clasp Efficient Appliances for People & the Planet

NET ZERO HEROES

Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience

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*Reviewer is also a member of the CLASP Board of Directors.

DESIGN

Teal Media

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Acronyms & Abbreviations

AR6	Intergovernmental Panel on Climate Change Sixth Assessment Report
ARPA-E	Advanced Research Projects Agency-Energy
BAU	Business as usual
BRL	Brazilian Real
CFL	Compact fluorescent lamp
CGAP	Consultative Group to Assist the Poor
CH_4	Methane
cm	Centimeter
CO	Carbon monoxide
CO_2	Carbon dioxide
COVID	Coronavirus disease
EESL	Energy Efficiency Services Limited
EJ	Exajoule
EPC	Electric pressure cooker
ESG	Environmental, social, and governance
ESMAP	Energy Sector Management Assistance Program
EU	European Union
FAO	Food and Agriculture Organization
F	Fahrenheit
FY	Fiscal year
GBP	British Pound Sterling
GDP	Gross Domestic Product
GHG	Greenhouse gas
Gt	Gigaton
GWh	Gigawatt hour
GWP	Global warming potential
IE5	International Efficiency Class 5
IEA	International Energy Agency
in	Inch
INR	Indian Rupee

IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hour
LED	Light emitting diode
LPG	Liquefied petroleum gas
MEPS	Minimum energy performance standards
Mt	Megaton
MWh	Megawatt hour
N_2O	Nitrous oxide
NDC	Nationally determined contribution
NO_x	Nitrogen oxides
NZE	Net zero emissions
OGCCC	Off-Grid Cold Chain Challenge
PM-KUSUM	Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan
R&D	Research and development
RBF	Results-based financing
SDG	Sustainable Development Goal
SEAD	Super-Efficient Equipment and Appliance Deployment
SEforALL	Sustainable Energy for All
U4E	United for Efficiency
UJALA	Unnat Jyoti by Affordable LEDs for All
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
USAID	United States Agency for International Development
USD	United States Dollar
WHO	World Health Organization
WMO	World Meteorological Organization

Dear Partners,

With an ever-narrowing window of opportunity to avert climate catastrophe, CLASP has reflected on where the appliances sector must dial in ambition for maximal benefit to people and the planet. In that context, we are pleased to introduce our landmark publication Net Zero Heroes: Scaling Efficient Appliances for Climate Change Mitigation, Adaptation & Resilience.

The paper underscores the immense potential of efficient appliances and equipment to slash carbon emissions and catalyze sustainable development. Efficient appliances are powerful, proven mitigation solutions. Appliances also play pivotal roles in people's lives, enhancing productivity, well-being, and comfort—even more so as the climate crisis impacts each and every one of us.

Despite this potential, underinvestment in demand-side efforts puts us at a crossroads. CLASP's report shows that the appliances sector is not on track to meet net zero emissions goals on the timeline established by the Paris Agreement, and that there are profound inequities in access to appliances, leaving billions of people vulnerable.

Inaction is no longer an option—and we don't have time to waste on dangerous distractions.

CLASP calls on leaders and partners alike to unite in purpose, prioritizing fast progress on the Net Zero Heroes—the 10 appliances core to achieving net zero and strengthening adaptation and resilience capacity.

For these 10 appliances, CLASP's paper identifies ambitious, near-term efficiency targets necessary to deliver on 2050 net-zero pledges. The appliances sector must reach far beyond current global best practices to protect our collective future. As a lifelong appliance efficiency champion, it's daunting for me to realize how much we must accomplish as a sector, and how quickly.

CLASP's message is clear: Be a hero. Join us in supercharging efforts to enhance appliance energy efficiency.

Christine Egan
Chief Executive Officer, CLASP

KEY FINDINGS

The appliance sector is projected to significantly overshoot the IEA's Net Zero by 2050 targets, jeopardizing efforts to achieve the goals of the Paris Climate Agreement. Meanwhile, billions of people still lack access to appliances that are increasingly vital as weather patterns shift.

But a clear pathway to planet- and people-friendly appliances exists. CLASP has identified the ten appliances that should form the basis of an unprecedented efficiency push: the Net Zero Heroes.

THE CHALLENGE

- The appliance sector accounts for 39.3% of all energy-related CO_2 emissions—roughly equal to the combined emissions of China, Europe, and Brazil in 2020. Tens of billions of appliances are in use today, and their numbers continue to grow.
- In a business-as-usual scenario, the appliance sector will overshoot the IEA's 2050 net zero target by at least 9 gigatons of CO_2. Even if current benchmark appliance efficiency policies were adopted worldwide, the sector's emissions would still exceed the IEA's 2050 target by at least 7 gigatons.
- Of the 3.6 billion people living in regions highly vulnerable to climate change, many lack basic appliances needed to adapt. At least 1.2 billion people do not have access to an air conditioner or fan, while at least 1.7 billion lack access to a refrigerator-freezer. Only 15% of the world's population own electric cooking appliances, despite the substantial health and climate benefits they offer.

THE SOLUTION

- Appliance efficiency offers a proven, cost-effective means of reducing emissions, improving resilience, and catalyzing sustainable development.
- To realize the appliance sector's mitigation and adaptation potential, governments and manufacturers must rapidly supercharge the efficiency of ten key appliances: the Net Zero Heroes. This group comprises LED lighting, air conditioners, comfort fans, refrigerator- freezers, heat pump space heating, heat pump water heaters, electric motors, electric cookers, televisions, and solar water pumps.
- Examples of targets provided for each Net Zero Hero include: doubling the efficiency of new air conditioners and refrigerator-freezers by 2030; transitioning to electric cooking worldwide; and phasing out fluorescent and incandescent lighting by 2025.
- By meeting these targets, the global community can avoid 9.2 gigatons of CO_2 in 2050 relative to business as usual while reducing exposure to climate risks and improving quality of life for people around the world.

EXECUTIVE SUMMARY

Efficient appliances, lighting, and equipment are critical climate solutions, situated at the nexus of mitigation, adaptation, and sustainable development. However, not enough is being done to maximize their benefits. In this paper, CLASP lays out actions that must be taken by 2030 to put us on a pathway to net zero emissions (NZE) and enable a just energy transition. CLASP identified the ten appliances most vital to meet global climate mitigation targets and improve people's lives: the Net Zero Heroes.

Appliances[i] are cornerstones of life, essential for productivity, wellbeing, and—increasingly—coping with global warming and its associated hazards. From providing life-saving cooling services to offering new income-generating opportunities, efficient appliances are key to climate-resilient development and a productive, low-carbon future for all.

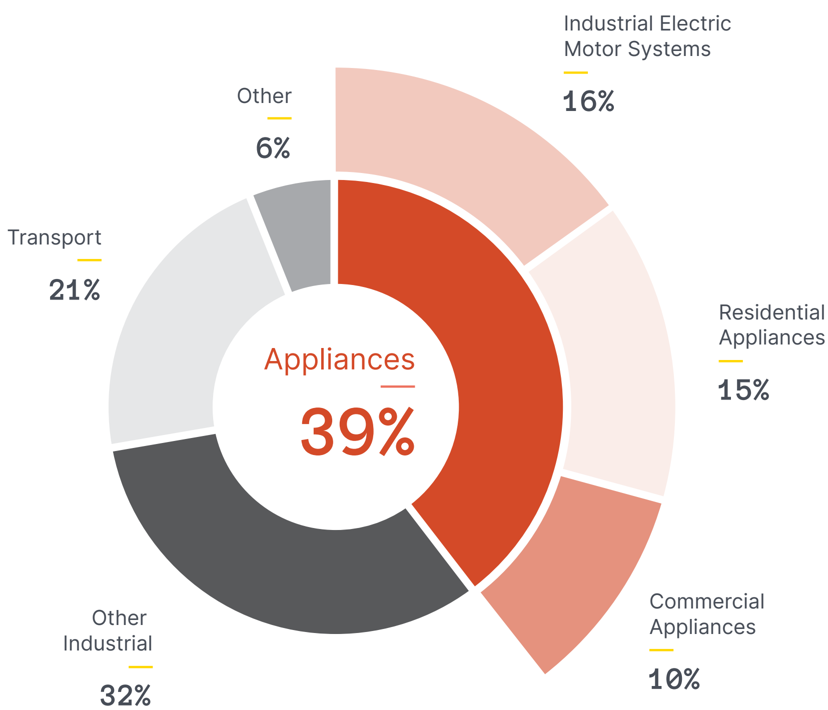
Efficient appliances and equipment strengthen climate resilience—driving access to cooling, information and food security, and improving health and productivity—and enable several of the United Nation's Sustainable Development Goals.[*]

***Note:** *SDG 1: No Poverty, SDG 2: Zero Hunger, SDG 3: Good Health & Wellbeing, SDG 4: Quality Education, SDG 5: Gender Equality, SDG 6: Clean Water & Sanitation, SDG 7: Affordable & Clean Energy, SDG 8: Decent Work & Economic Growth, SDG 10: Reduced Inequalities, SDG 11: Sustainable Cities & Communities, SDG 13: Climate Action, SDG 15: Life on Land*

i. Throughout this paper, we use the term “appliances” to refer to appliances, lighting, and equipment.

