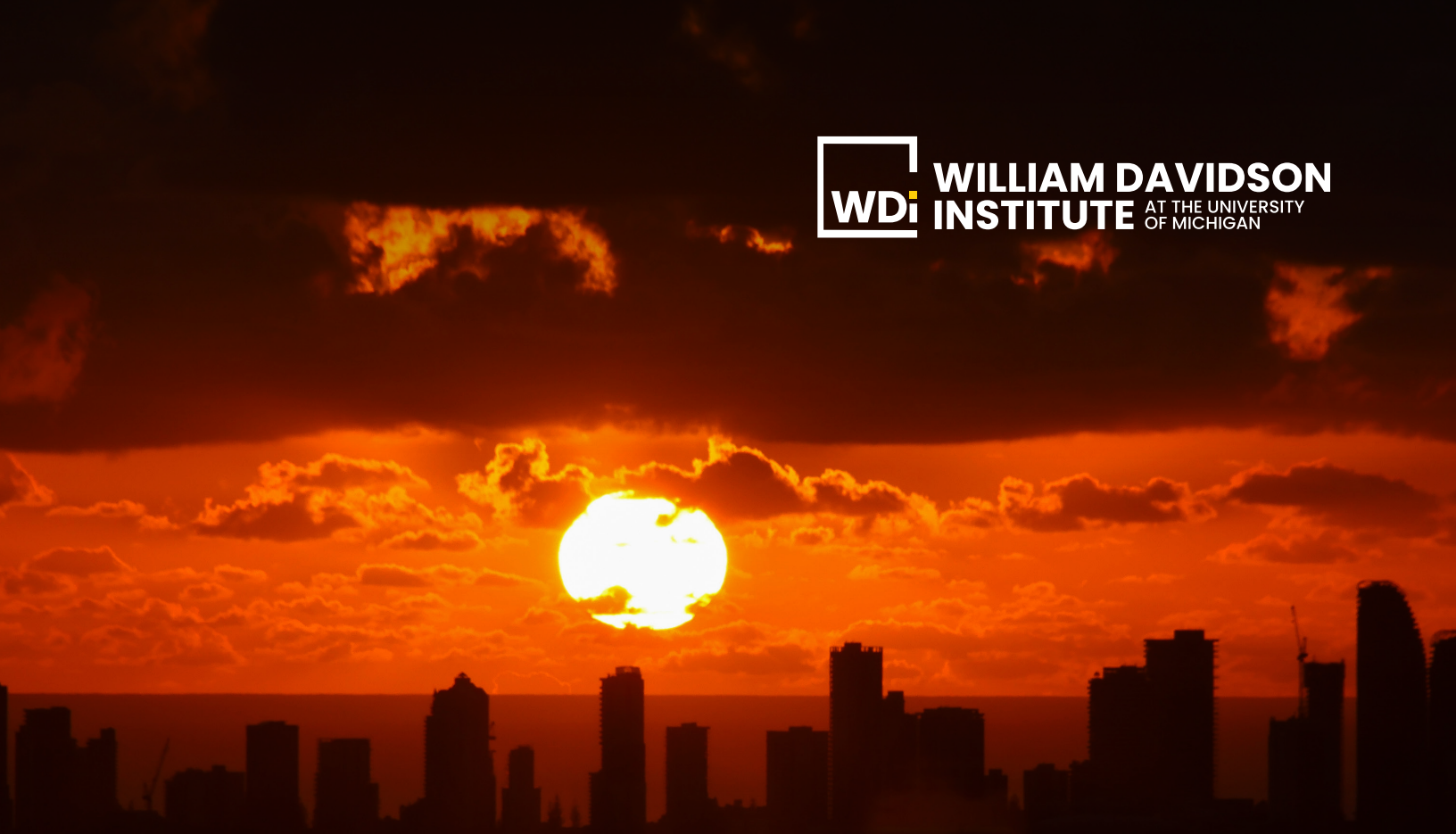

WILLIAM DAVIDSON INSTITUTE AT THE UNIVERSITY OF MICHIGAN

Beyond the Horizon

What off-grid solar and clean cooking can reveal about the road ahead for clean cooling.

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About WDI

The William Davidson Institute is a solutions-driven non-profit affiliated with the University of Michigan. We operate as allies to the change-makers—entrepreneurs, investors, governments, and academia—collaborating to drive pioneering solutions. We serve as a knowledge builder, enterprise accelerator and ecosystem catalyst.

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Contents

Clean cooling is at an inflection point. The need is clear, proof-of-concept technologies exist, and the market is forming. The decisions made now will shape the sector for a generation. The experience of off-grid solar and clean cooking tells us what might lie over the horizon.

