run more in a hot climate than a cooler climate, all else being equal. The size of the solar array and energy storage system may change depending on solar resource availability.
- **Tax and duty regimens –** The rate at which system components are taxed along various stages of the value chain.
- **Transportation and Retailing –** The cost of transporting system components from the point of manufacture to where it is sold and sales margins in the local market.

Revenue (productive benefit) is a critical aspect of affordability, but it does not affect the upfront system cost. Productive benefit is often an important metric to compare against system cost to determine affordability and payback time.

In this report, we do not generate an exhaustive list of use case scenarios or show how varying all possible factors can affect price. Instead, to convey key messages, we emphasise major themes and lessons that help identify important considerations and "levers" that exist for influencing system cost and, correspondingly, increasing off-grid refrigeration system affordability.

Given the diversity of use cases and market conditions, we establish a "reference condition" for presentation purposes. The following assumptions are made for all subsequent figures and results unless stated otherwise:

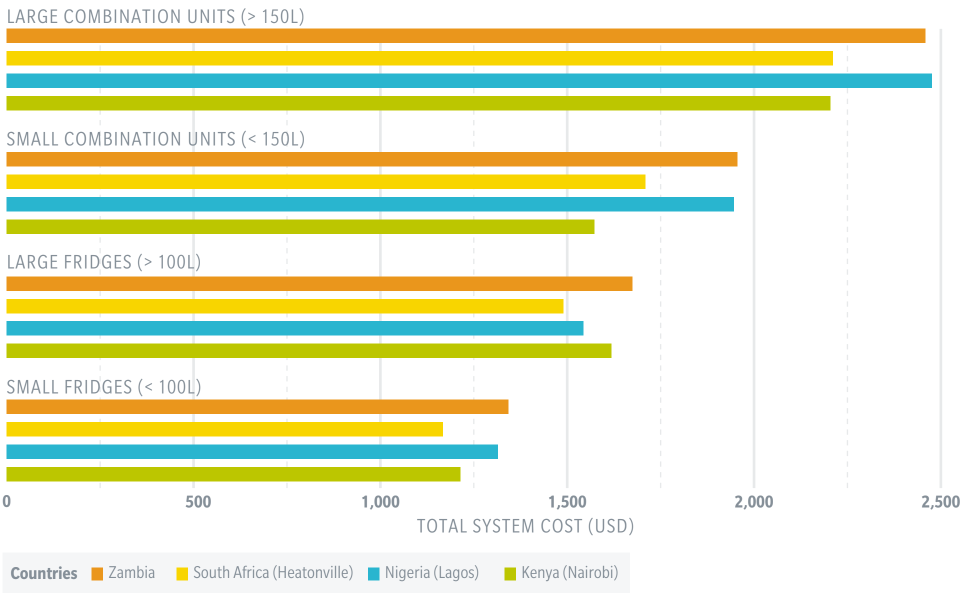
- **Climate:** Kenya (Nairobi weather data used to represent nearby off-grid areas).
- **Use Case:** Cold drinks.
- **Loading Intensity:** Moderate (50 drinks/week).
- **Power System Days of Autonomy:** 2.
- **Operation and Maintenance**: $162 per year; battery replacement every three years not included $162/year annual service fee[7].

When interpreting results, it is important to note that we apply available data, acknowledging that significant gaps in knowledge remain that will affect price estimates, especially in specific markets/geographies. The results presented should be considered first approximations that help inform activities and strategies for reducing cost, but they should be complemented (and refined) with evidence from the field. Modelling efforts such as these are not replacements for field evaluations.

4.1 Factors Leading to Variability in Total System Cost

A variety of factors can lead to variability in refrigeration system cost within and between countries and use cases. Figure 4.1 shows the average system price across four markets, assuming identical reference use case conditions. Among example countries, a complete system for the same refrigerator unit (see Figure 4.4 for all cost components considered) and use application varies by as much as 15%. It is worth noting, however, that these differences are modest relative to the differences between refrigerator types (refrigerator vs. refrigerator + freezer). In later sections we examine the major drivers of cost and resulting strategies for improving affordability.

Figure 4.1. Average refrigeration unit system costs in several markets; estimates assume identical use case characteristics but account for local ambient temperature and duty regimens (reference conditions for all remaining assumptions). Refrigerator units considered were those that were tested under the Global LEAP Competitions as of 2018 (N=31).



[7] This operation and maintenance cost is fixed across all systems evaluated using the cost model regardless of size. Assumes $4 quarterly for routine maintenance and $158 annually for major maintenance based on assumptions outlined in: https://www.path.org/resources/total-cost-of-ownership-tool-for-cold-chain-equipment/

4.2 Productive Benefit Potential

For assessing system affordability, it can be useful to compare system prices to the productive benefit expected from owning a refrigeration system. Figure 4.2a provides one such example, by comparing net income (revenue) required to pay back the system under various financing structures. O&M costs are applied assuming 10 years of service must be recouped within the specified payback period (e.g. 2, 4, 6, 8, 10 years). The middle zone (between dashed lines) corresponds to a transition zone, where systems may be affordable in some but perhaps not all situations given typical revenue levels reported by shop owners after procuring their refrigerator. These zones are informed by results from pilot field deployments of off-grid refrigerator units used for drink chilling in Uganda, performed as part of the Global LEAP Results Based Financing programme. Although there remains significant uncertainty in some cost components – namely O&M, local retailing costs, and productive benefit – the results are roughly consistent with stakeholder impressions of viability. The majority of systems only become viable at a payback period of six years or more given underlying assumptions. A variety of factors could help reduce system cost to bring more units below the threshold cut off and are explored in later sections.

Figure 4.2b applies the same assumptions as Figure 4.2a, but omits taxes and duties from the refrigeration system and all power system components (with the exception of batteries). All curves become shift downwards, making systems more affordable, but have the most notable effect on systems with payback periods of six years or greater.

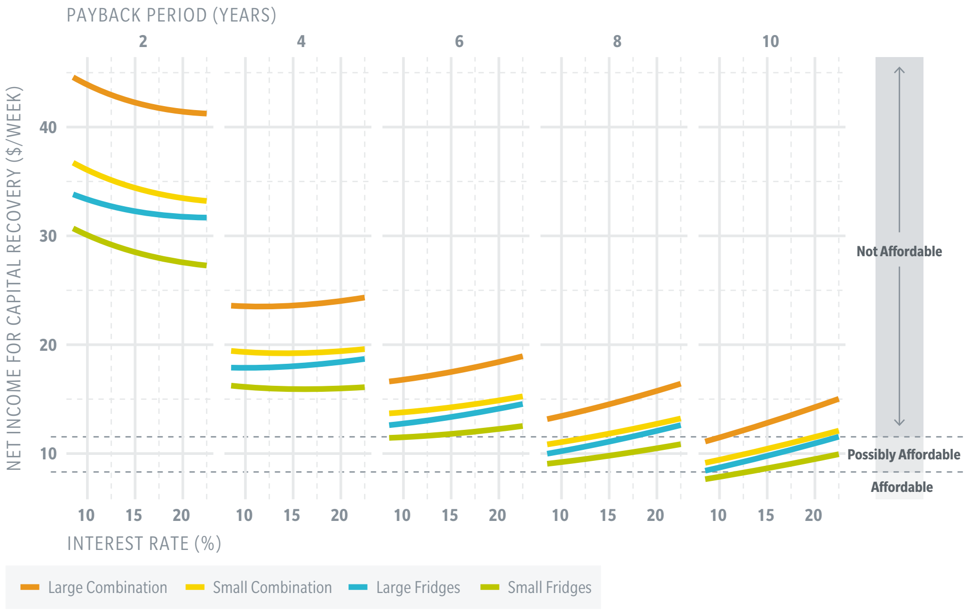


Figure 4.2a. Net income required for capital recovery of full system cost including O&M at various interest rates and payback periods (reference scenario assumptions). Assumes zero down payment at purchase.

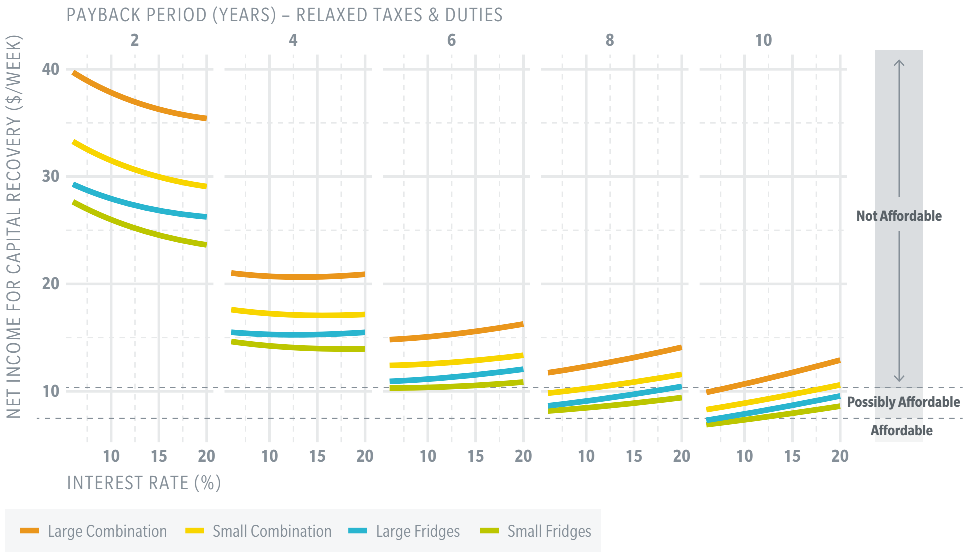


Figure 4.2b. Net income required for capital recovery of full system cost excluding select duties, but including O&M, at various interest rates and payback periods (reference scenario assumptions). Taxes and duties on refrigerators and power system components are assumed exempt, with the exception of batteries.