However, appliances have a major climate impact. They are responsible for nearly 40% of energy-related carbon dioxide (CO_2) emissions globally. This staggering amount is harming people and the planet—and the total annual energy demand and emissions from appliances are only increasing.[1,2,3]

FIGURE A. GLOBAL TOTAL ENERGY-RELATED CO_2 EMISSIONS BY SECTOR (2021)[ii]



Note: *This estimate includes indirect emissions (from electricity and heat) apportioned across sectors, (35.9 Gigatons [Gt] total).*

Source: *CLASP analysis*

To estimate the total climate impact of the appliances sector, CLASP has combined emissions from residential and commercial buildings, the electric motor-driven systems used in industry, *and* biomass cooking and heating.

CLASP modeling finds that appliances are not on track to do their part in reaching NZE by midcentury and limiting global warming to 1.5 °C. In a business-as-usual (BAU) scenario, CLASP estimates that the appliances sector will surpass the International Energy Agency (IEA)'s NZE mitigation target by at least 9 Gt CO_2 in 2050.[iii]

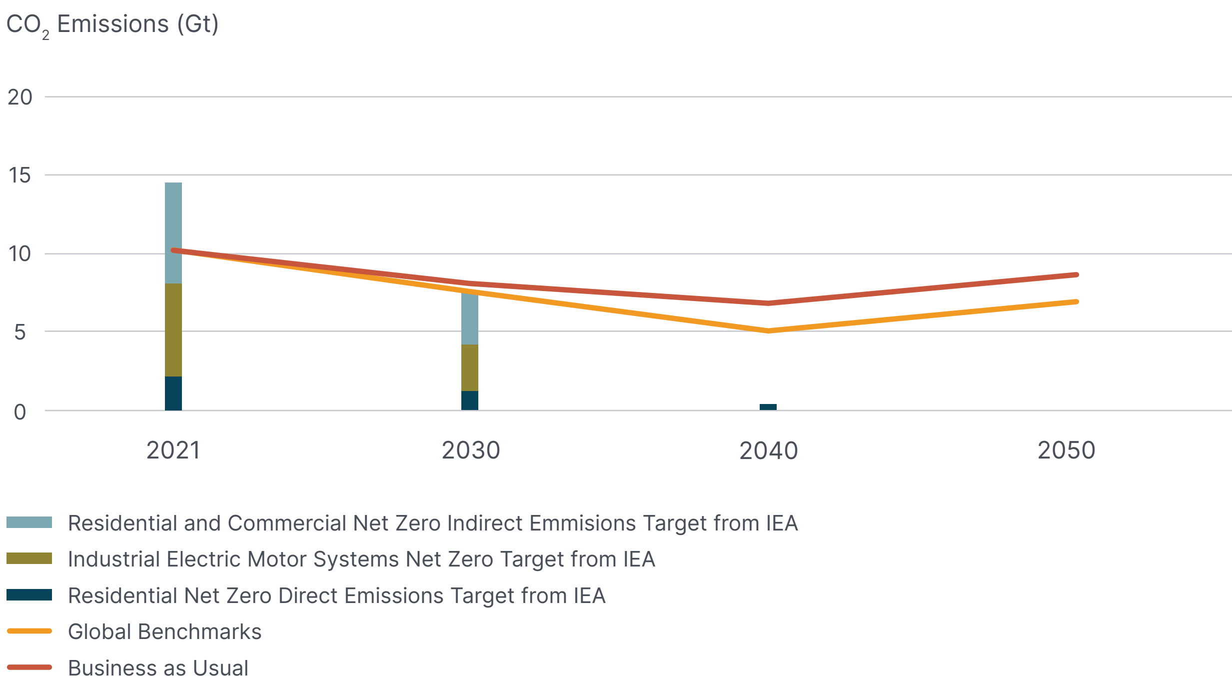
Even if countries universally adopted current global benchmark appliance efficiency policies, 2050 emissions would exceed the NZE mitigation target by at least 7 Gt CO_2.

ii. CLASP analysis of IEA, "World Energy Outlook 2022," tbl. WORLD_TFC_STEPS, WORLD_CO2_STEPS, with indirect emissions apportioned among sectors using IEA, "CO_2 Emissions from Fuel Combustion," 2020, tbl. SECTOR, SECTORH, ignoring any electrification between 2018 (latest year available) and 2021. Energy used for desalination, estimated at 2 EJ and originally included in Buildings by IEA moved to Other.

iii. This 9.2 Gt estimate includes the mitigation potential for the following appliances: motors, space heating, ACs, lighting, refrigerator-freezers, TVs, fans, solar water pumps and electric cooking.

Without dramatic change, appliances will exceed their share of the renewable energy budget. IEA's Net Zero by 2050 Roadmap calls for adding a huge amount of renewable electricity generation capacity to the global grid. Any additional demand over and above this "renewable energy budget" would need to be met by burning fossil fuels. The 9 Gt CO_2 emissions in excess of NZE referenced above would result from the additional fossil fuel electricity generation required to power appliances under BAU (Figure B).

FIGURE B. CO_2 EMISSIONS UNDER BAU & GLOBAL BENCHMARKS SCENARIOS



Note: *Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2023-2025. Modeled CO_2 emissions under BAU and today's best appliance efficiency policies for major residential appliances and industrial electric motors systems (lines); overlaid with IEA's Net Zero Emissions by 2050 trajectory for the relevant sectors (bars). Assumes electric grid decarbonization in line with Net Zero by 2050 Roadmap.*

Simultaneously, appliances are not on track to benefit all who need them. **3.6 billion people live in regions that are highly vulnerable to climate change, and many of those same people still lack access to even the most basic appliances needed to adapt to a warming world.**

This paper estimates the size of the access gap for ten types of appliances and equipment with important climate adaptation, resilience, and other human development benefits. For example, at least 1.2 billion people lack access to an air conditioner or fan for space cooling (Table A). **Without urgent action, inequitable gaps in appliance access will persist, undermining delivery of a just energy transition.**

TABLE A. GLOBAL APPLIANCE OWNERSHIP/ACCESS (LATEST YEAR AVAILABLE)

APPLIANCE	BASE POPULATION* (BILLIONS)	POPULATION THAT OWNS APPLIANCE (BILLIONS)	POPULATION THAT DOES NOT OWN APPLIANCE (BILLIONS)	PERCENT OF POPULATION THAT OWNS APPLIANCE	PERCENT OF POPULATION THAT DOES NOT OWN APPLIANCE
Lighting	7.7	7.0	0.7	91%	9%
Air Conditioners and Fans	2.4	1.2	1.2	50%	50%
Refrigerators-Freezers	7.7	6.0	1.7	78%	22%
Heat Pumps	2.4	0.8	1.6	34%	66%
E-Cooking	7.3	1.1	6.2	15%	85%
Solar Water Pumps	2.1	0.0	2.1	1%	99%
Televisions	7.7	6.7	1.0	87%	13%
Mobile phones	7.7	5.8	1.9	76%	24%
Radios	3.2	0.9	2.3	28%	72%

**The base population varies based on data availability and the relevance of each appliance. Refrigerator, television, lighting, and mobile phone access gap data were available for 162 countries, e-cooking data were available for 148 countries, air conditioner and fan data were available for 66 countries, radio data were available for 51 countries, heat pump data were available for 25 countries, and solar water pump data were available for 13 countries. Please see Annex A: Appliance Access Gap Methodology for the complete list of countries and data sources.*

Despite these dire projections, we can get on track with Net Zero targets by supercharging efforts to improve appliance energy efficiency. Appliance efficiency is a proven, cost-effective climate mitigation strategy and an enabler of end-use electrification, grid decarbonization, and expanded access to life-changing appliances. Improved efficiency can lead to greater climate resilience and adaptation by improving affordability, thereby bringing appliances within reach of more people.

CLASP has identified the appliances at the core of achieving NZE by 2050, improving quality of life, and enabling climate change adaptation and resilience: the “Net Zero Heroes.” CLASP has set recommended energy efficiency and other targets for each Net Zero Hero, as shown in Table B.