01 Introduction

WHY THE NEXT DECADE OF CLEAN COOLING MATTERS

Clean cooling is at a defining moment in its development. The decisions made in the next few years will shape whether the sector realizes its potential as both a climate and human development solution. Two sectors addressing similarly fundamental energy needs — off-grid solar and clean cooking — have already navigated this early, high-stakes phase of market development, and their experiences, including the missteps, offer a practical guide for what lies ahead.

The urgency is not in question. Climate change is driving temperatures to levels that the Intergovernmental Panel on Climate Change projects will expose more than half to-three quarter of the world's population to life-threatening heat and humidity by 2100. The burden falls disproportionately on low- and middle-income countries (LMICs), where population growth, geographic location, and unplanned urbanization exacerbates the effects of extreme heat. These factors, and the greater overall economic vulnerability of these communities, reduces resiliency and their capacity to adapt to rising temperatures.

The United Nations Environmental Program (UNEP) predicts access to cooling could more than triple by 2050, which would drive emissions for the sector to 7.2 billion tons of CO_2 equivalent (CO_2e) under a business-as-usual strategy. A sustainable cooling pathway could dramatically reduce the climate impact of this growth to 2.6 billion tons of CO_2e, while saving up to $43 trillion in cumulative energy and infrastructure costs by 2050.

The past decade has seen substantial gains in energy access more broadly in LMICs around the world. Off-grid solar has matured and scaled with over 50 million off-grid solar products sold in Sub-Saharan Africa in 2022 and 2023, and off-grid solutions accounted for more than half of new household electricity connections in the period 2020–2022. There is much more to do, but the off-grid solar sector has developed and refined the business model innovations, built the enabling environment, and attracted the capital necessary to scale.

Clean cooking's trajectory has been different. In 2010, the sector was at an important inflection point. Progress had been frustratingly slow compared to off-grid solar and the global population that lacked access to clean cooking had reduced by just 140 million in the previous decade. Harmonized standards were a couple of years away, and carbon financing was still just an idea with potential. It wasn't clear what the next phase of the sector's development would look like. Since then, almost a billion more people have gained access, driven by innovation in business models, technology, and policy. There are some headwinds, notably when it comes to carbon finance integrity for clean cooking and the sustainability of clean cooking business models. But

while there is still work to do — over 2 billion people still lack access to clean cooking — the progress is clear.

Clean cooling is at that same inflection point today. The need for clean cooling is clear: inclusive access to affordable cooling solutions is essential to support adaptation to the effects of climate change already being felt around the world, acutely so by the most vulnerable communities in LMICs. But that cooling must also be efficient — cooling currently accounts for more than 7% of global greenhouse gas emissions, making solutions that reduce energy consumption and mitigate climate emissions a priority. Promising business models and technical innovations that improve energy efficiency of cooling devices and lower the Global Warming Potential (GWP) of the refrigerants they contain continue to emerge. The promise of carbon financing for clean cooling exists, but it's not clear yet just how the sector

> **Cooling currently accounts for 7% of global greenhouse gas emissions.**

can best capitalize on it. And as both the solar and clean cooking sectors have demonstrated, the decisions that are made in the early stages of market formation tend to be sticky, partly because the systems that emerge, such as standards, norms and financing mechanisms, are highly resistant to change once established.

This paper explores five areas where the solar and clean cooking sectors have generated the most relevant — and sometimes counterintuitive — insights for clean cooling: **consumer behavior and business model innovation, standards and quality assurance, carbon integrity, end-of-life management, and financial incentives.**

02 Comparing Sectors

THREE MARKETS, ONE MARKET-BUILDING CHALLENGE

There are many similarities across clean cooling, off-grid solar and the clean cooking sectors. These sectors address some of the most fundamental energy needs of low-income households, and provide important societal impacts. All three involve high up-front costs, require significant education and behavior change, and innovative business models that can sustainably reach low-income households. Both off-grid solar and clean cooking are far enough ahead in their development to have generated potentially useful insights for clean cooling on what has worked and what hasn't.

This comparison examines the core function of the market (consumer behavior and business model innovation), the system of rules that govern the market (standards, carbon integrity) and the market's support functions (end-of-life management and financial incentives).

There are, of course, many other challenges the clean cooling sector will need to navigate, such as addressing affordability and accessibility constraints, building supply chains that can distribute products in hard to reach places, and ensuring that the right kind of concessional and commercial financing is available to share risk and drive scale. While all of these are important considerations, this paper focuses on a subset of decision points that:

- have proven pivotal for the off-grid and clean cooking sectors,
- demonstrate counterintuitive or unpredictable outcomes, and
- where the clean cooling sector still has time to take the learnings from these experiences on board.