4.3 Cost Breakdown Overview

The following sections examine the contributions of various system components and steps along the value chain to the total system cost.

Figure 4.3 shows the cost breakdown for the average system in each refrigerator size category. The results suggest that non-appliance costs are a significant contributor and accounting for similarly large percentages of total system cost across refrigerator classifications, on average. Costs associated with the power system, duties/taxes, and transport are large contributors to system cost, accounting for as much, if not more, than the appliance itself on average. Differences between geographies and applications will lead to variability in relative cost breakdowns, but the importance of non-appliance costs will likely remain.

The refrigeration systems that are the most affordable are not necessarily the ones with the most efficient refrigerators. Figure 4.4 shows cost breakdowns for systems designed for individual refrigerators. More efficient refrigerators require smaller power systems – all else being equal – but are generally more expensive to manufacture. Lower production volumes are another potential factor. High duty rates on refrigerators, coupled with low cost and duties on some power system components, can lead to situations where it is not cost effective to improve the efficiency of the refrigerator. This is true because any additional refrigerator cost is amplified by high duties on the refrigerator itself. In many key markets, however, these high duties and sales taxes are waived for power system components. Duties and taxes are discussed in greater detail in a later subsection.

Strategies for reducing power system costs are possible but must be considered early in the system design stage. Application of high efficiency refrigerators in weak-grid or mini-grid settings may present situations where more efficient appliances are beneficial but do not require the power system sizes of an off-grid application (or a solar power system at all). Refrigeration applications that can tolerate slightly higher cabinet temperatures (target cooling temperatures higher than 4 – 5°C) would require smaller power systems, but may not be feasible/safe for some applications (i.e. highly perishable goods).

Figure 4.3. Relative cost breakdowns for the average refrigeration system in each type category assuming reference conditions. Component fractions represent the average across individual refrigeration systems in each category.

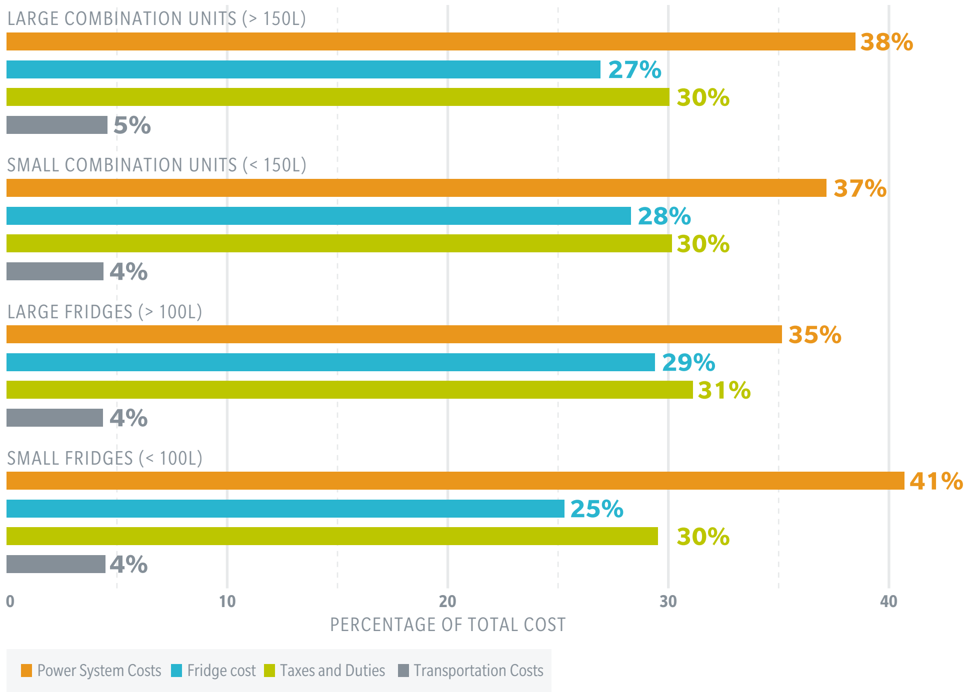
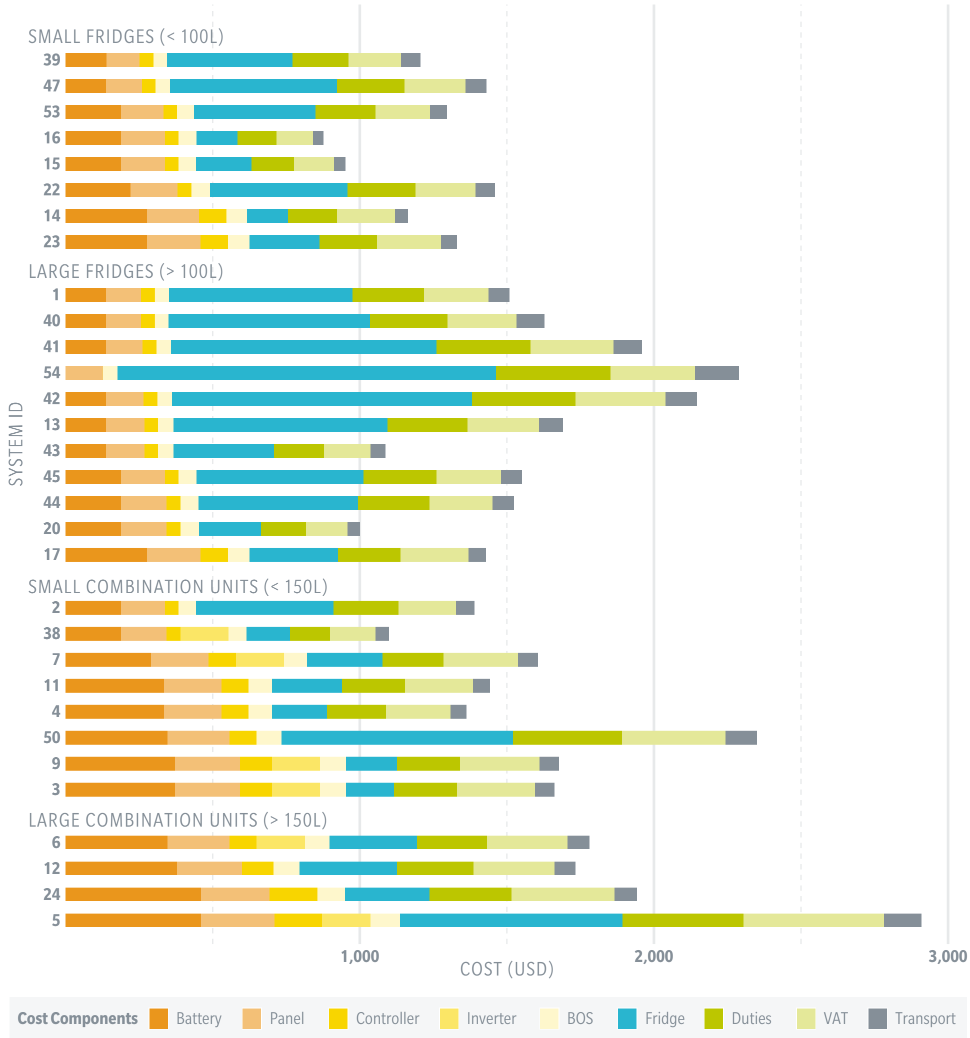


Figure 4.4. Individual system costs and breakdowns for refrigerators tested as part of the Global LEAP Competition, assuming reference conditions.



4.3.2 Cost Breakdowns – India

India is a unique market in that some refrigerator appliances are manufactured in-country, and so are not subject to import duties. For comparison, Figure 4.5 shows average cost breakdowns of refrigeration systems by size category and configuration, modelled for a region in India[8]. The figure differentiates between systems assembled with refrigerators manufactured in India, and those manufactured (and imported) from elsewhere. Taxes and duties account for 19 – 27% of total system cost on average, which is about 5 – 10% less than for the same system in Kenya. These estimates take into account differences in the duty rates on all system components, including pieces of the power system and the refrigerator unit itself. It is worth noting that several units were removed from analysis as lab testing indicated that they would not be capable of maintaining the setpoint temperature at an ambient temperature of 30°C.

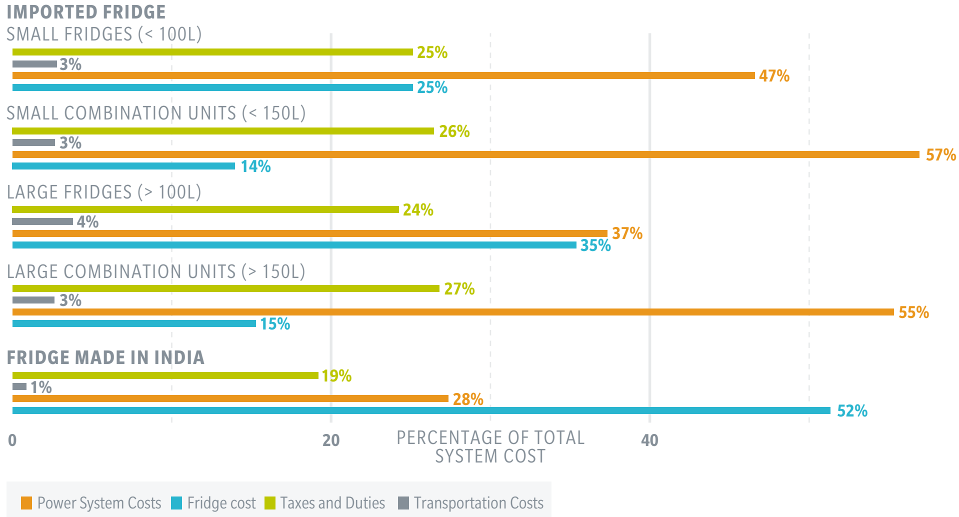


Figure 4.5. Relative cost breakdowns for the average refrigeration system in each type category for systems in India. Reference use case conditions apply. Component fractions represent the average across individual refrigeration systems in each category.