TABLE B. NET ZERO HEROES: TARGETS & PROJECTED IMPACTS

LED LIGHTING

TARGET

- **Completely phase out fluorescent and incandescent lighting by 2025**
- **Double the luminous efficacy of new LEDs by 2030 to take advantage of rapid technological improvement**

2040 MITIGATION RELATIVE TO BAU

0.2 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.03 Gt CO_2

OTHER BENEFITS

- Eliminate mercury pollution from production, breakage, and disposal of fluorescent lighting
- Reduce waste due to longer LED lifetimes

AIR CONDITIONERS

TARGET

- **Double the efficiency of new units by 2030**
- **Transition to low-GWP refrigerants in accordance with the Kigali Amendment to the Montreal Protocol**

2040 MITIGATION RELATIVE TO BAU

0.8 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

1.1 Gt CO_2

OTHER BENEFITS

- 123 million people with first access[iv]
- 116 million people with improved thermal comfort
- 93 million people with improved health and wellbeing

COMFORT FANS

TARGET

- **Require permanent-magnet motors in new table, ceiling, and pedestal fans by 2025**

2040 MITIGATION RELATIVE TO BAU

0.04 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.03 Gt CO_2

iv. For air conditioners and refrigerator-freezers, we extended SEforALL's analysis to forecast the number of households benefiting from first access and assumed an average household size of 3.74 persons to estimate the number of people benefiting.

REFRIGERATOR-FREEZERS

TARGET

- **Double the efficiency[v] of new units by 2030[4]**

2040 MITIGATION RELATIVE TO BAU

0.1 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.2 Gt CO_2

OTHER BENEFITS

- 262 million people with first access
- 39 million people with improved quality of life
- 26 million people with improved food security and nutrition

HEAT PUMP SPACE HEATING

TARGET

- **Stop sales of fossil fuel equipment to fully transition stock to heat pumps by 2050**

2040 MITIGATION RELATIVE TO BAU

1.2 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

1.8 Gt CO_2

OTHER BENEFITS

- Eliminate methane leakage from space heating
- Reduce outdoor air pollution from space heating

HEAT PUMP WATER HEATERS

TARGET

- **Stop sales of fossil fuel equipment to fully transition the stock of storage water heaters to heat pumps and solar thermal by 2040**

2040 MITIGATION RELATIVE TO BAU

0.2 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.3 Gt CO_2

OTHER BENEFITS

- Eliminate methane leakage from water heating
- Reduce outdoor air pollution from water heating

v. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

ELECTRIC MOTORS

TARGET

- **Double the efficiency[vi] of new industrial motor systems (controls, motor, and motor-driven equipment) by 2030[5]**
- **Greatly accelerate the replacement rate of existing stock by 2030 to achieve full replacement by the most efficient motors (IE5) by 2035**

2040 MITIGATION RELATIVE TO BAU

3.4 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

5.1 Gt CO_2

OTHER BENEFITS

- Improved industrial competitiveness, productivity, and quality control

ELECTRIC COOKING

TARGET

- **Fully transition to electric cooking worldwide[vii]**

2040 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

OTHER BENEFITS

- 3.7 million premature deaths avoided annually
- 0.7 million fewer children with asthma
- Improved respiratory and heart health
- Time savings and reduced deforestation by eliminating the need to gather firewood
- Eliminate methane leakage from cooking

TELEVISIONS

TARGET

- **Require European Union (EU) Tier 3 efficiency levels everywhere by 2025**

2040 MITIGATION RELATIVE TO BAU

0.03 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.02 Gt CO_2

vi. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

vii. For electric cookers, the benefits shown here are in the year the target (a full transition) is achieved. The mitigation potential provided is a conservative estimate. The CO_2 reductions represent the emissions that could be mitigated annually from reduced fuelwood harvest in 84 countries, sourced from the Clean Cooking Alliance's report, *Accelerating Clean Cooking as a Nature-Based Climate Solution*. Likewise, the mitigation potential does not include the reductions methane emissions from leaks in gas infrastructure because other greenhouse gas emissions were not included in the scope of this analysis.

SOLAR WATER PUMPS

TARGET

- **Fully transition to electric water pumping for irrigation**[viii]

2040 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

OTHER BENEFITS

- 98 million people with improved food security
- 15 million smallholder farmers with yield increases >30%
- 0.85 million new jobs in the agricultural sector
- $100 USD billion in fuel cost savings annually

TOTAL

2040 MITIGATION RELATIVE TO BAU

6.7 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

9.2 Gt CO_2

Note: *For electric cookers and solar water pumps, the benefits shown here are in the year the target (a full transition) is achieved. For air conditioners and refrigerator-freezers, we extended SEforALL's analysis to forecast the number of households benefiting from first access and assumed an average household size of 3.74 persons to estimate the number of people benefiting. Due to rounding, numbers presented throughout this and other documents may not add up precisely to the totals provided and percentages may not precisely reflect the absolute figures.*

Source: *CLASP analysis*

MEETING CLASP'S NET ZERO HERO TARGETS WOULD:

- Avoid 9.2 Gt of CO_2 in 2050 relative to BAU, enabling appliances to do their part in meeting IEA's Net Zero goal.
- Reduce exposure to climate risks and improve quality of life through enhanced food security and economic opportunity for over 100 million people.
- Improve health outcomes for nearly 100 million people.

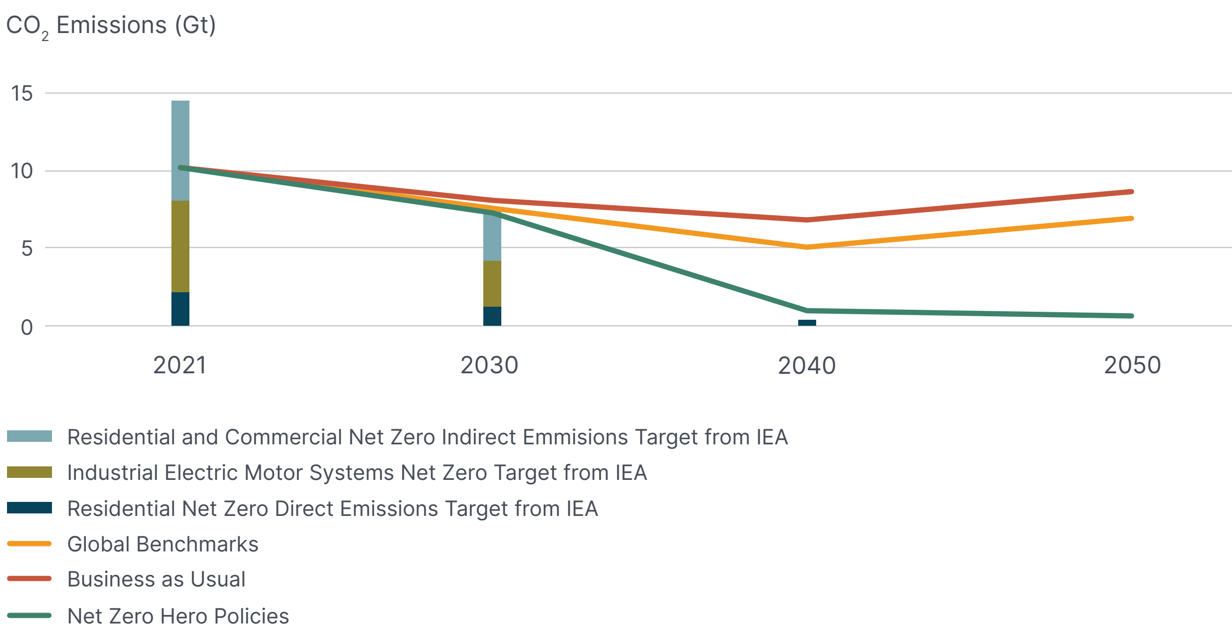
viii. For solar water pumps, the benefits shown here are in the year the target (a full transition) is achieved. The mitigation potential provided is a conservative estimate. The 0.4 Gt potential represents the avoided CO_2 emissions that we would expect in a single year if the access gap was closed with solar water pumps rather than diesel pumps in 13 countries. It does not include the additional emissions reductions that would be achieved by transitioning the existing stock of diesel irrigation pumps to solar-powered or electric water pumps. If we were to expand our analysis to include all countries and the replacement of diesel pumps with solar or electric pumps, the mitigation potential would be significantly higher.

In Figure C below, we graph emissions for the appliances analyzed in Mepsy under the Net Zero Hero scenario as well as the Global Benchmarks and BAU scenarios. **The Net Zero Hero scenario is the only scenario that can sufficiently drive down energy use and emissions to keep net zero goals alive**. As policies aligned to the targets shown in Table B come into effect, emissions are projected to fall significantly after 2025 to 1 Gt in 2040 and 0.6 Gt in 2050.

The Net Zero Heroes are focused on appliances with mitigation potential. However, for maximal climate resilience impacts, products like mobile phones and radios could also be prioritized to close access gaps.

The Net Zero Heroes can be scaled—made more efficient, affordable, and accessible—through proven, cost-effective policy and financing mechanisms.