MOST MATURE

Off-Grid Solar

Scaled business models, widespread PAYG, mature standards. Now facing its next frontier: end-of-life and e-waste.

KEY LESSONS: SCALE & LIFE CYCLE MANAGEMENT

MOMENTUM BUILDING

Clean Cooking

PAYG + IoT unlocked sustained use. Carbon methodology turbulence is the cautionary tale for every adjacent sector.

KEY LESSONS: INTEGRITY & CONFIDENCE

INFLECTION POINT

Clean Cooling

Technology developing and market structure forming. The decisions taken now will shape standards, methodologies, and incentives for decades.

KEY LESSONS: MARKET FORMATION

03 Consumer Behavior & Business Model Innovation

FROM SELLING UNITS TO SUSTAINING USE

Context

Early attempts to scale clean cooking solutions focused on communicating the benefits of greater fuel efficiency, or the potential improvements in health due to reduced indoor air pollution. Neither the promise of future cost savings from increased fuel efficiency, nor potential positive health impacts reliably increased the likelihood that households purchased a clean cooking solution. Innovation efforts primarily focused on improving the technical performance and efficiency of stoves or developing new distribution and sales approaches. The mistake the sector made was choosing the number of clean cookstoves distributed as its metric of success, rather than whether those devices were being used in a sustained manner. The gap between the theoretical performance of clean cooking solutions under lab conditions and assumed consumer behavior, and the reality in the field, has been the subject of consistent scrutiny.

Despite owning a more cost efficient and healthier stove, households continue to use traditional fuels such as charcoal or wood fuel to cook some of their meals. It's not uncommon to see three or more technologies used concurrently by a single household, a practice called fuel stacking. Sometimes the choice comes down to taste preferences — certain foods taste better when cooked over charcoal or wood. The perceived cost efficiency of the fuel is an important factor as well. Households often prefer to use charcoal rather than LPG gas for dishes that require slow cooking over a long period.

What did the clean cooking sector do?

The problem for clean cooking as a sector was that successful sales didn't translate to sustained use and reduced carbon emissions. However, the increase in popularity of Pay as You Go (PAYG) business models has shifted the incentive structure away from selling as many units as possible, and towards models that directly tie revenue to usage. Rather than a single sales transaction, PAYG cooking models provide equipment

free of charge and the customer pays only when they use the device. This requires businesses to better understand their customers' needs and behaviors, while delivering high levels of customer service.

These models work best when they are enabled by innovations in Internet of Things (IoT) metering devices that provide remote and real time data collection on usage, as well as remote management capabilities. For example, M-Gas, a PAYG provider of LPG stoves and fuel in Kenya uses network-connected smart meters to charge its customers as they use their stove. The smart meter, which provides detailed, real-time analytics allows M-Gas to develop further insights into customer behavior. When fuel levels are running low, smart meters alert M-Gas, which can deploy technicians to replace the cylinder — even before the customer notices.

The technical and business model changes inherent in PAYG align incentives across the value chain to remove the barriers to sustained use therefore minimizing fuel stacking. This supports the sustainability of clean cooking businesses, reduces carbon emissions, and reduces energy costs for the household.

Like fuel stacking, but for cooling

The clean cooling sector has a similar consumer behavior challenge to solve, but it is much more complex. When provided with a more efficient and cheaper cooking solution, a household is unlikely to cook substantially more food. The demand for cooked food is constrained by the cost of ingredients, the available time for cooking, and the nutritional needs of the family. The same isn't true for cooling. Given a more efficient and cheaper cooling solution, it is possible, even likely, that a household will choose to consume more cooling. This might mean running a room air conditioner for more hours in the day, in more rooms, or at a lower temperature to increase the family's comfort. If a more efficient refrigerator is cheaper to operate, a household might decide to buy a bigger one to store more food, which locks in a higher baseline level of consumption. While we can predict how energy consumption might increase as access increases, reductions in energy consumption due to efficiency gains are less predictable. There is already some evidence that explores this rebound effect, which is often more pronounced in low-income settings where consumption is already below optimal levels. A study from China found that acquiring an AC unit with energy efficiency labeling actually increased household energy consumption by 17.2% annually, increasing to almost 22% during summer months.

What can the clean cooling sector do?

The rebound effect is structurally similar to fuel stacking in that it is a rational behavior that nonetheless reduces the impact of an energy efficient product. Taking a cue from the clean cooking sector, clean cooling should invest in business models that incentivize lower emissions

CLEAN COOKING

Fuel stacking

Households keep using traditional fuels alongside clean stoves — a rational behavior that erodes the impact of efficient products.