4.4 Refrigerator Size and Configuration

Refrigeration system costs are heavily driven by power system components. Refrigerator appliances with two compartments – refrigerator and freezer – are not necessarily more expensive than refrigerator-only devices, but they do require significantly more power on average. This is due to a combination of the additional energy required to keep the freezer compartment at the setpoint temperature and efficiency losses from the upright cabinet orientation relative to the chest designs.

Figure 4.6 shows the contribution of the power system to total system cost in relative (%) and absolute (USD) terms. Variation in the power system resilience reflects design modifications arising from the way the system is operated and its implications on power demand. The resilience of a system is a measure of how well a system can "cope" with deviations from what was assumed to be "typical" usage during the design phase. Factors that increased resilience might protect against include behavioural (larger cooling loads) and environmental (solar resource, high temperatures) conditions. As it relates to use cases, a system that is having to cool products more frequently (higher turnover of products) might benefit from more power system resilience.

[8] 30°C average temp, 4.95 full sun hours (consistent with Lucknow in June). Use case characteristics same as base scenario. Any unit that would be unable to meet setpoint temp based on lab testing at the given average environmental temp is dropped as it is assumed that it would not provide adequate service in-field.

Within each refrigerator type there is a large degree of variation in cost, even after grouping by size, reflecting the variability in refrigerator efficiencies (e.g. less efficient systems need larger power systems and vice versa). Regardless, relative contributions show that even under a minimum resilience setup, the power system is a major cost component of an off-grid refrigeration system, often accounting for roughly half of the system cost, but no less than one third for a given appliance tested. Power system costs are heavily driven by the refrigerator type – specifically if it has a freezer – and to a lesser extent cabinet volume and the assumed level of power system resilience.

Resource and awareness campaigns that help educate consumers and retailers/distributors on trade-offs between different refrigerator designs and assist in "right sizing" designs for service needs may help reduce consumer risk. For some use cases less sensitive to temperature and spoilage, designing for cabinet temperatures that are still cooler than ambient but not as low as 4°C may be one mechanism for reducing overall system cost.

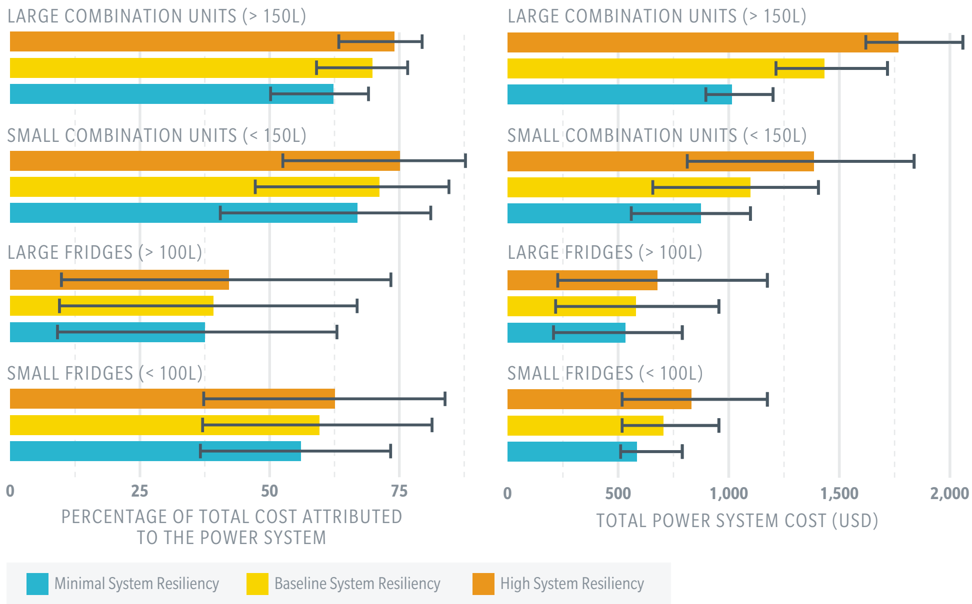


Figure 4.6. Average power system contribution to cost in relative (top) and absolute (bottom) terms assuming resilience levels of the power system. Error bars correspond to the maximum and minimum in each product group. All influential factors except those related to solar array overate (degree to which solar array is oversized) and days of autonomy are the same across resilience levels. The resilience levels are defined as follows: Minimal (solar array overate factor = 1.0; days of autonomy = 1), Baseline (1.2, 2 days), High (1.4, 3 days). Note: Kenya does not tax some power system components, which effectively reduces the cost contribution of the power system, all else being constant.

4.5 Taxes and Duties

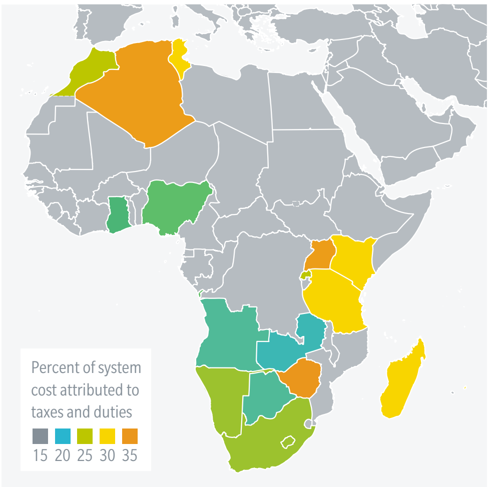
Import duties and taxes can represent between 24 – 33% of total system cost, accounting for more than a quarter of the total cost in all but 1 modelled unit. 57% of modelled units had tariff costs (all components) greater than the refrigerator unit under our reference condition assumptions. In many key markets, refrigerators are classified as luxury goods upon import and are thus taxed at relatively high rates. Power system component are also taxed, but often at a lower rate than the refrigerator. In many African markets, solar panels, and controllers are duty free, although batteries remain taxable. It is important to note that the large difference in the level to which these two system components are taxed could hamper efforts to promote and encourage the use of more efficient appliances. This underscores the need to complement logistical strategies to reduce exposure to duties (e.g. in country assembly) with policy-level efforts that help address institutional barriers affecting refrigeration and, potentially, other appliances supported under the LEIA initiative.

Figure 4.7 shows the percent of system upfront cost due to import duties. This can also be interpreted as the maximum achievable reductions in total system upfront cost possible through mechanisms that alleviate import duties on system components (refrigerator and power components). Note that not all countries are shown due to missing data on local sales tax and VAT[9]. Appendix figures show the contribution of duties and taxes to total system cost (Figure B.1) and international freight (Figure B.2).

Figure 4.8 panels show African import duties for compressor refrigerators, upright refrigerators and freezer combos, and compressor refrigerator parts. The figure highlights the relatively high rates across most of Africa for different refrigeration classifications. Figure 4.9 panel shows the difference in rates between assembled units and parts for compressor refrigerators.

Local assembly may be a near-term strategy for reducing system upfront costs and establishing local technical capacity for after-sales service. In Kenya, for example, a compressor style refrigerator fully assembled is taxed at 25% upon arrival, while equipment for a compressor refrigerator is taxed at 8%. While promising, deeper dive assessments are needed to test the economics of such a logistical shift. Factors that might be considered include identifying in which countries such an approach would work, the cost of local assembly and storage, and access to materials required to complete assembly. This might include, for example, a cost benefit analysis of the factors and costs of production at the current point of origin vis a vis a newly established local assembly facility.

Figure 4.7. Percent of total system cost attributed to taxes and duties for the same system in 17 countries in Africa. Environmental conditions are assumed to be constant across all areas for comparability. Countries in grey were not modelled due to missing or incomplete data on VAT/sales tax rates.



[9] Addressing these gaps is feasible would require a country-by-country review. Given the timeframe of this study this effort was not undertaken as part of Phase 1 work.

Figure 4.8. Import duty rates for compressor refrigerators, upright refrigerator and freezer units, and compressor refrigerator parts for African countries. Greyed countries indicate that there was no data available. For an importing country, tariff rates for refrigerator commodities may differ across individual trade partners. Import rates are weighted based on the value of refrigerator commodities coming from individual partner countries.

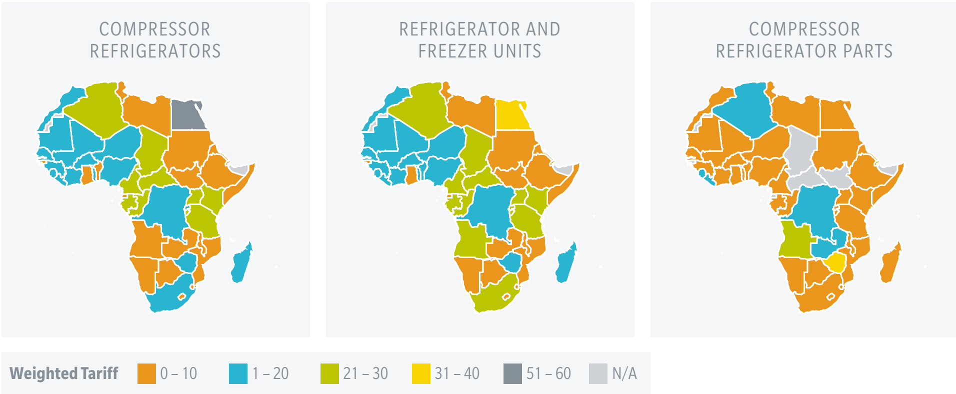
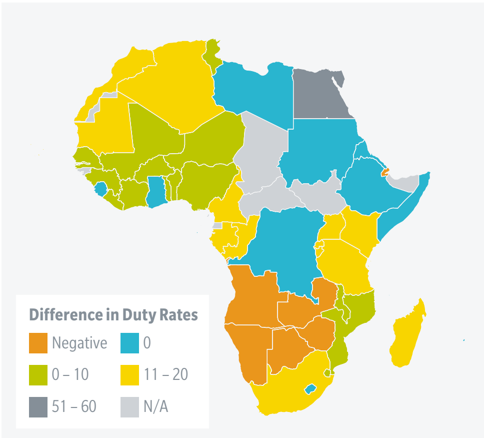


Figure 4.9. Percentage point difference in import duty rates between compressor refrigerators (841821) and compressor refrigerator equipment (841861). Countries in yellow indicate that equipment is taxed at a higher rate than a fully assembled refrigerator. Countries in grey do not have a specified duty rate for refrigerator equipment so are not calculated.