FIGURE C. CO_2 EMISSIONS UNDER BAU, GLOBAL BENCHMARKS & NET ZERO HEROES SCENARIOS



Note: *Modeled CO_2 emissions from appliance efficiency policies for major residential appliances and industrial electric motor systems (lines); overlaid with IEA's Net Zero Emissions by 2050 trajectory for the relevant sectors (bars). Assumes electric grid decarbonization in line with the Net Zero by 2050 Roadmap. Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2025-2030.*

Source: *CLASP analysis*

RECOMMENDATIONS

CLASP calls on all actors to align their efforts with the Net Zero Hero targets and do their part to ensure initiatives for Net Zero Heroes are funded, implemented, and scaled at a rate never seen before.

Concerted action is required. Achieving the targets for all Net Zero Heroes will require governments, manufacturers, and others to act with speed and focus. In many cases, governments and others may face trade-offs between actions for the Net Zero Heroes and other appliance efficiency solutions. With little time left to meet the targets in Table B, it is imperative to prioritize Net Zero Hero targets even if it leads to a delay in other solutions.

To support a just energy transition, CLASP also advocates for broadening the climate adaptation and energy access agendas to include and prioritize efficient appliances.

This would require underscoring the critical role of appliances in climate-resilient development and expanding the focus of the energy access agenda to include access targets for appliances and equipment along with new connections and kilowatt hours (kWh). Additional analysis is needed to identify, assess, and calibrate appliance access goals and map the pathways to closing existing access gaps.

GOVERNMENTS

- **Increase the stringency of appliance policies and the frequency of revision at the speed and scale needed to achieve Net Zero Hero Targets.** Appliance policies such as minimum energy performance standards (MEPS) and energy labels are critical tools. Adopting the levels recommended in United for Efficiency (U4E)'s Model Regulation Guidelines and CLASP's World's Best MEPS is a good start, but will not be enough. Governments will have to redouble their efforts and go much further to reach CLASP's Net Zero Hero targets, outlined in Table B.
- **Bring other measures to bear.** CLASP recommends a suite of policies and market development programs that work to clear the market of the most inefficient products (via MEPS), promote the adoption of efficient appliances (via comparative labels, financing and financial incentives, bulk procurement, and awareness-raising efforts), and drive technology innovation (via research and development funding, awards and competitions, and endorsement labels). Governments will need an "all of the above" approach to drive efficiency improvements and electrification at the speed and scale necessary to achieve the targets in Table B.

- **Plan, track, and measure.** Develop roadmaps with specific, time-bound targets for appliance efficiency improvement and enhanced access to efficient appliances. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) should incorporate appliance efficiency into their Nationally Determined Contributions (NDCs) and Net Zero Roadmaps. Countries with significant energy access deficits should integrate access to efficient appliances into their national electrification plans, clean cooking strategies, and sustainable economic development plans. Regular data collection about appliance ownership and usage should be utilized to help governments track which interventions are supporting households and the marketplace, and inform additional action. Market surveillance should be used to confirm compliance with policies.

- **Maximize the multiple benefits of efficient appliances by taking an intersectional approach to designing ambitious plans and policies.** Appliance-focused measures can deliver important equity, health, economic, environmental, climate, and energy security benefits simultaneously. Policies designed with only one of these as a goal risk missing out on the others. Stakeholders will need to come together across sectors (e.g., health, development, agriculture, and environmental justice) to set goals consistent with the targets in Table B and design policies and programs to reach them.

- **Collaborate internationally to stop the dumping of inefficient appliances.** Regional harmonization of standards and cooperation on market surveillance across borders can help block substandard appliances. These efforts benefit all countries in the region. Appliance-exporting countries should go further and discourage the production of all appliances that do not meet domestic efficiency, refrigerant, or other requirements. Uniform guidance across importing and exporting markets can send clear signals to manufacturers that inefficient appliances are no longer acceptable.

- **Expand the capacity of local manufacturers to produce efficient appliances.** In some countries, training and technology transfer will be needed to ensure Net Zero Heroes can be manufactured domestically. Where appliance manufacturing provides jobs, such measures could be indispensable to obtaining broad support for appliance policies and effecting a just energy transition.

MANUFACTURERS & DISTRIBUTORS

- **Produce only appliances and equipment that meet Net Zero Hero targets and avoid dumping low quality products in lower income markets.** Appliance manufacturers should stop producing appliances that do not meet minimum standards in their countries of origin and exporting them to markets that have less stringent standards. They should instead use their influence to promote the sale of more efficient appliances across the globe. For greater impact, manufacturers can join forces through industry associations and global initiatives such as U4E, EP100, and the We Mean Business Coalition. Such efforts can help companies achieve their own NZE and other climate targets.

- **Steer consumers toward the Net Zero Heroes.** Distributors' stocking decisions have enormous influence on what consumers buy. Distributors also influence how appliances are labeled and presented in stores and online. Appliance distributors should work in concert with manufacturers and governments to shift consumers' purchases toward high-efficiency appliances and accelerate the phase-out of fossil-fueled appliances.

DONORS & FINANCIAL INSTITUTIONS

- **Increase funding for appliance efficiency and access programs.** All actors from both the public and private sectors will need to do more to accelerate the pace of progress. Energy supply has benefitted from subsidies for many years. Financial support on the demand side will be needed for everything from appliance policy development and technology transfer to market surveillance and consumer financing. Efficient appliances sit squarely at the nexus of climate mitigation and adaptation and can deliver benefits for people and the planet simultaneously. Appliance programs should be funded accordingly.

- **Leave no one behind.** Governments and development partners must deploy end-user subsidies and concessional financing to ensure everyone can access energy-efficient appliances, as a just energy transition demands. Consumer financing plays a critical role in lowering the first-cost barrier, especially for low-income consumers and those living beyond the reach of the electric grid. Stimulating demand for efficient appliances is just as important in rural electrification efforts as ensuring that the electricity supply is sufficient, reliable, and sustainable. Financing that enables rural households to purchase and operate good-quality appliances will lead to an increase in electricity demand, which in turn improves the economics of further investment in grid extension and distributed renewable energy.

CIVIL SOCIETY ORGANIZATIONS

- **Advocate for efficient, affordable appliances.** Efficient appliances deliver important benefits to consumers. Policymakers, manufacturers, and others need to know that these benefits matter to consumers, especially to low-income consumers who struggle most with high energy costs and low access to energy services. Consumer, energy, environmental, and health advocates must argue vigorously for ambitious, people-centered climate action and hold decision makers accountable for meeting the targets in Table B.

01 Appliances: Impacts & Benefits

Woman with Solar TV. *Credit: CLASP*

01

The Paris Agreement presents nations with a dual mandate to decarbonize their economies and help vulnerable groups adapt to a changing climate. Recognizing this need, the Intergovernmental Panel on Climate Change (IPCC) has advocated for a climate-resilient development approach that integrates adaptation measures and their enabling conditions with mitigation to advance sustainable development for all.[6]

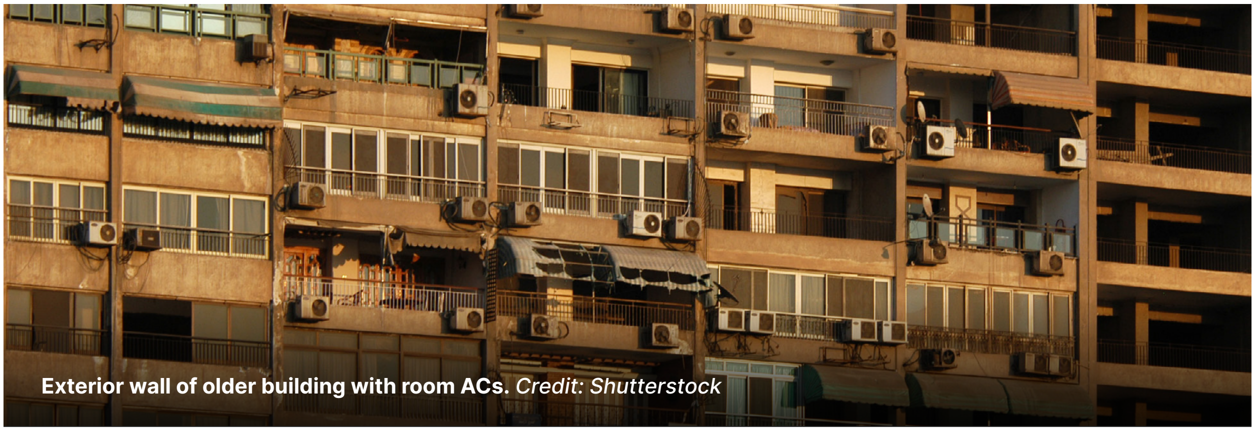
Appliances are at the nexus of mitigation, adaptation, and resilience. They form a larger part of the solution to climate change than many realize. In fact, higher efficiency appliances are essential to achieving the goals of the Paris Agreement and promoting climate-resilient development.

> Higher-efficiency appliances are essential to achieving the goals of the Paris Agreement and promoting climate-resilient development.