CLEAN COOLING

The rebound effect

More efficient AC can lead to more hours of cooling, bigger fridges, lower thermostats — reductions in consumption are less predictable than gains in access.

intensity through sustained and efficient use, rather than rewarding unit sales and distribution. PAYG style models such as Cooling as a Service (CaaS) incentivize providers to maximizing the efficiency of the devices they provide. If the same cooling quality of service can be provided to customers using more efficient equipment, and therefore at lower cost, then it is the provider who benefits. Providers are also incentivized to optimize consumption practices, which may include providing their customers with behavioral nudges (e.g. providing real-time data on energy usage, how their usage compares with other users, default settings optimized for efficiency, etc.) that make more efficient consumption behavior the path of least resistance.

04 Standards & Quality Assurance (QA)

ENFORCEMENT IS THE HARD PART

Context

In its early stages, the off-grid solar sector experienced a variety of quality issues with both photovoltaic (PV) panels and other system components. This eroded consumer trust in the technology itself, as well as hurting the reputation of companies providing the systems. Quality issues in the off-grid solar sector were not limited to the technology itself. As PAYG business models began to reach scale, challenges with how off-grid solar products were being sold further eroded consumer trust and confidence. Without a quality sales and customer qualification process, consumers entered into contracts that they can't afford, or bought products they didn't know how to use.

What did the off-grid solar sector do?

The potential for "market spoilage" due to low quality products prompted the off-grid solar sector to prioritize development of quality assurance standards to reduce the prevalence of low-quality products in the market. These standards have been widely adopted and have helped to restore trust in the sector. Challenges remain, however, and low-quality products still make it on to the market. As recently as 2017, Lighting Global tested the top selling non-quality verified solar products in five countries and found that none of them met quality assurance standards. While it has taken some time, these standards have been adopted at scale and helped to shape the market by linking quality standards and certification to access to capital and conducive policy treatment such as lower import duties.

To address quality assurance in how off-grid solar products are sold, the Global Off Grid Lighting Association (GOGLA) has developed a Consumer Protection Code that aims to put in place standards for consumer protection, in particular for PAYG business models where consumers are entering into payment contracts.

What's the difference in clean cooling?

Currently in the clean cooling sector Minimum Energy Performance Standards (MEPS) have been developed by many countries, but like the experience of Lighting Global in 2017 shows, there can be large gaps between standards on paper and enforcement in practice. And when standards vary between countries, dumping of low-quality products becomes both legal and profitable. For example, 93% of room air conditioners exported from China to South East Asian markets don't meet China's own MEPS. For the Latin American and Caribbean region, it is 44%. Harmonization of standards can limit this potential for dumping of products that don't meet efficiency standards in their country of origin. Ghana has demonstrated the effectiveness of policies that create strong enforcement mechanisms that push the market towards greater efficiency.

What can the clean cooling sector do?

Standards organizations focused on clean cooling market building should develop a framework that codifies MEPS in advance of market growth and before significant market spoilage problems emerge. Policymakers should develop incentive and enforcement mechanisms that link these quality standards to capital access and favorable policy treatment. For example, using standards as qualifying criteria for access to results-based financing or other subsidy schemes, reduction in import tariffs, or requiring public sector entities to only procure products that meet the standards.

93% of room air conditioners exported from China to South East Asian markets don't meet China's own MEPS. For the Latin American and Caribbean region, it is 44%.

05 Carbon Integrity

INTEGRITY BUILDS MARKETS

Context

Clean cooking projects have consistently attracted critique that focuses on the gap between how stoves perform in the lab, versus how they perform in the real world. In more recent years this focus has shifted to whether the carbon credits associated with clean cooking accurately represent the real-world emissions reductions they claim. For example, a key parameter in the calculation of clean cooking carbon credits is the fraction of non-renewable biomass (fNRB) that is assumed to be consumed by a household prior to the introduction of a clean cooking solution. If this fraction is low, then the actual emissions reduction impact of a clean cookstove will be low since the fuel that was being used prior to the clean cookstove introduction was already coming from renewable sources.

What did the clean cooking sector do?

Perceptions of over-crediting of clean cooking projects, whether due to insufficient monitoring, reporting and verification, or the choice of baseline parameters such as fNRB has led to an erosion of trust in the quality of clean cooking carbon credits, and consequently the price that they attract. In 2025, the Clean Development Mechanism updated the default fNRB values used in clean cooking carbon methodologies to provide more conservative and accurate estimates of the carbon credits generated by clean cooking projects. This was the first time the fNRB value had been updated since 2017, and since then the amount of carbon finance flowing to clean cooking projects has risen exponentially. While legacy clean cooking credits have not been invalidated, the resulting turbulence in the sector provides a glimpse of what can happen when the integrity of carbon methodologies lags market growth.

What's the difference in clean cooling?