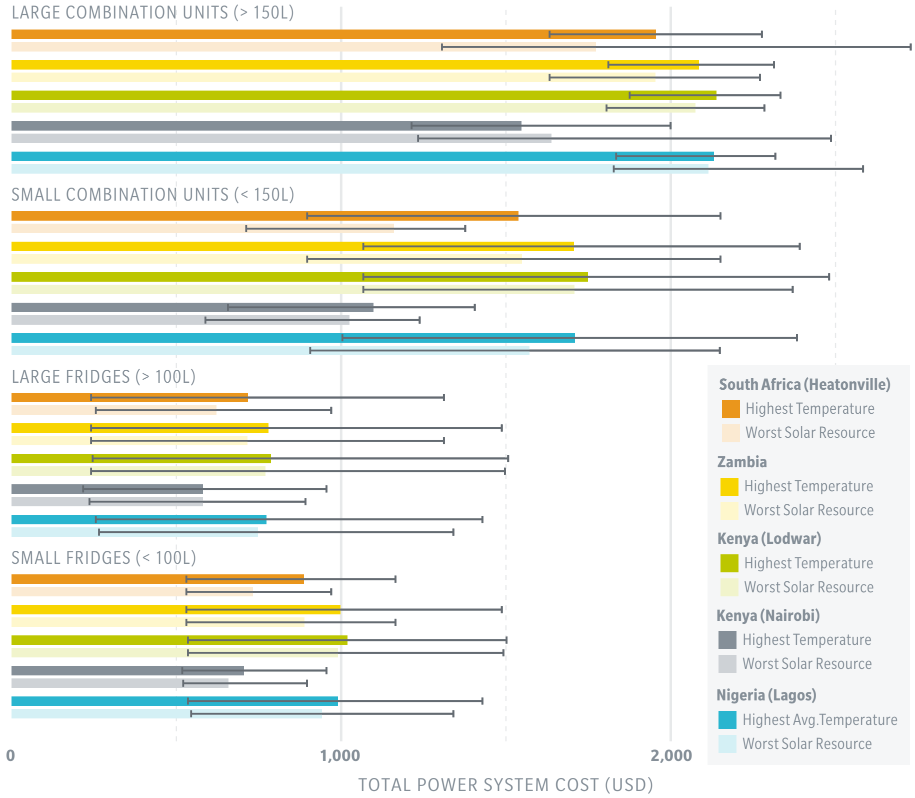
4.6 Environmental Factors

Environmental factors affect system performance and design but are not considered potential levers for cost savings. Assessing how these factors affect system design and cost, however, does help inform whether specific systems are 'market-ready' with respect to price and performance capabilities.

Several environmental factors can affect refrigeration system design and cost. Ambient temperature affects how long the compressor must run to maintain cabinet steady state temperature, affecting power system design and even appliance selection. The same refrigerator operated identically in a warmer climate will consume more energy to maintain the same cabinet temperature. In extremely hot conditions, some refrigerators may be unable to achieve setpoint temperatures, which can increase the risk of compressor failure. Based on lab tests conducted as part of the Global LEAP refrigerator awards competitions, several refrigerators were unable to achieve/maintain temperature set points when ambient temperatures were in excess of 32°C, for example. The solar resource in an area can affect energy generation and storage potential, and so it will also affect system cost through its effects on the power system design.

Figure 4.10 shows the estimated cost for systems designed for the month with the worst solar resource or highest ambient temperature, on average. When designing power systems, it is often common practice to design around the period of the year with the worst solar resources. An alternative approach for refrigeration, however, is to size the system to accommodate cooling during the warmest season of the year (i.e. when the refrigerator will need to work the hardest to maintain setpoint temperature). In all instances, designing for the warmest ambient temperature yielded a system that is more expensive. This reflects the need for more energy storage to allow the refrigerator to run its compressor longer/more frequently.

Figure 4.10. Total power system cost for selected geographies considering effects of temperature and solar resource. Error bars correspond to the minimum and maximum of individual units within each refrigerator category. Assumes reference condition usage characteristics.



4.7 Use Case

User interaction with a refrigerator influences system performance, but to varying degrees depending on its use case. In a retail setting, the refrigerator typically needs to accommodate larger cooling loads due to more frequent turnover of refrigerator contents than a domestic use case, for example. These behavioural factors have been suggested as a key reason why energy consumption estimates based on lab testing are generally lower than what is measured in-field under actual usage conditions[10]. Specifically, a major reason noted for differences between lab and field estimates of energy requirements is the frequency of door openings and loading[11].

Figure 4.11 shows a breakdown of daily energy requirement for different aspects of operation. Most of the energy is used to maintain temperature, but characteristics of the cooling load also play an important role, even under modest loading assumptions. Figure 4.11 illustrates the effect of varying the cooling load on power system costs. Doubling the baseline cooling load results in only a small (15% average) difference in daily energy requirement, translating to only modest effects on overall system price (0.5% – 17%).

[10] See Abagi, Nyamolo, et al. "State of play and innovations in off-grid refrigeration technology: lessons learned from current initiatives." Energy Efficiency (2019): 1 – 16.

[11] User surveys conducted as part of Global LEAP have also suggested that some refrigerators are unplugged for parts of the day, potentially leading to increased energy consumption.

However, the assumptions for loading are based on lab-based tests that are relatively new and should be refined based on field-based observation and assessment.

Figure 4.11. Daily energy requirements assuming reference conditions. Error bars correspond to uncertainty of required energy for cooling contents (red component).

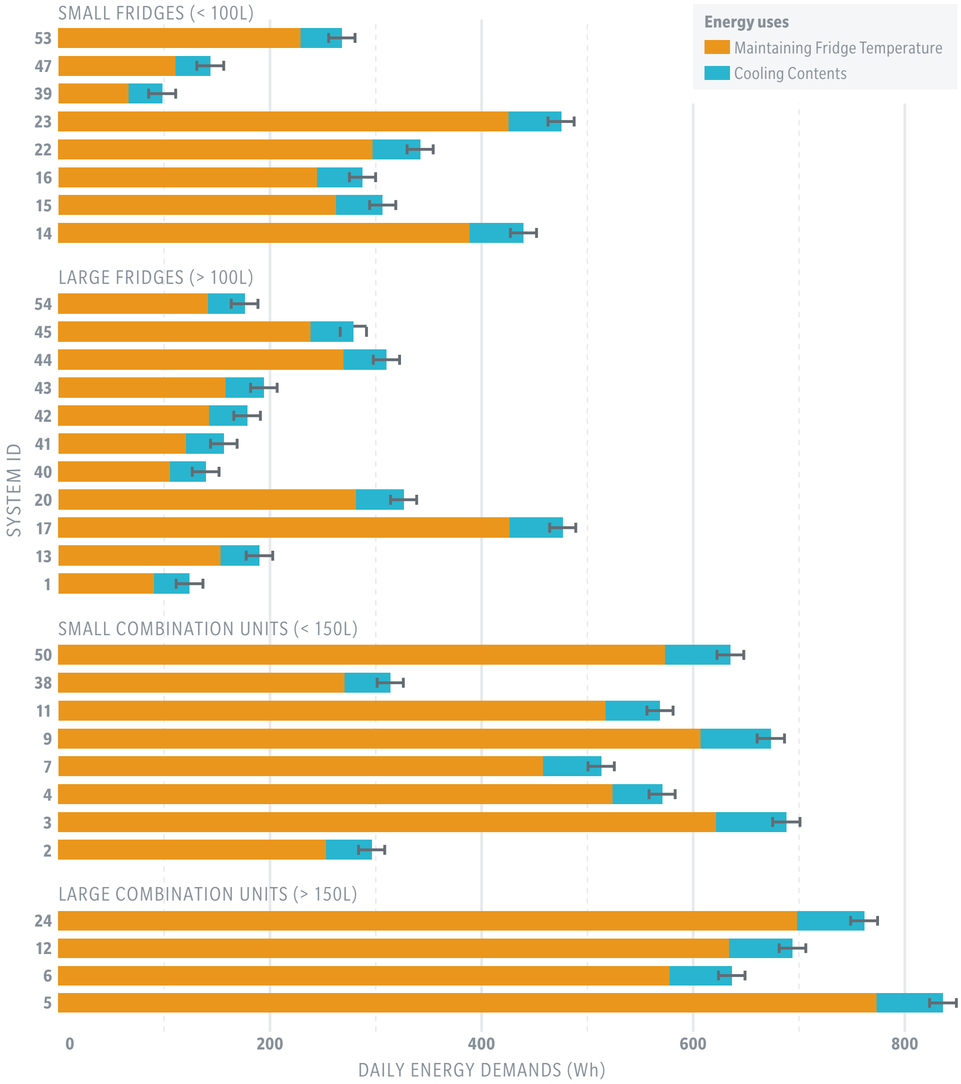
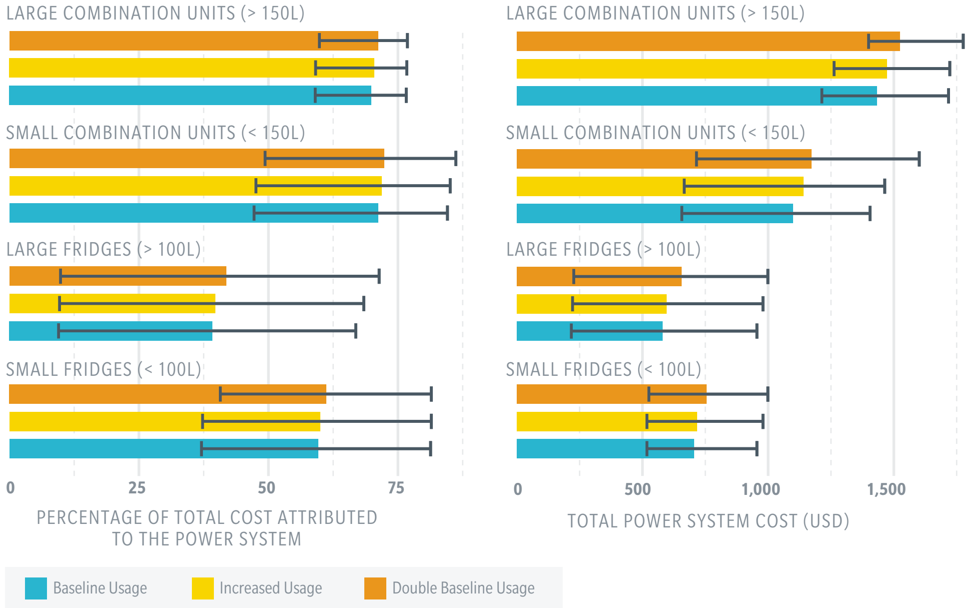