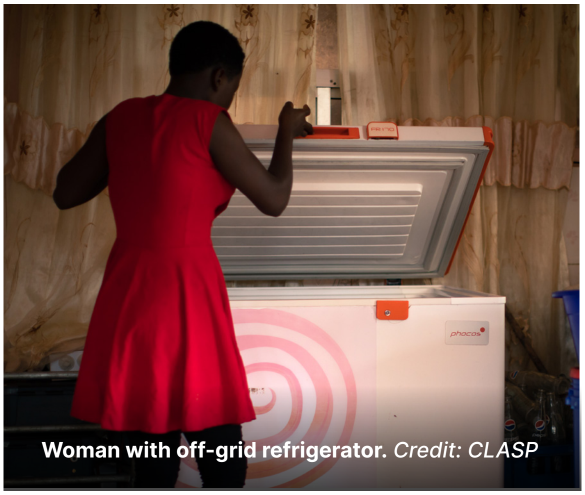
Appliances are responsible for 39% of all energy-related CO_2 emissions. We cannot achieve NZE without significantly improving appliance energy efficiency. Tens of billions of appliances are in use today,[7] all of which consume electricity or burn fuel, emit other pollutants, or result in further energy use and pollution during manufacture. This number is growing.[8] The resultant emissions and air pollution are already harming millions today and changing the world in ways that will impact future generations.[9] Greenhouse gas (GHG) emissions and air pollution can be mitigated through efficiency (using less energy) and electrification (switching from direct fuel combustion to low-carbon electricity).

At the same time, as many as 3.6 billion people live in regions that are highly vulnerable to climate change.[10] CLASP estimates that hundreds of millions to billions of people lack access to electricity and the appliances needed to cope with a warming world. Expanding access to efficient appliances must be an essential component of any climate-resilient development approach. From lifesaving cooling services to communication devices that provide vital lifelines to information and business opportunities, efficient appliances empower people to live a quality life and build resilience to climate risks. Expanded access to these life-changing appliances provides an array of social, economic, and other benefits to households that further bolster community resilience, adaptive capacity, and climate-resilient development. CLASP estimates that universal access to, or ownership of, ten essential appliances can help deliver 12 of the 17 United Nations (UN) Sustainable Development Goals (SDGs). An equitable, low-carbon, and climate-resilient future is not possible without universal appliance access.

This section makes the case for why efficient appliances must be elevated in the global climate dialogue. It is divided into two parts: the energy and GHG impacts of appliances globally and the climate adaptation, resilience, and sustainable development benefits of efficient appliances.



Exterior wall of older building with room ACs. *Credit: Shutterstock*



Woman with off-grid refrigerator. *Credit: CLASP*

Part one begins with a review of appliance energy use and appliances' contribution to climate change. We analyze the GHG emissions from burning fossil fuels to generate that energy. When referring to appliances' climate mitigation potential, we focus on appliances used in residential and commercial buildings (encompassing all appliances, heating and cooling systems, and lighting used in homes and buildings, but not the electricity used to charge electric vehicles) as well as the electric motor-driven systems used in industry (encompassing industrial motors and their system components such as variable-speed drives, fans, pumps, and compressors). This total also includes emissions from biomass used in cooking and heating.

Appliances are also responsible for the release of other non-CO_2 GHG emissions and short-lived climate pollutants. Limiting or eliminating the release of all appliance-related emissions is needed to halt climate change. However, when estimating the climate impact of appliances, CLASP's analysis focuses solely on CO_2 emissions and does not include non-CO_2 GHG and short-lived climate pollutant emissions, or methane and refrigerant emissions from leakage. If we were to include these emissions in our analysis, appliances would have an even greater impact on global GHG emissions and warming. Part one concludes with a short description of these pollutants and their warming potential.

Part two provides an overview of the climate resilience, adaptation, and sustainable development benefits that appliances offer. It makes the case for why appliances should be a central component to any climate-resilient development approach by mapping ten appliances essential for building climate resilience (lighting, air conditioners, fans, refrigerators, heat pumps, e-cooking, mobile phones, televisions, radios and solar water pumps) to their climate resilience benefits and related SDGs. The set of appliances assessed in this analysis differs from the set of appliances used to estimate global energy demand and resulting CO_2 impacts. In part two, we do not assess appliances and equipment used in commercial buildings or the industrial sector, nor do we assess residential water heating. CLASP recognizes that expanded access to efficient commercial appliances and equipment, like cold chain technology, is also essential to improving climate adaptation and resilience. However, our analysis focuses on residential appliances, highlighting the benefits to individual households. We expand the series of household appliances to include low energy-consuming appliances like radios, cell phones, and televisions, as well as household productive use appliances like solar water pumps. We include these appliances because they offer critical climate resilience or adaptation benefits.

TABLE 1. SUMMARY OF APPLIANCES INCLUDED IN SECTION 1

APPLIANCES ESSENTIAL TO CLIMATE CHANGE MITIGATION	APPLIANCES ESSENTIAL TO CLIMATE RESILIENCE AND SUSTAINABLE DEVELOPMENT
Section 1.1 evaluates the climate impact of the following residential, commercial, and industrial appliance categories: ▪ All-electric appliances (e.g., televisions, refrigerators, etc.) ▪ Heating and cooling systems ▪ Lighting used in homes and buildings ▪ Electric motor-driven systems encompassing the motor and motor driven unit (e.g., pump, fan, compressor, etc.)	Section 1.2 evaluates the resilience benefits of ten residential appliances: ▪ Lighting ▪ Air conditioners ▪ Fans ▪ Refrigerators ▪ Heat pumps ▪ E-cooking ▪ Mobile phones ▪ Televisions ▪ Radios ▪ Solar water pumps

1.1 Climate Impacts

ENERGY USE AND CARBON EMISSIONS

Appliances represent a large share of global final energy consumption and emissions. According to the IEA, the buildings sector accounted for 30% of total global final energy consumption in 2021.[11] Industry accounted for more than one-third.[12] But it is not the homes, offices, or factory *buildings* that are consuming the energy and emitting CO_2 and other GHGs. It is the appliances *inside* those structures. These devices transform energy into useful work, providing essential services, enabling communication and entertainment, saving labor, contributing to livelihoods and wellbeing, and powering industrial processes at all scales. Demand for these services is growing, particularly in emerging economies.

To estimate the total climate impact of the appliances sector, CLASP has combined emissions from:

- Residential and commercial buildings (encompassing all appliances, heating and cooling systems, and lighting, but not electric vehicles)
- The electric motor-driven systems used in industry (encompassing industrial motors and their system components, such as variable-speed drives, fans, pumps, and compressors)
- Biomass used in cooking and heating.

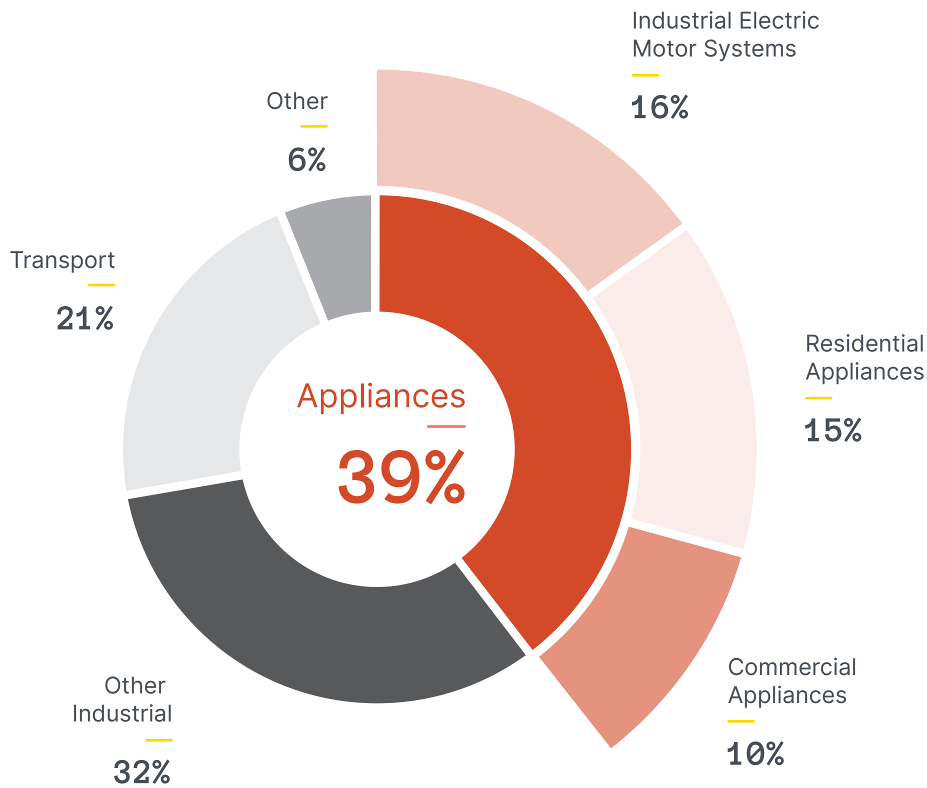
CLASP's analysis finds that appliances accounted for 35% of global energy demand[ix] and nearly 40% of global energy-related CO_2 emissions in 2021. These emissions come either from the direct combustion of fossil fuels that are delivered to the building or indirectly from electricity. While the share of electricity generated from renewable and other emissions-free sources is growing, historically, fossil fuels comprised approximately 80% of the global generation mix.[13] This estimate does not include emissions from methane or refrigerant leakage, which are discussed later in this section.