The transition to low GWP refrigerants is underway in industrialized nations, but it will take a decade or more, and the transition is not yet happening at scale in low-income markets. Some financing measures are beginning to be put in place to coordinate action and accelerate this transition. The Kigali Amendment to the Montreal Protocol provides for the establishment of a Multilateral Fund, which provides funding to support phasing down

the use of Hydrofluorocarbons (HFCs) in low-and middle-income countries. However, at $53 million, this is mismatched with the scale of the need, and is designed to channel funding to countries, and not to support private sector innovation in the way that carbon markets do.

Carbon financing provides an alternative mechanism to accelerate this transition. Carbon financing methodologies have begun to come online to incentivize the recovery and destruction of HFC refrigerants, and the scaling of efficient devices that use low GWP refrigerants, but already the landscape is crowded. There are 12 methodologies in the Voluntary Carbon Market (VCM) compared to just 3 for clean cooking. Despite this complexity, to date clean cooling only accounts for 4.7% of carbon credits across both the voluntary and compliance markets, and projects are heavily skewed towards high income markets. As clean cooking has demonstrated, and indeed the cooling sector has already learned, the risk of methodology gaps and integrity challenges is not a hypothetical concern.

What can the clean cooling sector do?

Policymakers and advocacy organizations should prioritize adoption of robust methodologies sooner rather than later. The International Finance Corporation predicts that the annual clean cooling market could double by 2050, and the risk for clean cooling is that the necessary methodologies aren't in place until after a large project pipeline has been built.

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Ensuring the integrity of these methodologies early on is equally important. Accurate modeling of rebound effects in clean cooling carbon methodologies could turn out to be just as influential to the sector as fNRB assumptions have been in clean cooking. Standards organizations should prioritize investment in modeling real-world conditions and human behaviors, rather than making assumptions based on performance under ideal lab conditions. Making the right decisions now will avoid potentially expensive and disruptive revisions in the future.

06 End-of-Life Management

THE REFRIGERANT LIABILITY HAS NO PRECEDENT

Context

Of the three energy access sectors we're examining, off-grid solar has reached the highest level of market maturity, with 50 million products sold in Sub-Saharan Africa in both 2022 and 2023. This progress has delivered life-changing impact, providing access to light, communications, and economic empowerment through productive uses. However, at some point in the future, the solar panels, batteries, and other components will degrade and produce less output until such point as they are replaced. The e-waste problem

that this will create is growing and it isn't clear that the recycling infrastructure exists at scale to handle it.

What did the off-grid solar and clean cooking sector do?

In 2020 the off-grid solar sector in Sub-Saharan Africa produced 12,000 tons of waste, an increase of 545% over 2016 levels. While some components like batteries may have a useful life of less than 5 years, the useful live of photovoltaic (PV) panels could be more than 10 years, meaning the scale of the future liability and its costs are unclear. Off-grid solar carbon financing doesn't account for the embedded carbon emissions in these devices, and business models don't incentivize operators to recover recyclable resources. The recycling infrastructure will catch up when the incentives are aligned, either from the economic opportunity of recovering and recycling rare earth metals, critical minerals, or other resources, or regulations are ushered in that compel the proper recovery and disposal of potentially toxic components.

The clean cooking sector hasn't dealt with the issue of end-of-life management, either. As the sector shifts from products that are easily recycled such as improved stoves made with metal and ceramic, and towards devices with electronics, batteries, and other potentially hazardous elements, this may change.

End-of-life waste was not a major concern in the early stages of either sector. In some ways, how to handle millions of devices after they've been providing energy access for a decade or more, is a good problem to have. But the context has changed in the intervening years. Soon, both off-grid solar and clean cooking manufacturers may need to navigate regulations that make them directly responsible for the full lifecycle of their products. Extended Producer Responsibility regulation is common in developed markets and is starting to take off in Sub-Saharan Africa, which requires manufacturers to bear the cost of recovery and recycling of waste associated with their products.

The clean cooling sector faces similar end-of-life management challenges to the solar sector — potentially millions of new physical devices distributed to households and businesses around the world. But the regulatory environment is much more mature now than it was when the solar sector was on the cusp of scaling up. Clean cooling operators won't have the luxury of ignoring the waste challenge for much longer.

What's the difference in clean cooling?

The clean cooling sector has another challenge when it comes to end-of-life management that solar or clean cooking haven't had to contend with. While clean cooling devices reduce carbon emissions through greater efficiency that leads to reduced electricity consumption (notwithstanding the rebound effect we discussed earlier), the refrigerants these devices use represent a significant climate liability estimated to equate to one-third of the device's carbon footprint.