Figure 4.12. Contribution of power system cost in relative and absolute terms assuming various loading conditions of the refrigerator. Estimates are for drink chilling and apply reference conditions for all other assumptions.



4.8 Conclusions: Cost Model

The total cost of a refrigeration system includes not only of the refrigerator unit (appliance), but also the power system and costs associated with importation and retailing. To help identify opportunities for improving affordability of refrigeration, a cost model was developed to break down the cost of a refrigeration system, accounting for local market factors.

Results from these cost breakdowns revealed that only around one third of the total system cost was attributed to the refrigerator appliance. Under reference conditions, more than half (60%) of the refrigerator systems modelled had combined component tariffs that were greater than the refrigerator appliance itself. The high import duties applied to refrigerators in many countries, coupled with relatively low power system component costs and duties, can result in situations where the most affordable system is not one with the most efficient refrigerator.

Despite the historically low costs of solar, the power system can still account for more than one third of the total system cost. Strategies for reducing power systems begin at the appliance selection stage, given that large degree of variation in energy required to run systems of different sizes and configurations.

User behaviour is a potentially important factor affecting system performance. Although there is some evidence to suggest that systems in-field consume upwards of twice the amount of energy than is estimated from lab tests, there is still relatively little evidence about the relationship between appliance interaction and system performance. Considering the limited evidence about the productive benefits of refrigeration – a critical aspect of affordability – these gaps in user knowledge emphasise the critical need for well-designed field assessments and pilot studies in key markets and use applications.

05 Recommendations

Based on updates to the use case segmentation map, discussions with stakeholders, cost model development, and model results, we provide several recommendations for informing future LEIA efforts. These activities would help address critical knowledge gaps affecting the sector's understanding of the viability of refrigeration in specific use cases and markets.

In-field evaluations of refrigerator usage, performance, and productive benefit in specific use cases and key markets.

There is a lack of robust in-field data with which to assess or validate the viability of off-grid refrigeration in key use cases and markets. High priority issues to be addressed as part of these programmes include:

1. Productive potential and determinants of productive benefit.
2. Risk landscapes (ecosystem factors affecting productive potential).
3. Customer preferences, needs, usage characteristics; implications on system performance.
4. In-field performance of refrigeration systems to inform updates to laboratory test procedures.
5. Long-term performance and user experience (enrolment of customer cohort).
6. In-country value chain cost components.
7. Willingness and ability to pay.

Development of a framework (guidance document) describing best practices for field study design and reporting procedures.

Evidence on the productive benefit of refrigeration in off- and weak-grid areas and other aspects of viability is limited, and the quality of available information is varied. Studies reporting changes in income characteristics following refrigerator purchases/procurement exist for several use cases, but measurement approaches and reporting methods are varied, making comparability across studies conducted in different contexts difficult.

A framework that guides in the design and reporting of field evaluations is needed to ensure that individual studies provide the most value to the sector. This framework can be designed specifically for refrigeration, but close collaboration with other appliance working groups is merited as there is likely to be significant overlap. This framework should consider application of remote monitoring and questionnaire-based instruments and how the resulting data and metrics "flow down" into complementary programme efforts (i.e. lab testing, cost modelling, etc.).

Desk-based studies around the potential cost tradeoffs of near-term strategies for reducing system cost and improving affordability in specific geographies.

While this work helped to identify major cost components affecting the affordability and upfront cost of refrigeration systems, there remain major information gaps in local market (i.e. national and subnational levels). Significant steps can be made to address these gaps in the near term that do not require major field activities, but would still help distributors identify and prioritise areas to scale efforts.

These activities include:

- Estimating the costs and trade-offs associated with in-country assembly of refrigeration systems.
- Examinations into potential policy levers that could help reduce duty and VAT in all major markets.
- Improved estimates of in-country mark-ups and transportation costs.

Application of cost model analyses for other appliances under the LEIA initiative.

The results from the current study demonstrate the potential value of understanding the contribution of all steps along the value chain.

Pilot Studies that examine refrigeration in the context of weak-grid and minigrid settings.

Power system costs were a significant cost component of off-grid refrigeration systems. Applications where efficiency may be valued but do not necessarily require sizing of the power system for an off-grid application may reduce this cost component.

A Annex A: Cost Model Methods

The cost model framework is designed to output the capital cost of a refrigeration system accounting for local conditions and factors that affect the performance and price of components. Energy demands of the fridge are estimated based on characteristics of the contents being cooled and their quantity. Next, we specify the requirements of the solar power system. Finally, these power system specifications are used to estimate the cost of the power system components. Another key component of this model is the estimation of country specific costs, these costs include: Value Added Taxes (VAT), duties and international transportation. These are estimated based on the pre-tax and transport costs of each of the components combined with detailed country, partner and HS code level data bases of duties rates and transport margins as well as country specific VAT rates. The database of fridges used in the model currently are the contestant products in the 2017 Global LEAP Off-Grid Refrigeration Competition. However, the model is flexible to accept additional fridge data.

Required Energy Needs

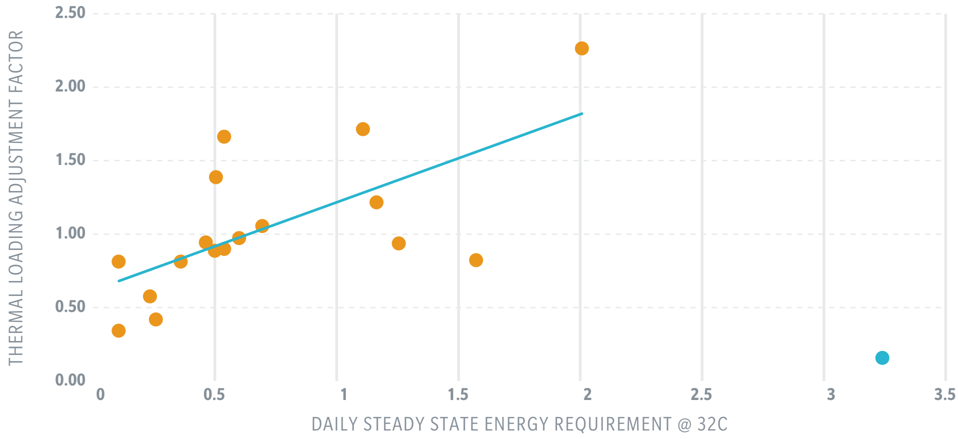
The energy needs of a fridge can be thought of in two parts: (1) the energy needed to keep the fridge at a given temperature under steady state conditions and (2) the energy required to cool items.

Energy needed to keep the fridge at temperature under steady state conditions (i.e. without opening the door or cooling additional food stuffs) was estimated based on lab measurements performed as part of the Global LEAP Off-Grid Refrigerator Competition. Results from these tests are reported in units of energy per day at three different ambient temperatures (16, 32 and 43°C), all with a consistent interior temperature of 5°C in the fresh food compartment. For cost modelling, we interpolate results between these ambient temperatures to estimate performance at temperatures between 16 and 43°C. Some of the fridges that were tested and included in the cost model were not able to achieve the desired interior temperature of 5°C at or above 32°C. We assume these products are not suitable for any ambient temperature above the highest successful test as part of the cost model.

The second part of the fridge's energy demand is energy required to cool food items that are put in the fridge. We utilise data from a load processing test preformed on 19 of the fridges in the 2018 Global Leap Competition to develop a relationship between the heat energy removed from the food items and the electrical energy needed to cool it to cabinet temperature. The load processing test consists of adding a known volume of water at ambient temperature to the refrigerator and calculating the additional electricity (compared to steady state) required to cool the food items and remove heat added by opening and closing the fridge door to add the items. We apply results from these tests to estimate a ratio between electrical energy demand and thermal energy removed from food items, for each refrigerator unit. We refer to this ratio as the thermal loading adjustment factor (TLAF).

Thermal loading adjustment factors varied by several times between products, ranging from 0.42 to 2.26. Most of the products had a factor just less than 1. TLAF was found to be highly correlated with refrigerator steady state energy demand, as shown in Figure A.1.