The resultant fuel-related emissions—both due to on-site combustion and off-site electricity generation—totaled 14 Gt CO_2, or 39% of the global total, in 2021. Figure 1 puts these emissions in the context of all sources of energy-related emissions.

Convenience store with cooler. *Credit: Shutterstock*

ix. If we take the residential and commercial sectors and the end-uses within them, and the 68% of the electricity used in industry that powers motor-driven systems, the total final energy consumption of appliances would be 35% of the global total.

FIGURE 1. GLOBAL SHARE OF TOTAL ENERGY-RELATED CO_2 EMISSIONS BY SECTOR (2021)[x]



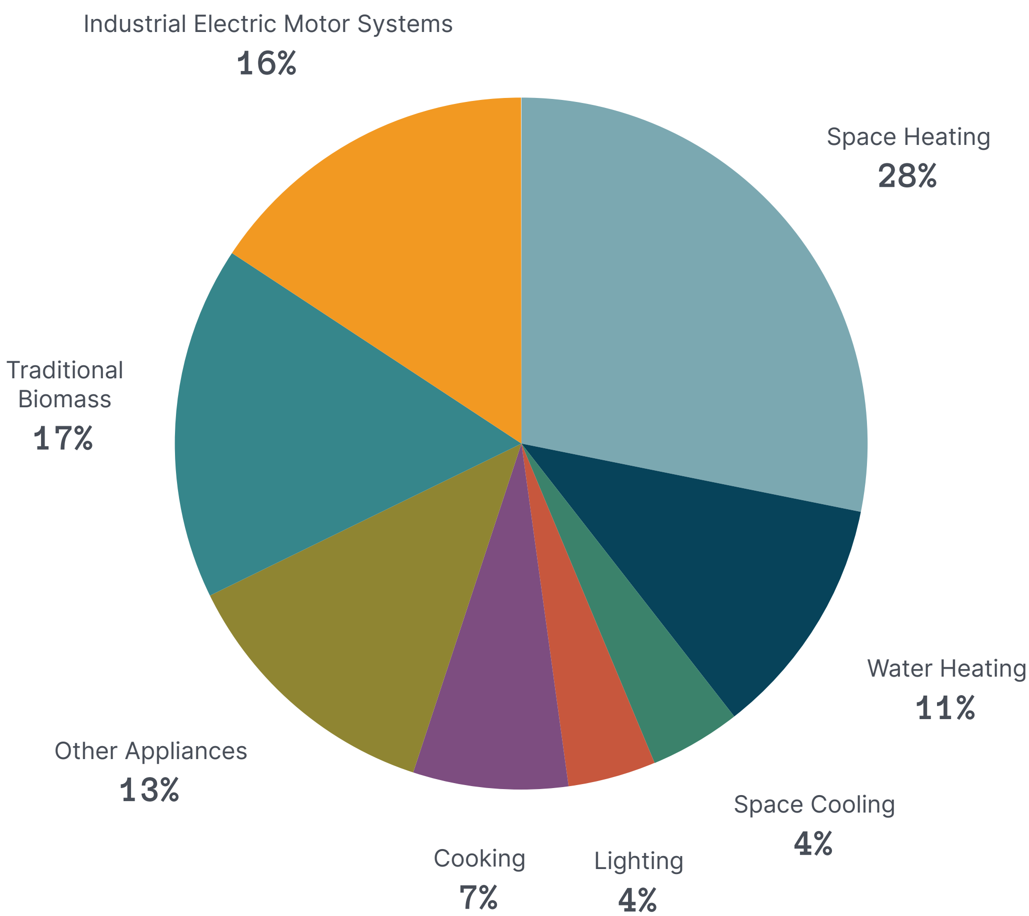
Note: *Includes total energy-related CO_2 emissions by sector in 2021 with indirect emissions (from electricity and heat) apportioned across sectors. 35.9 Gt total across all sectors.*

Man standing near wall of ACs in South Korea. *Credit: Unsplash | noodle kim*

x. CLASP analysis of IEA, "World Energy Outlook 2022," tbl. WORLD_TFC_STEPS, WORLD_CO2_STEPS, with indirect emissions apportioned among sectors using IEA, "CO_2 Emissions from Fuel Combustion," 2020, tbl. SECTOR, SECTORH, ignoring any electrification between 2018 (latest year available) and 2021. Energy used for desalination, estimated at 2 EJ and originally included in Buildings by IEA moved to Other.

IEA further breaks down the energy use of appliances into end-use or major functional categories. Figure 2 shows the energy breakdowns for 2020, the most recent year for which detailed data are available. Emissions breakdowns for the individual end-uses were not available.

FIGURE 2. APPLIANCE FINAL ENERGY CONSUMPTION BY END USE (2020)[14]



Note: *The total final energy consumption for all end uses above totals 148 Exajoules (EJ)*

Space heating is the largest energy user by far, although the load from air conditioning is growing due to rising incomes in countries with hot and humid climates paired with more extreme and frequent heat waves everywhere. Past IEA analyses have estimated that space-cooling loads could grow nearly threefold from 1.5 billion air conditioners today to 4.4 billion by 2050.[15] Also of note is energy use for cooking. Globally, around 2.4 billion people[16] still cook using traditional solid fuels,[xi] leading to significant health and global warming impacts.

xi. Solid fuels include coal/lignite, charcoal, wood, straw/shrub/grass, agricultural crops, and animal dung.

Appliance efficiency standards can curb energy from cooling appliances. China's world-leading AC MEPS have helped to eliminate 70% of the most inefficient models from the market and are expected to avoid 2,322 Mt of CO_2 emissions cumulatively through 2030.

Read the full case study, *Revolutionizing Cooling and Climate: China's Pioneering AC Efficiency Standards*.

OTHER GREENHOUSE GAS EMISSIONS

Fuel Combustion Emissions

CLASP's analysis does not quantify non-CO_2 GHG emissions from direct use for the appliances sector, nor does it estimate the climate impact of methane and refrigerant leaks. Meeting our Net Zero Hero targets for the appliance sector, outlined in Section 3, would yield reductions in important GHG and short-lived climate pollutants like nitrous oxide (N_2O) and black carbon. These climate pollutants have significant warming potential and also contribute to poor air quality, harming human health.

Methane (CH_4) and N_2O are also emitted during fuel combustion, but in quantities that are four to six *orders of magnitude* smaller than CO_2. So, despite these other gasses' high global warming potential (GWP) compared to CO_2, their absolute impact *from combustion* is minuscule.[17,18] They are, therefore, usually ignored in impact analyses.

The one pollutant of note with a large GWP is black carbon. Black carbon is not a gas, but a particulate emitted during incomplete combustion of solid fuels—such as coal or biomass. Black carbon is the second largest contributor to global warming after CO_2.[19] Eliminating black carbon and its associated GWP is yet another benefit of transitioning from traditional biomass, coal, and kerosene to clean cooking and light emitting diode (LED) lighting.

Emissions from Leaks

Energy demand alone does not tell the complete climate impact story of the appliance sector. Fossil fuel appliances and heat pumping appliances (mainly air conditioners, heat pumps, and refrigeration) can also release methane and refrigerants into the atmosphere directly through leaks in the equipment itself, or through leaks in pipes and distribution networks, and fuel extraction and processing in the case of fossil fuel appliances. These leaks can have significant climate impacts. Methane has 82-87 times[xii] the GWP of CO_2,[20] while many refrigerants used today have a GWP hundreds or thousands of times[xiii] that of CO_2.[21]

CLASP's analysis did not quantify the climate impacts from methane or refrigerant leaks when estimating the total emissions from the appliances sector. Additional information about their climate impacts is presented below.

Methane (natural) gas was previously proposed as a "bridge fuel" and a cleaner alternative to coal for space heating and electricity generation, as well as an alternative to coal and traditional biomass for cooking. The availability of cheap methane gas extracted through hydraulic fracturing ("fracking"), drove a sizable decrease in grid emissions in the United States (US). China, India, and Indonesia implemented large-scale campaigns to effectively transition most of their population from coal to liquefied petroleum gas (LPG) or methane gas stoves.