While solar panels and their components may slowly degrade, without proper recovery infrastructure in place, when cooling devices fail or are disposed of incorrectly, these refrigerants are released into the atmosphere immediately. Hydrofluorocarbons (HFCs) are the most common refrigerants in use today. 49% of air conditioning units sold in Sub-Saharan Africa use R410A, which is a climate pollutant with a GWP that is almost 2,000 times that of CO_2. A further 47% use R22, which has a GWP of almost 1,800. The installed refrigerant bank globally represents an estimated 24 billion metric tons of CO_2 equivalent. This could grow to 33 billion Metric Tons of Carbon Dioxide Equivalent ($MTCO_2e$) by 2050.

What can the clean cooling sector do?

While the high-level agreements exist to curb the release of HFCs into the atmosphere via the Montreal Protocol and Kigali Amendment, policymakers regulating the clean cooling sector should act now to ensure that the infrastructure is built to meet these targets in practice. The safe and responsible handling of end-of-life cooling

1/3

Of a cooling device's total carbon footprint is attributable to its refrigerant alone.

2,000x

The Global Warming Potential of air conditioning refrigerants is up to 2000 times that of CO_2.

24 Billion $MTCO_2e$

In the global installed refrigerant bank — projected to grow to 33 billion $MTCO_2e$ by 2050.

devices and their refrigerants, or Lifecycle Refrigerant Management (LRM), will require a workforce of highly trained and certified technicians to keep units in good working order to avoid leakage, and to recover refrigerants during disposal. It will also require harmonization of policies regionally to ensure countries with less stringent regulatory requirements don't become dumping grounds for leaky units or non-compliant disposal. Punitive measures should make it economically non-viable for the private sector to ignore these regulations.

In parallel, policymakers should also incentivize the transition to low GWP refrigerants that lower the climate liability of new devices. While low GWP refrigerants are still in the early stages of development, a clear market opportunity, potentially driven by carbon financing or other financial mechanisms, can help to accelerate the transition.

07 Financial Incentives

FROM FINANCING ASSETS TO FINANCING OUTCOMES

Context

Unsurprisingly many of the gaps and challenges we've discussed across the off grid solar and clean cooking sectors exist to some degree because of a misalignment of financial incentives — either direct revenue opportunities or the avoidance of punitive costs tied to specific behaviors. The waste challenge for end-of-life solar components exists because there is no clear revenue model for the recovery or recycling of this waste. And the market spoilage experienced by the sector happened because there was no financial consequence for selling low-quality products or providing poor consumer service.

Similarly in clean cooking, in the early stages of the sector's development there was no financial incentive for cookstove manufacturers to ensure the sustained use of their products and the dis-use of more polluting technologies. The rational strategy was to sell as many stoves as possible without worrying too much about how frequently they were actually used by the household, apart from the influence this might have on referrals or repeat sales.

What did the off-grid solar and clean cooking sectors do?

An important transition happened in both solar and clean cooking sectors when the emphasis shifted from financing asset ownership to financing outcomes. In the case of solar, this transition was initially driven

by standards. It wasn't enough to sell solar products, those products, and the business model, had to deliver a high-quality customer experience.

In the case of clean cooking, the transition was driven by PAYG and carbon financing. It wasn't enough to sell clean cookstoves, those stoves now needed to be used in sustainable ways. Despite these lessons, many results-based financing schemes in the clean cooking sector continue to define success as the distribution of stoves, rather than their sustained use, and use manual methods for verification.

What's the difference in clean cooling?

Clean cooling is at risk of building the same infrastructure, one that incentivizes asset ownership, not outcomes. Without ongoing relationships with households to optimize cooling consumption, rebound effects might erode the benefits of energy efficiency. Without a financial interest in the recovery of harmful refrigerants from units at the end of their useful life, clean cooling providers may fail to maintain devices resulting in leakage, or dispose of them informally, allowing these refrigerants to be released into the atmosphere.

What can the clean cooling sector do?

Investors in the clean cooling sector should scale support for PAYG models for clean cooling. The expansion of

Clean cooling is at risk of building the same infrastructure, one that incentivizes asset ownership, not outcomes.

these models will develop the technology infrastructure, business model patterns, and customer experience standards that will be necessary to increase readiness for high-quality carbon financing at scale. These models will unlock the data and consumer insights that will create new opportunities for innovation, as is happening today in the clean cooking sector.

In parallel, donors and development finance institutions designing results-based financing programs should define success in terms of access and climate outcomes, rather than sales or distribution of cooling devices. Grid operators, who often already have a regulatory incentive to promote energy efficiency, can offer on-bill financing of efficient cooling devices that address the high up-front costs. Policymakers should develop the financial incentives to build the infrastructure to recover and recycle refrigerants now, before the climate liability associated with the installed refrigerant bank grows further. Even if the transition to low GWP refrigerants happens at pace, the alternatives will still require careful handling.