Figure A.1. Relationship between thermal loading adjustment factor and daily steady state energy demand. The blue point was removed from analysis.



In order to estimate the daily energy required for cooling food, we apply specific heats of various food items and the thermal mass of the item being cooled. A database of the specific heat value of various foods (kj/kg-K) was assembled as part of this project. Once the mass (and type) of food stuff to be cooled is determined, the temperature change (ambient temperature minus cabinet temperature) and specific heat can be used to determine the heat energy to be removed from the food. The thermal load adjustment factor described previously was used to convert this thermal energy change to an electrical energy demand.

The benefit of splitting the energy needs into these two parts is that it allows estimation of fridge energy demand under a wide variety of conditions and use cases. By understanding the energy need associated with cooling thermal mass (food placed in the fridge) we can estimate the additional energy needs associated with increased usage of the fridge and types of products being cooled, both as characteristics of a use case. By understanding the relation between steady state energy needs and ambient temperatures, we can estimate the effects of climate on the energy needs of the fridge.

Power System Specifications

Energy needs of the refrigeration system are used to inform specifications of a corresponding solar power system. This power system consists of solar panel, battery, charge controller and an inverter (AC units only).

The following equation describes the relationship between generated energy from an appropriately sized solar panel (left hand side) and demanded energy including safety factors (right hand side). This relation is used to calculate the minimum required rating (Wp) of solar panel needed to power the fridge.

$$(N_{sys} * PV_{wp} * FShr) \geq Sf_{gc} (RD_{dmd})$$

Where:		
N_{sys}	is the net system efficiency	60% (ESMAP 2015)
PV_{wp}	is the peak power rating of the solar array	Wp
FS_{hr}	is the number of full sun equivalent hours available	hours
SF_{gc}	is the safety factor for daily generation capacity	1.2 (assumed)
RD_{dmd}	is the daily energy demand of the fridge	Wh

The battery size is specified based on the watt-hours of energy storage provided. The following equations describes the relationship between the usable energy storage provided by the battery (right hand side) and the required energy storage (left hand side). Two constraints are used so two equations are presented here. The first constraint is based on the assumed days of autonomy for the fridge and the second is a constraint which ensures that if all of the food that would be consumed for a given number of days (assumed to be 7) to be placed in the fridge at once, the battery would be able to provide the necessary energy to cool the food to 5°C.

$$B_{wh} * DOD \geq DE_{wh} * DA$$

$$B_{wh} * DOD \geq FCE_{wh} * DFC$$

Where:		
B_{wh}	is the total storage capacity of the battery	Wh
DOD	is the allowable depth of discharge	0.70 (Szabó et. Al 2011)
DE_{wh}	is the total daily energy requirement of the fridge	Wh
FCE_{wh}	is the daily energy requirement to cool food stuffs	Wh
DA	is the specified days of autonomy	2 days (assumed)
DFC	is the specified days of food cooling required	7 days (assumed)

The charge controller is sized based on its allowable DC power input. As the DC power input to the charge controller comes from the solar panel, we constrain the size of the charge controller to be greater to or equal to the peak wattage of the solar panel.

The inverter is sized based on the rated continuous power draw. We specify that the inverter must be rated to supply continuous power equal to or greater than the measured power draw of the refrigerators compressor. Inverters are only specified for fridges which only accept AC power.

Additional Constraints and Considerations

A few additional constraints are used to ensure that the fridge itself is able to meet the needs of the end use and ensure that the cost of the power system is approximated robustly.

The first constraint affects food cooling capability of the fridge. Due to having small or undersized vapour compression refrigeration systems, it is possible that a fridge would not be able to cool the daily thermal mass in a reasonable amount of time. To ensure that the fridge is capable of cooling the daily thermal mass "quickly", we estimate the amount of time that would be required for this cooling. This is estimated using the following equation. If this cooling time is greater than the specified acceptable (default of four hours) cooling time the fridge is not considered to be acceptable for the use case.

$$CT = \frac{DE_{wh}\left(\frac{CT}{24}\right) DFC * TLAF}{WC}$$

Where:		
CT	is the time required to cool 1-day worth of food stuffs	hrs
TLAF	Is the thermal loading adjustment factor	Unitless
WC	Is the measured draw of the fridge compressor	W

Another constraint which was placed on the power system components is that the size specified has been observed in the market data. This constraint is applied to ensure that the cost of power system components are estimated from available products on the open market by preventing specification of component ratings that would not be available to purchase. This discretisation constraint also means that in some cases no one battery or solar panel is sufficient to meet the energy needs of the system meaning that multiple components are needed (i.e. if 400w of solar is needed two 200w panels could be specified)

Another consideration is the cost of small parts and wiring needed to complete the power system. This is commonly referred to as the Balance of System cost (BOS). For our purposes it is estimated to be 40% of the cost of the PV modules (Szabó et.al. 2011).

Component Costs

To estimate the cost of each of the components in the solar power system we utilise linear models based on the same attribute for which we specify the sizing. In this section we will cover how pre-tax, transportation and duties costs are estimated and show the resulting linear models. Cost data for these models was gathered from four online retailers: Mangoo Market Place, Wholesale Solar, EcoDirect and Solaroid Energy.

Three key data sets were used to estimate the country specific costs: taxes, duties and transportation. The first estimates transport margins based on real data from participating countries and a wide variety of explanatory variables.

This was gathered from OECD, more information can be found in their publication[12]. The transport margin represents the percentage of the cost which is attributed to international transportation. This data set is disaggregated by a 4-digit HS code, reporter country (importing) and partner country (exporting). The second data set reports duties in terms of percentage of product value and is disaggregated by 6-digit HS code partner and reporter[13]. The third data set simply reports VAT rates for individual countries[14].

For estimating the FOB price of a power system component the following steps are taken:

- Retail costs and performance specifications for many products are gathered (scraped) from web sources.
- The VAT costs are subtracted using the appropriate VAT rate.
- Duties are subtracted.
- Transportation costs are subtracted.

This results in a cost the is representative of the FOB price plus the margin taken by an online distributor, so is not a pure FOB. These calculated prices are then used to generate linear models which relate price to performance metrics and used as inputs to the cost model. Within the cost model, each of the country specific costs for the market in question are added back to the price predicted by the linear model. In this way our model is able to estimate costs for systems under different market conditions.

For the solar power systems, we do not have specific data on the country of origin so we assume that they are covered under general duty schemes; in most cases countries only have a few partner countries which have duty free trade exemptions and all other countries are covered under the general duty rates. For the estimation of shipping costs, we assume that they are being manufactured in China.

The fridges themselves use the same methodology as the power system components in terms of removing country specific costs then re-applying the correct country specific costs. A key difference is that we do not utilise a linear model to estimate the average cost, as we report the capital cost of purchasing each individual fridge based on product-specific data. Another key difference is that we know the country of origin for each fridge, making our initial subtraction of duties and transportation costs more accurate.

We also maintain flexibility to account for locally specific price increases. That is to say that most end users will likely pay more for their product than it is advertised for on the internet due to a greater number of supply chain steps. As limited data exist to inform this, the current default multiplier is 1.

The following table reports the sample size for each of solar power system component and breaks the sample size down by country. The following figures show the scatter and linear model used for each of the power system components.

12 http://www.oecd.org/sdd/its/Estimating-transport-and-insurance-costs.pdf

13 http://atlas.cid.harvard.edu/data-downloads

14 https://www.ey.com/gl/en/services/tax/worldwide-vat–gst-and-sales-tax-guide-2019–-rates

Table A.1. This table shows the sample size used to develop linear models of cost for each of the power system components as well as the breakdown of countries where the products are sold.

	Panel	Battery	Inverter	Charge Controller
India	18	2	10	8
Mauritius	2	0	0	0
Nigeria	22	35	85	10
Tanzania	11	5	0	10
Ghana	0	0	3	1
South Africa	0	0	2	11
USA	154	146	251	19
Total	**207**	**188**	**351**	**67**

Figure A.2. PV panel linear model.

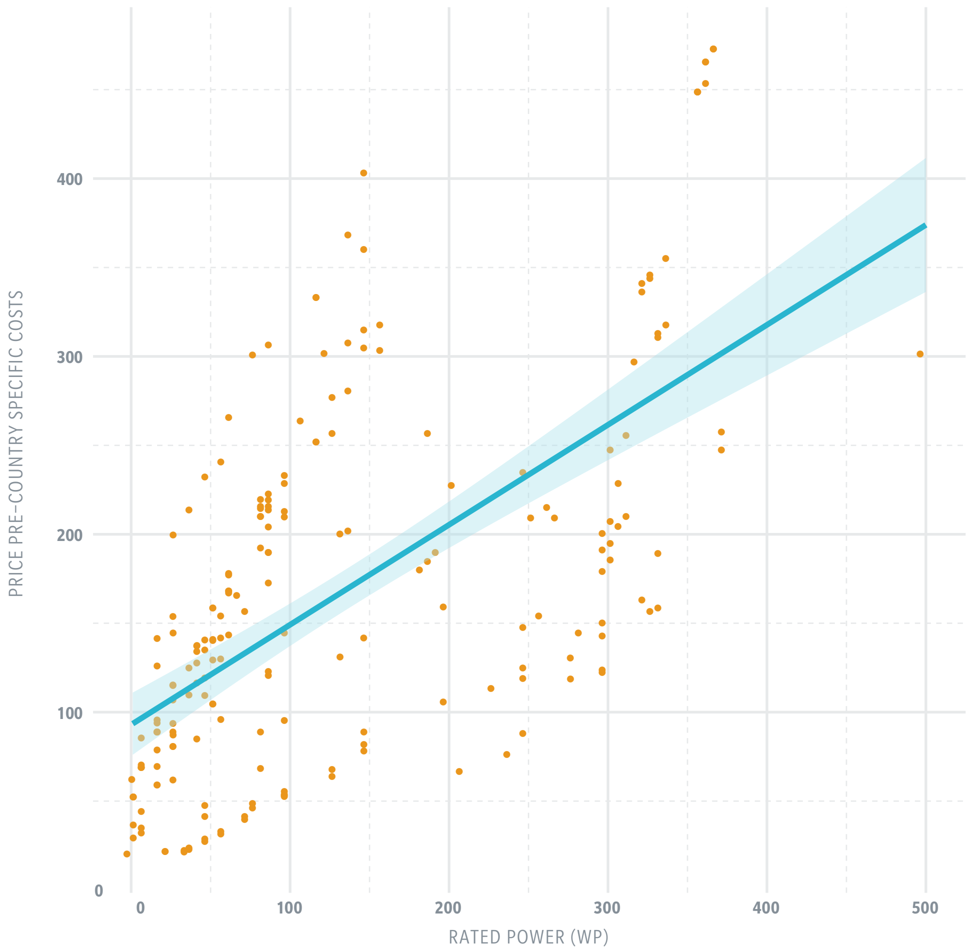


Figure A.3. Lead acid battery linear model.