While the health and global warming impacts of methane combustion are smaller than those of coal or traditional biomass, significant amounts of methane leak into the atmosphere during extraction, distribution, and use. Estimates of methane leakage in the US range from 1.4%[22] to 4.7%[23] of total consumption. Methane has 82-87 times[xiv] the GWP of CO_2.[24] Once realistic leakage estimates are factored in, the climate impacts of methane-fueled appliances double compared to combustion alone.[xv] As there remains some controversy regarding the amount of leakage, we have excluded both methane and refrigerant leakage from our estimates of total emissions from the appliances sector, resulting in a more conservative estimate.

xii. 20 year timeframe.

xiii. R22, a hydro-chloro-fluorocarbon (HCFC) commonly used in air conditioners and heat pumps, has a global warming potential (GWP) that is 5,690 and 1,960 times greater than CO_2 over a 20 and 100 year timeframe; while it's non-ozone depleting hydro-fluorocarbon (HFC) replacement, R32, has a GWP of 2,690 (20 year) and 771 (100 year).

xiv. 20 year timeframe.

xv. Based on CLASP analysis.

Close up of gas stove in use. *Credit: Teona Swift*

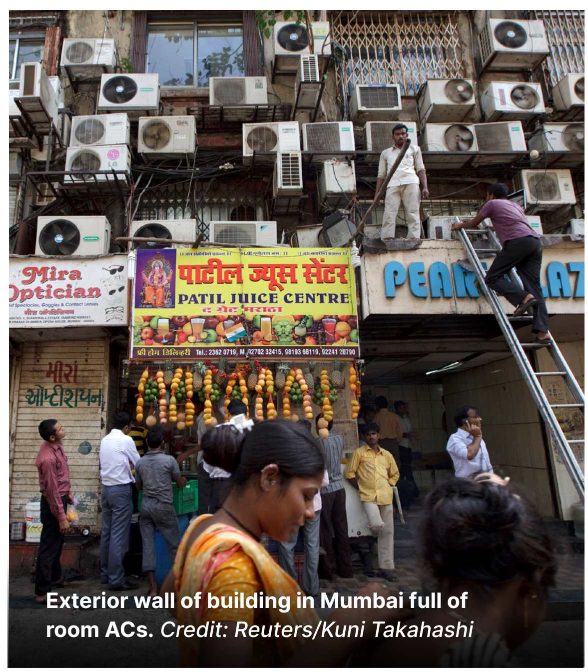
While efficiency reduces energy consumption and the associated direct and indirect CO_2 emissions, methane leakage also occurs upstream of the appliance. The primary way to eliminate methane leakage from the appliance sector is to transition from gas to electricity and decommission the gas distribution system. In the case of space heating, water heating, and clothes drying, that transition will rely largely on heat pumps—a technology that collects heat from ambient air, concentrates it, and then brings it inside a conditioned space, such as a building, water tank, or dryer drum.

Air conditioners, refrigerators, and heat pumps all use **refrigerants** to transfer heat between conditioned and unconditioned spaces. Many refrigerants used today have a GWP hundreds or thousands of times greater than CO_2.[xvi] As with gas infrastructure, leakage can also be an issue for heat pumping technologies.

The impact of refrigerant leakage depends on a number of factors, including the type of refrigerant used, charge size, typical leakage from piping, equipment maintenance, and recycling rate at the end of life. Larger systems, such as those used in commercial refrigeration, require more refrigerant and often have long pipe runs between the cabinet and the outdoor unit, with more opportunities for leakage. In contrast, many of the heat pumps used in homes, such as those used in household refrigerators and freezers, clothes dryers, and many water heaters, are self-contained and factory-sealed, minimizing leakage.

As with methane leakage, efficiency does not affect refrigerant leakage. Instead, to curb the impacts of leakage, policymakers will have to use policies to implement the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer and require lower-GWP and natural refrigerants, quality installation, and refrigerant capture and recycling at end-of-life.

In summary, appliances account for a significant share of global greenhouse emissions. CLASP estimates that appliances are responsible for nearly 40% of all global energy-related CO_2 emissions. If we were to account for other GHG emissions and emissions from leaks, appliances' contribution to climate change would be even greater. It is therefore critical that governments prioritize appliance efficiency and electrification now in order to mitigate the negative environmental impacts of appliances.



Exterior wall of building in Mumbai full of room ACs. *Credit: Reuters/Kuni Takahashi*

xvi. R22, a hydro-chloro-fluorocarbon (HCFC) commonly used in air conditioners and heat pumps, has a global warming potential (GWP) 5,690 and 1,960 times greater than CO_2 over a 20- and 100-year timeframe, while its non-ozone-depleting hydro-fluorocarbon (HFC) replacement, R32, has a GWP of 2690 (20-year) and 771 (100-year). Intergovernmental Panel On Climate Change, "The Earth's Energy Budget, Climate Feedbacks and Climate Sensitivity Supplementary Material (7SM)."

1.2 Adaptation & Resilience Benefits

Section 1.1 identifies the negative climate impacts of energy inefficient appliances and equipment, highlighting the need for mitigation via more stringent policies and other measures. At the same time, there is a need to expand access to efficient appliances to the billions of people who currently lack access.

This section highlights the critical role appliances play in enhancing climate adaptation and resilience globally. Rather than focus on the adverse environmental impacts of inefficient appliances, we discuss the positive benefits of expanded access to efficient appliances needed to build resilience to climate change while promoting sustainable development.

CLASP has identified ten essential household appliances central to enhancing climate resilience and meeting the UN SDGs (Table 2).[xvii] These include appliances essential for lighting, maintaining thermal comfort (air conditioners, fans, and heat pumps), enabling cleaner cooking and food preservation (e-cooking and refrigeration), expanding access to vital information (mobile phones, televisions, and radios), and enhanced food security and productivity (solar water pumps).

Women working in a fan factory, Bangladesh. *Credit: CLASP*

xvii. While the ten appliances included in this section are common to all households, we recognize that not every household needs every one of each of the appliances listed. In hot climates, there may be no need for space heating; conversely, in cold climates, there may be no need for space cooling. People use radios, cell phones, and televisions to connect with others, but not every household will require all three. Solar water pumps are just one type of powered equipment used in income-generating activities. At the same time, there is a need to extend access beyond these ten appliances.

TABLE 2: CLIMATE RESILIENCE BENEFITS & SDG INTERLINKAGES FOR TEN APPLIANCES

APPLIANCE	SUSTAINABLE DEVELOPMENT GOALS INTERLINKAGES		CLIMATE RESILIENCE BENEFITS
LIGHTING	**1:** No Poverty **3:** Good Health & Wellbeing **4:** Quality Education **5:** Gender Equality **7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth	**9:** Industry, Innovation & Infrastructure **10:** Reduced Inequalities **11:** Sustainable Cities & Communities **13:** Climate Action	**Health** **Productivity**
AIR CONDITIONERS	**1:** No Poverty **3:** Good Health & Wellbeing **7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth	**10:** Reduced Inequalities **11:** Sustainable Cities & Communities **13:** Climate Action	**Thermal Comfort** **Productivity**
FANS	**1:** No Poverty **3:** Good Health & Wellbeing **7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth	**10:** Reduced Inequalities **11:** Sustainable Cities & Communities **13:** Climate Action	**Thermal Comfort** **Health** **Productivity**
REFRIGERATORS	**1:** No Poverty **2:** Zero Hunger **3:** Good Health & Wellbeing **5:** Gender Equality **7:** Affordable & Clean Energy	**10:** Reduced Inequalities **11:** Sustainable Cities Communities **13:** Climate Action	**Food Security** **Health** **Productivity**
HEAT PUMPS	**3:** Good Health & Wellbeing **7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth	**10:** Reduced Inequalities **11:** Sustainable Cities Communities **13:** Climate Action	**Thermal Comfort** **Health** **Productivity**

TABLE 2 (CONTINUED)			
APPLIANCE	**SUSTAINABLE DEVELOPMENT GOALS INTERLINKAGES**		**CLIMATE RESILIENCE BENEFITS**
E-COOKING	**1:** No Poverty **3:** Good Health & Wellbeing **4:** Quality Education **5:** Gender Equality	**7:** Affordable & Clean Energy **13:** Climate Action **15:** Life on Land	■ **Food Security** ■ **Health** ■ **Productivity**
MOBILE PHONES	**1:** No Poverty **7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth	**10:** Reduced Inequalities **11:** Sustainable Cities & Communities	■ **Access to Information** ■ **Productivity**
TELEVISIONS	**1:** No Poverty **4:** Quality Education **5:** Gender Equality **7:** Affordable & Clean Energy	**10:** Reduced Inequalities **11:** Sustainable Cities & Communities **13:** Climate Action	■ **Access to Information** ■ **Productivity**
RADIOS	**4:** Quality Education	**10:** Reduced Inequalities	■ **Access to Information**
SOLAR WATER PUMPS	**1:** No Poverty **2:** Zero Hunger **3:** Good Health & Wellbeing **4:** Quality Education **5:** Gender Equality **6:** Clean Water & Sanitation	**7:** Affordable & Clean Energy **8:** Decent Work & Economic Growth **10:** Reduced Inequalities **13:** Climate Action	■ **Food Security** ■ **Health** ■ **Productivity**

Affordable, high-quality, efficient appliances that run on renewable energy deliver essential services. When coupled with efforts to address other barriers like access to finance and capacity constraints, appliances improve livelihoods and drive climate-resilient and sustainable development in several ways, as outlined in the sections below.