08 Conclusion

THREE DECISION POINTS THAT WILL SHAPE THE NEXT DECADE

The themes we've discussed are not isolated issues with individual solutions — they are interconnected dimensions of a systems design challenge that will require extensive and coordinated problem solving and implementation. Carbon financing that fails to account for consumer behavior in the form of rebound effects will result in over-crediting of emissions reductions. Failing to plan for end-of-life recovery of refrigerants ignores a growing climate and health liability in the future that will be expensive in economic, ecological, and human terms. Standards that have weak enforcement on the ground will perpetuate the market for low quality, low efficiency

products that undermine investment in innovation. And business models that finance assets rather than outcomes will exacerbate all of these challenges.

Across these dimensions, there are three main decision points that will shape the next decade of clean cooling — where the clean cooling sector will feel the pressure to act quickly with incomplete evidence due to the urgency of the need. In these three cases, the experiences of the solar and clean cooking sectors have generated the clearest evidence about what might lie over the horizon for clean cooling.

1. Carbon methodology architecture

The first is carbon methodology architecture. The clean cooking sector didn't design its methodology assumptions to fail. But they were designed for a market that turned out to behave differently than expected. The rebound effect may be the fNRB equivalent for clean cooling efficiency credits, and the refrigerant recovery problem has no equivalent in the solar and clean cooking sectors, a liability that will only grow as the market scales. Methodology developers who wait for the project pipeline to mature before resolving these questions will find revision as disruptive as the clean cooking sector has.

2. Standards enforcement, not just standards design

The second is standards enforcement, not just standards design. The solar sector eventually produced a credible standards framework, but enforcement takes collaboration and persistence. The gap between China's MEPS and what actually reaches Southeast Asian markets is a preview of what cooling markets across Africa and South Asia will face. Ghana's enforcement model shows what's possible, but enforcement infrastructure is significantly easier to build before low-quality products are established in a market than after. Policymakers and standards bodies that treat compliance as an implementation detail rather than a critical success factor will repeat this mistake.

3. The metric of success for business models and financing

The third is the metric of success for business models and financing schemes. For clean cooling entrepreneurs, investors, and policymakers, outcome-based financing is a strategy where the incentives guide behavior across the value chain. The experience of solar and clean cooking shows where the clean cooling market may head with attention, and capital, shifting to models can deliver desired outcomes rather than outputs.

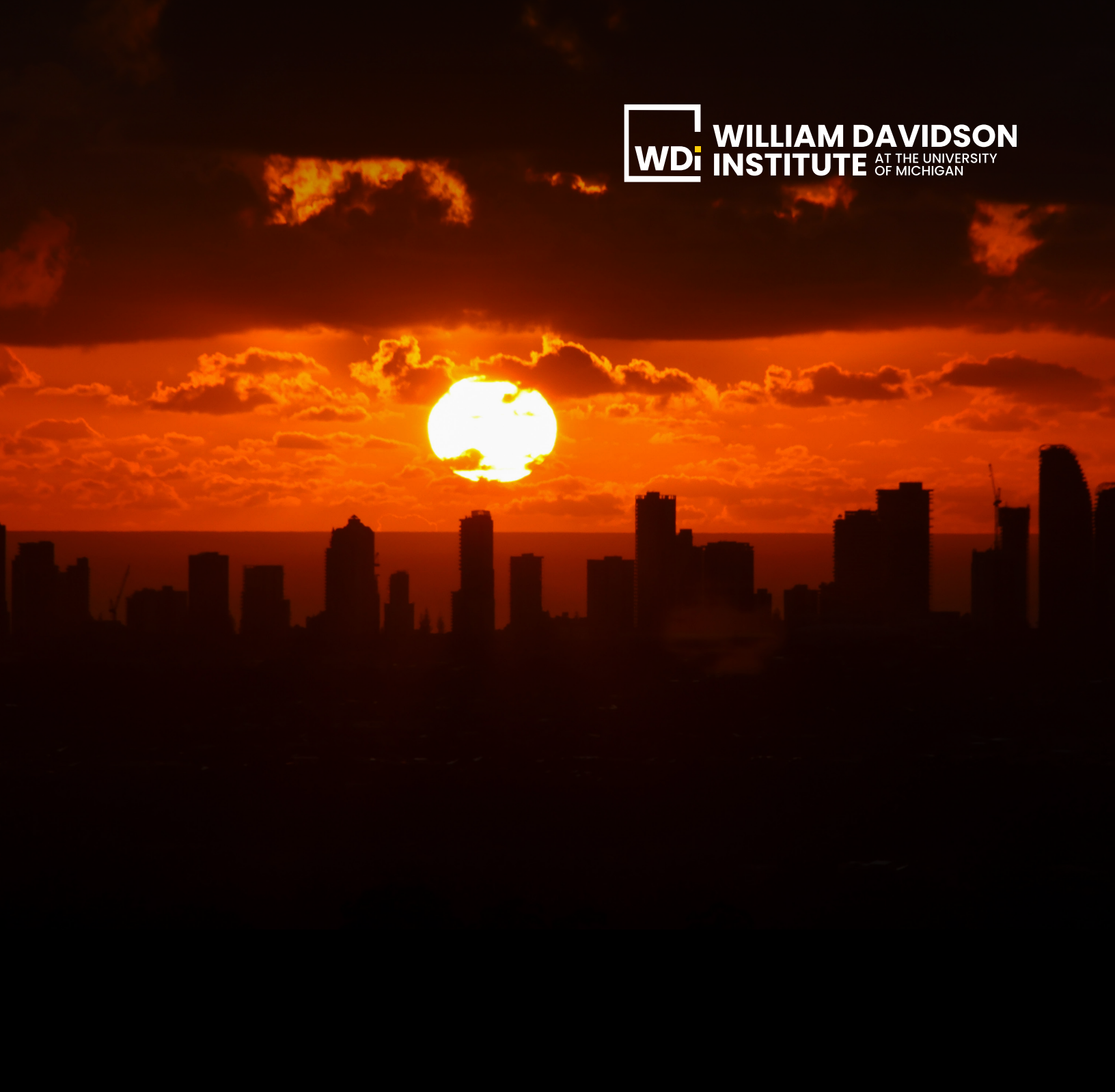
A coordinated agenda across stakeholders