Figure A.4. Charge controller linear model.

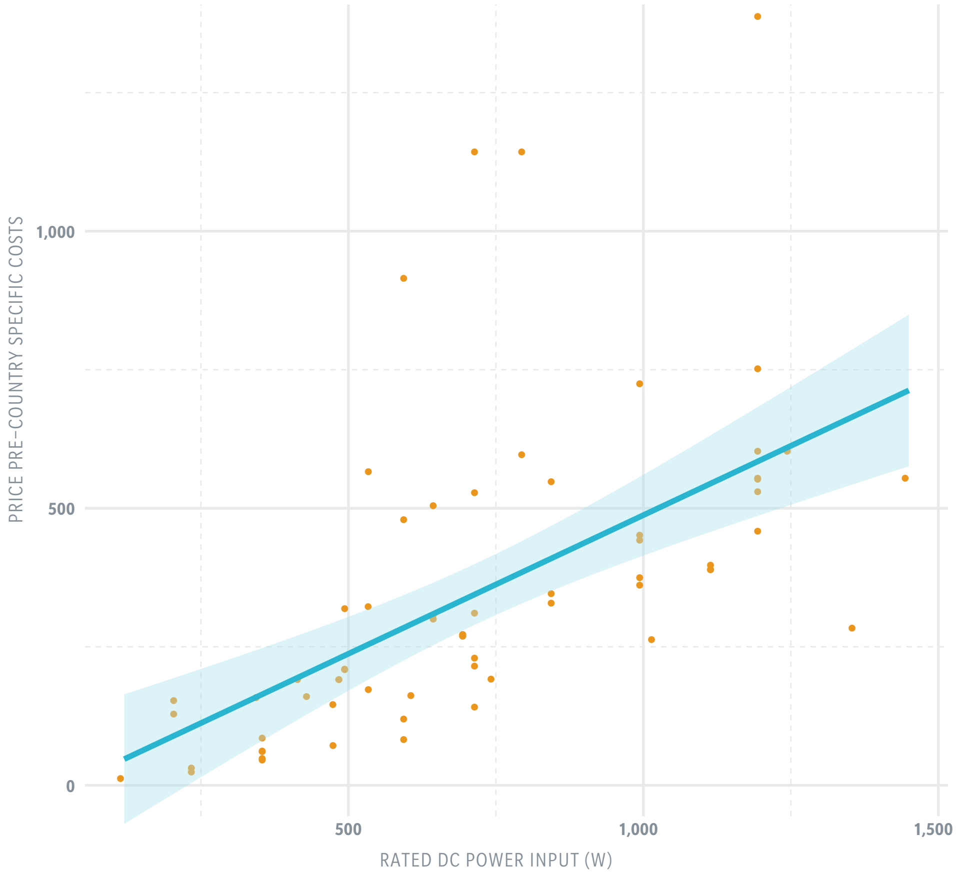
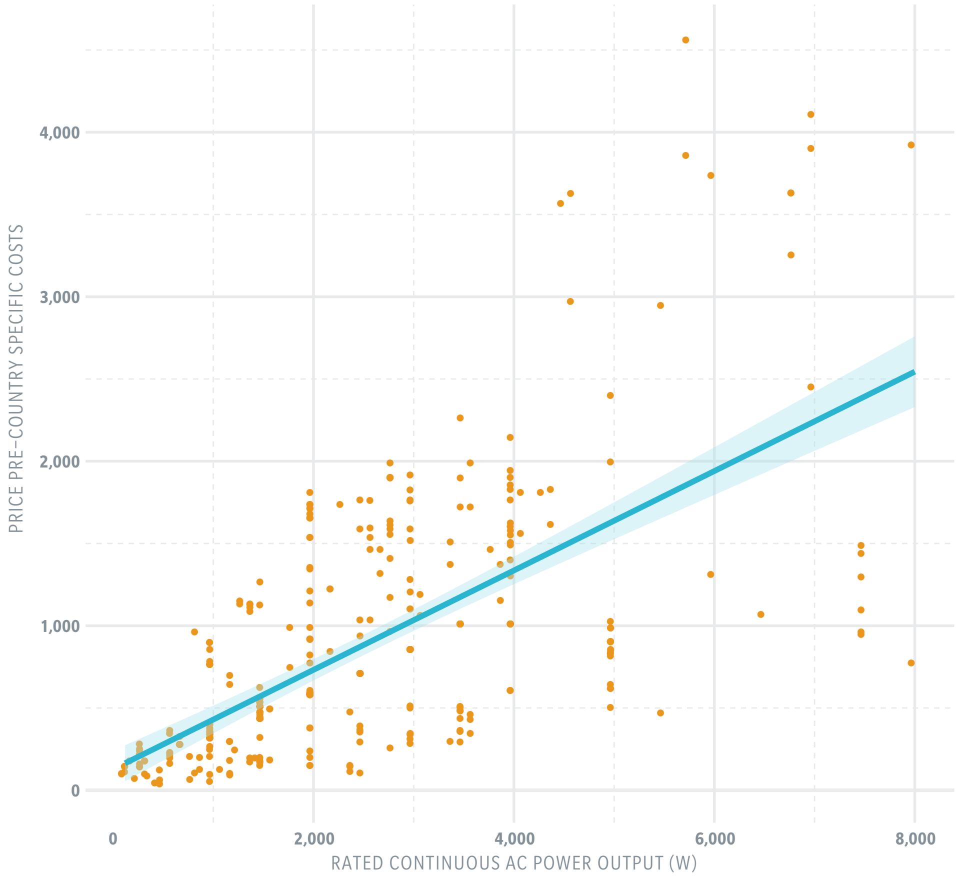


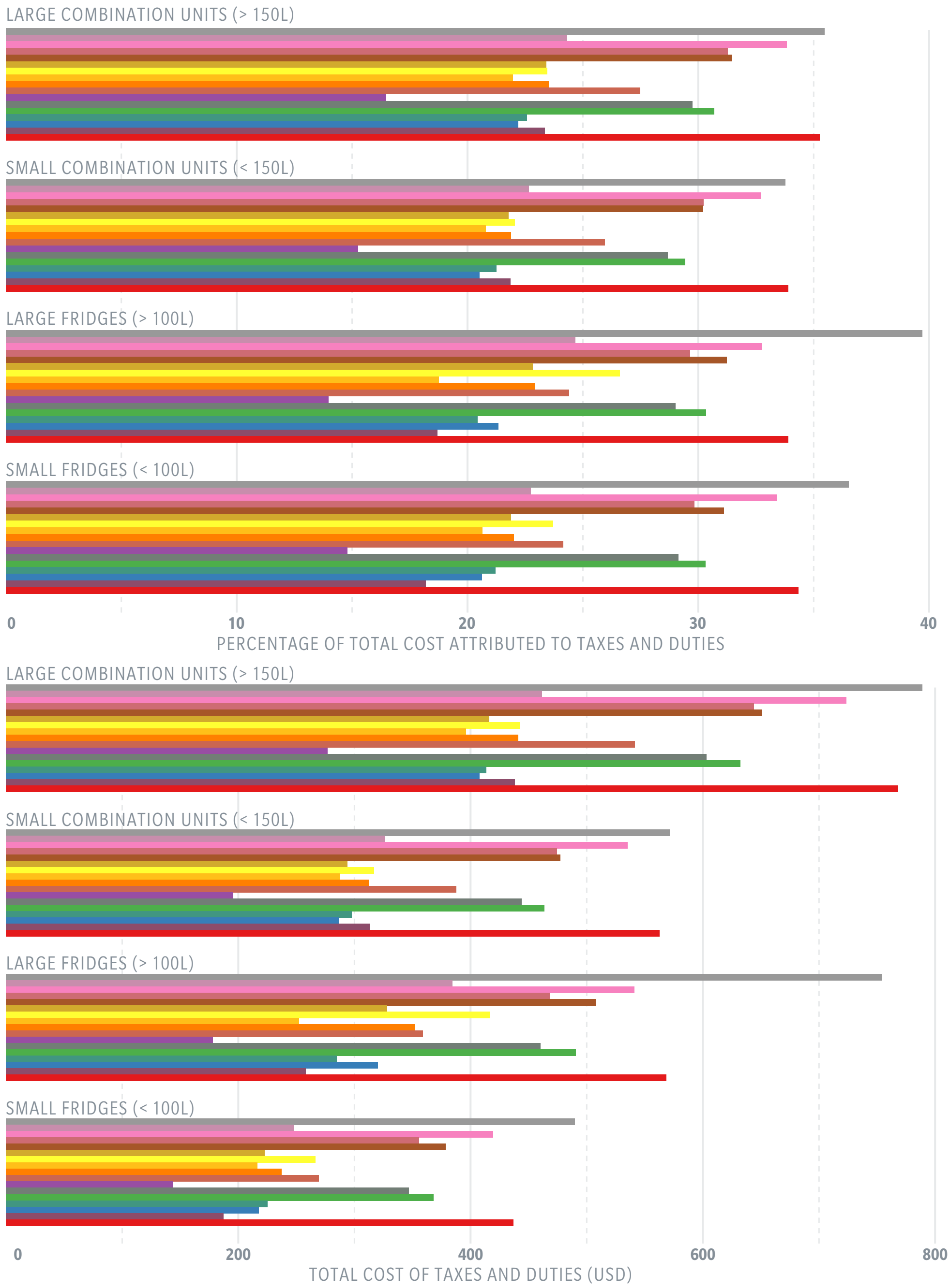
Figure A.5. Inverter linear model.



B Annex B: Additional Figures and Tables

Contributions of duties and VAT to total system cost (A.1), and international freight and transport (A.2) for various countries in Africa, in relative and absolute term.

Figure B.1. Contribution of taxes (VAT) and import duties to system cost in relative (top) and absolute (bottom) terms for 17 countries in Africa. Environmental conditions are assumed fixed across all locations for comparison purposes. Note that the order of bars are reversed from the order they are listed in the legend.



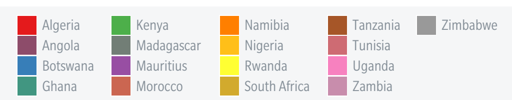


Figure B.2. Contribution of international transport (freight) to total system cost in (top) relative and (bottom) absolute terms. Note that the order of bars are reversed from the order they are listed in the legend.

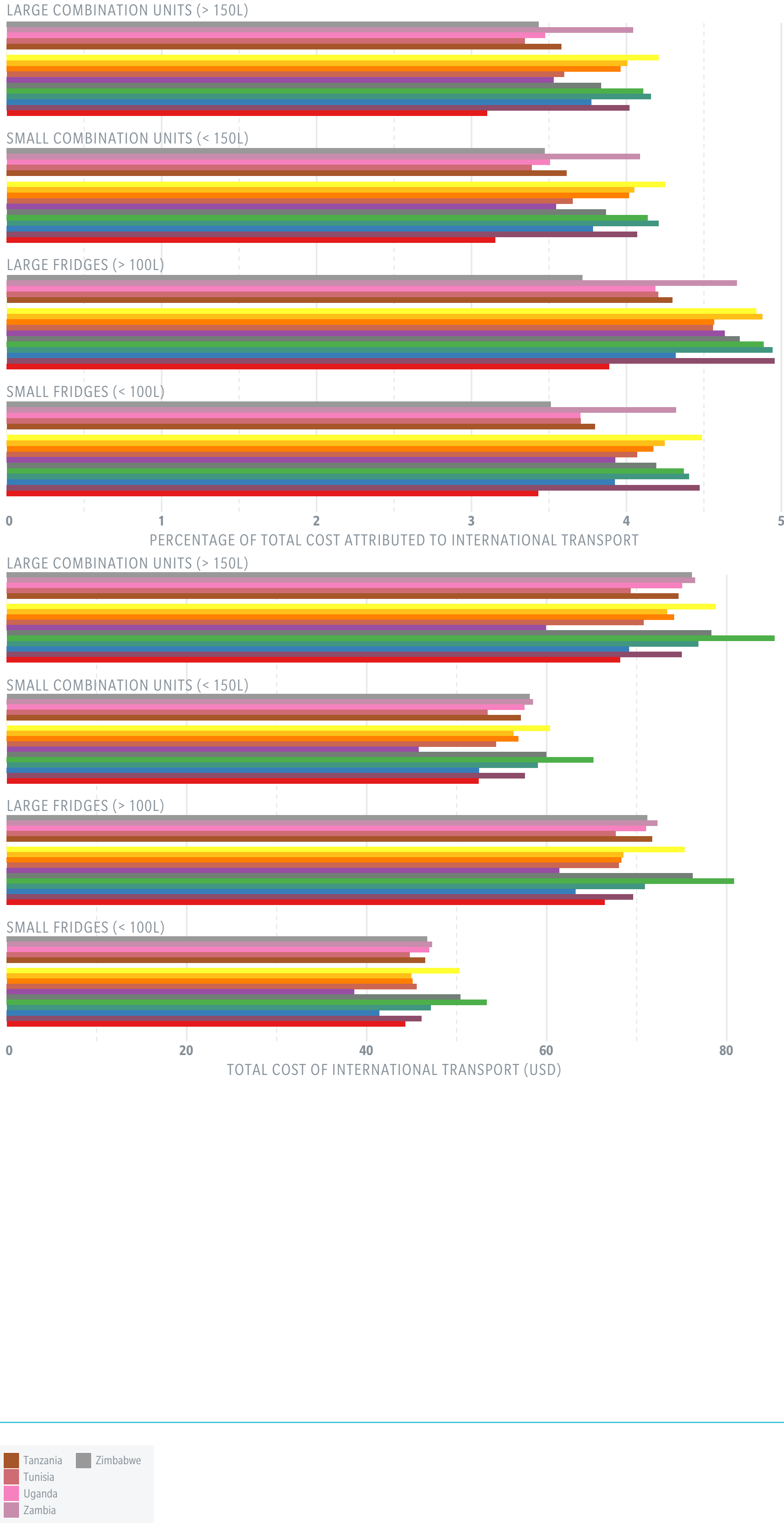


Table B.1. Changes in refrigeration system price under various tariff structures. Values correspond to values underlying Figure 0.3.

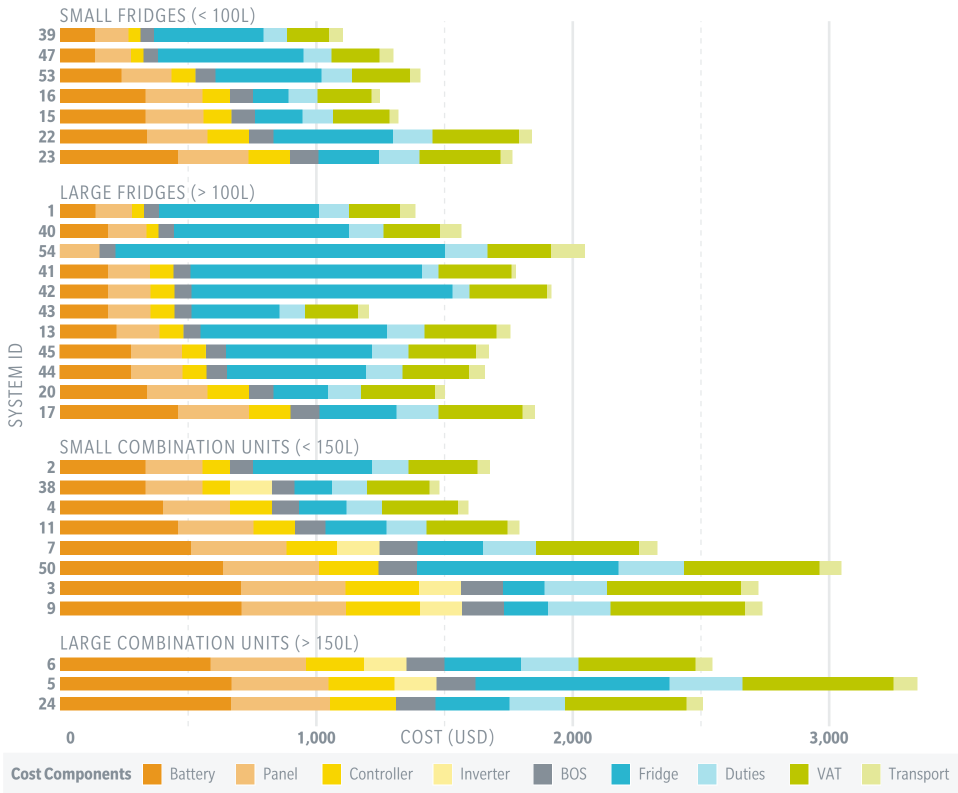
		Change in Cost Relative to "Typical" Situation	
Scenario	**Refrigerator Type**	**USD ($)**	**Percent (%)**
Full Duties and Taxes	Small Fridges (< 100L)	29	3%
Full Duties and Taxes	Large Fridges (> 100L)	26	2%
Full Duties and Taxes	Small Combination Units (< 150L)	49	3%
Full Duties and Taxes	Large Combination Units (> 150L)	60	3%
No Duties and Taxes: All	Small Fridges (< 100L)	-232	-20%
No Duties and Taxes: All	Large Fridges (> 100L)	-354	-23%
No Duties and Taxes: All	Small Combination Units (< 150L)	-260	-17%
No Duties and Taxes: All	Large Combination Units (> 150L)	-370	-19%
No Duties and Taxes: Refrigerator	Small Fridges (< 100L)	-133	-12%
No Duties and Taxes: Refrigerator	Large Fridges (> 100L)	-271	-18%
No Duties and Taxes: Refrigerator	Small Combination Units (< 150L)	-121	-8%
No Duties and Taxes: Refrigerator	Large Combination Units (> 150L)	-167	-8%

C

Annex C: India

Figure C1 presents individual cost breakdowns of refrigeration systems assuming taxes, duties, and transit costs for India. Power system requirements and refrigerator performance are estimated assuming average daily temperatures of 30C and 4.95 full sun hours. These conditions are representative of in Lucknow, Uttar Pradesh in June. This corresponds to the worst system performance conditions of the year in this area, leading to the most robust system design. The selected use-case conditions are identical to those used in the reference condition described in Section 5 of the main report.

Figure C.1. Individual system costs and breakdowns for refrigerator tested as part of the Global LEAP Competition, modelled for the India market.

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