Acting on these decisions requires coordination across the clean cooling value chain — regulators, funders, and innovators — with the end user at the center of every choice. The path forward demands that the sector make different choices than solar and clean cooking did at the equivalent stage: more data-driven, more outcome-oriented, and less willing to defer hard design choices and investments in critical infrastructure.

The table below summarizes concrete recommendations for clean cooling market actors, organized across the themes explored in this piece.

THEME	GOVERNMENT & POLICYMAKERS	INNOVATORS & ENTREPRENEURS	FUNDERS & INVESTORS
THEME 01 **Consumer Behavior & Business Models**	■ Mandate outcome-based verification tied to sustained use data, not unit sales. ■ Codify consumer protection standards for PAYG and CaaS contracts.	■ Scale PAYG / Cooling-as-a-Service models with IoT metering as the default. ■ Embed behavioral nudges (real-time feedback, efficient defaults) to curb rebound effects.	■ Underwrite business models that monetize usage, not units. ■ Use IoT-verified usage data as MRV evidence to unlock carbon finance.
THEME 02 **Standards & Quality Assurance**	■ Harmonize MEPS regionally and enforce anti-dumping from the outset. ■ Tie import duties and subsidy eligibility to standards compliance.	■ Build QA and testing frameworks ahead of scale ■ Invest in real-time metered data collection to close the lab-to-field performance gap.	■ Link access to concessional and commercial capital to standards certification. ■ Condition DFIs and donor facilities on credible quality assurance regimes.
THEME 03 **Carbon Integrity**	■ Require conservative, evidence-based carbon methodologies before large project pipelines are built. ■ Coordinate global commitments to Kigali Amendment implementation.	■ Model rebound effects explicitly in carbon methodologies. ■ Outcome-measurement technology to support results-based crediting.	■ Invest in high quality carbon projects to avoid risk of revisions. ■ Blend carbon revenues with concessional finance to de-risk first movers.
THEME 04 **End-of-Life & Refrigerant Management**	■ Support development and enforcement of Extended Producer Responsibility (EPR) regulations ■ Establish national refrigerant recovery and destruction registries.	■ Invest in low-GWP refrigerant R&D and recycling infrastructure. ■ Develop maintenance standards and training for last-mile technicians in refrigerant recovery and safe disposal.	■ Finance refrigerant recovery infrastructure through DFIs and blended capital. ■ Support methodologies for financing recovery and destruction of the existing refrigerant bank.
THEME 05 **Financial Incentives**	■ Align public incentives (subsidies, duties, tax) around outcome-based performance.	■ Redefine success metrics around reliability and sustained use, not sales.	■ Scale results-based financing (RBF) and PAYG tied to outcomes.

As with any innovation, the question of whether these outcomes will be achieved or not won't be determined by the technology, which is largely ready, but the ecosystem that enables it to reach those that need it. What was initially a technology challenge is now a market-building challenge. As solar and clean cooking have shown, this is both harder than it looks, and more important than it might initially seem.



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