LIGHTING & ELECTRICITY

Access to basic lighting and electricity[xviii] is needed to build climate resilience and power the appliances and equipment required to promote sustainable development. For example, distributed energy systems are more climate-resilient than centralized energy systems.[25] When people are displaced due to a natural disaster, for instance, distributed energy can be easily relocated within communities to provide immediate relief.[26] Lighting also helps bolster climate resilience by providing access to vital lighting services during extreme weather events, improving safety and wellbeing.[27]

From a sustainable development perspective, electricity and lighting access advances ten UN SDGs by providing households with the power they need to run appliances and equipment. Electricity and lighting access allows households and businesses to work productively and generate income after dark (SDG 1), power appliances needed to grow and preserve food (SDG 2), reduce exposure to harmful indoor air pollution and power health clinics (SDG 3), reduce unpaid domestic labor for women and children and expand education and employment opportunities (SDG 4 and SDG5), achieve universal energy access (SDG 7), promote equitable economic growth for households and communities (SDG 8, SDG 10, SDG 11), and reduce emissions from fuel combustion (SDG 13).

Young child reaching over table to turn on lamp. *Credit: Shutterstock*

xviii. CLASP's has grouped access to lighting and electricity to match current energy access targets under UN SDG 7: Affordable and clean energy. There is no universal definition for energy access. In this analysis we use the ESMAP and SEforAll's Multi-Tier Framework criteria for Tier One access as the minimum threshold to define energy access. Under this definition, households must have access to enough electricity to power basic task lighting and mobile phone charging.

THERMAL COMFORT

Efficient air conditioners, fans, and heat pumps provide critical cooling and heating services while lowering energy demand and resulting GHG emissions. From a climate resilience perspective, air conditioners reduce heat-related mortality and morbidity during extreme heat events, particularly among vulnerable populations such as the elderly and those with pre-existing health conditions. Fans provide a low-cost and energy-efficient means of cooling during heat waves, reducing the risk of heat stroke and other heat-related illnesses. Good quality appliances are more dependable during periods of extreme heat. For example, fans that meet international quality standards are exposed to a harsh environment with 40 °C [104 degrees Fahrenheit (F)] temperature and 93% humidity prior to testing, ensuring that they can function well under such conditions.[28]

Efficient cooling and heating appliances also advance at least seven SDGs by improving public health by reducing risk of heat-related illness (SDG 3),[29] improving energy efficiency (SDG 7), enabling better working conditions that boost productivity (SDG 8),[30] reducing inequalities in access to cooling services (SDG 10), improving living conditions and access to basic human services in urban environments (SDG 11), and mitigating GHG emissions (SDG 13).

COOKING & FOOD PRESERVATION

E-cooking appliances and refrigerators are essential drivers of human development. Both appliances advance a number of UN SDGs, which bolster economic and social development and improve climate resilience. These appliances help reduce the burden of unpaid labor, mostly for women and children, by reducing the need to collect fuelwood for cooking and to take frequent trips to the market, allowing additional time for educational, income-generating, or leisure activities (SDG 1, SDG 4, and SDG 5). A global transition to e-cooking would help reduce deforestation, GHG emissions, and exposure to harmful air pollution (SDG 5, SDG 13, and SDG 3). Unsustainable harvesting of fuelwood and incomplete burning of biomass (mainly for cooking) accounts for up to 2% of global GHG emissions and up to 25% of annual anthropogenic black carbon emissions.[31] Refrigerators help extend the shelflife of food, reducing food waste and contributing to improved food security (SDG 2).

Margaret Malelu, a participant in the Global LEAP Awards EPC usability testing. *Credit: CLASP*

FOOD SECURITY & PRODUCTIVITY

Access to efficient and good quality solar water pumps enhances food security and builds climate resilience on smallholder farms by enabling farmers to adapt to changing climatic conditions and maintain productivity when rainfall becomes more variable due to climate change. Solar water pumps are particularly beneficial to those smallholder farmers whose crops require a consistent water source, such as staple crops like rice and maize, and horticulture. Water pumping can increase yields as much as three-fold.[32]

Good quality solar water pumps are more resilient to a changing climate. VeraSol, an off-grid quality assurance program, simulates pump performance under drought conditions by testing a solar water pump's ability to withstand periods of inadequate water supply through dry run protection tests. The dry run protection prevents pumps from operating without water, reducing risks of overheating pump motors and breaking the mechanical seals, which would cause malfunction and permanent damage.[33]

Additional sustainable development benefits from solar water pumps may include higher incomes from increased yields (SDG 1),[34] improved food security (SDG 2),[35] enhanced water security when water resources are managed appropriately (SDG 6), and time savings that enable women and children to direct their time toward education, income generation, or leisure (SDG 1, SDG 4, and SDG 5). Efficient solar water pumps also enable access to energy services (SDG 7) and mitigate or prevent GHG emissions by displacing the need for diesel fuel (SDG 13). Together, these benefits can reduce inequalities within countries (SDG 10) and promote more inclusive and sustainable economic growth among smallholder farms (SDG 8).

ACCESS TO INFORMATION

Mobile phones, televisions, and radios help people access vital information. For example, before, during, and in the aftermath of natural disasters or severe weather events, these technologies serve as crucial communication tools, enabling people to access emergency information and contact authorities for assistance. Expanded access to mobile phones, specifically smartphones, help close the digital divide and promote climate-smart agriculture. For example, using a smartphone and mobile application, a farmer can upload photos of their crops to help detect crop diseases or fine-tune watering needs during a drought.[36] Farmers can also connect with new buyers, making them more resilient to disruptions in local supply chains.[37,38]

Communications technologies advance several UN SDGs. Access to television and cable programming has positive effects on school enrollment and literacy (SDG 4), family planning (SDG 2), financial decisions, and health, particularly for women and girls (SDG 5).[39] In India, television access was associated with a significant decrease in the reported acceptability of family violence toward women and of son preference, as well as increases in women's autonomy and decreases in fertility.[40] In some markets, televisions are used to generate additional income (SDG 1). A survey of off-grid-appropriate television consumers in Kenya, Rwanda, Tanzania, and Uganda found that 9% of respondents used their television as a productive use appliance and reported an average increase in income of $14 USD per week.[41]

02 Current Efforts Fall Short

Woman walking with umbrella in city at night, illuminated by street lights. *Credit: Getty Images*

02

Failure to limit global warming to below 1.5 °C poses a significant risk of reaching tipping points in the Earth's climate system that could amplify climate change and lead to far-reaching and potentially irreversible changes on a global scale.[42] The current average global surface temperature has surpassed the pre-industrial level by 1.1 °C.[43] Achieving NZE and limiting warming to 1.5 °C will require a far greater level of ambition than policymakers, manufacturers, and appliance purchasers and users have shown to date.[44]

There is also an urgent need to intensify efforts to adapt and build resilience to climate change. As many as 3.6 billion people live in regions that are highly vulnerable to climate change.[45] The planet is already feeling the negative social, economic, and public health effects of a warming world. Evidence from the IPCC's latest assessment report (AR6) shows that climate change has reduced food security, affected water security, and hindered efforts to achieve a just energy transition and meet the UN SDGs.[46] Many countries that are at the highest risk to climate-related damages lack access to the energy services and appliances needed to adapt and build resilience to them.

CLASP modeling shows that current efforts to mitigate climate change and expand access to appliances are insufficient.

CLASP modeling shows that current efforts to mitigate climate change and expand access to appliances are insufficient.

CLASP modeling shows that appliance emissions reduction efforts are not on track. Even meeting global benchmark policies (the best current or proposed policy for any particular appliance) will not achieve the reductions needed to reach NZE. Under a BAU scenario, appliance emissions would exceed the IEA's global target needed to achieve NZE in 2050 by 9.0 Gt CO_2. The current best global benchmarks would still exceed the target by 7.1 Gt in 2050.

At the same time, billions of people lack access to even the most basic appliances needed to adapt to a warming world. CLASP's modeling estimated appliance access, or adoption gaps, for ten essential appliances required to build resilience to climate change. Current appliance access gaps range from 675 million people (lighting and electricity) to over 6 billion people (e-cooking appliances).


Man walking with goods in basket, passing store with labeled appliances. *Credit: Reuters*

This section draws attention to the critical need to increase ambition for appliance efficiency and expand access globally. It is divided into two parts.

In part one, CLASP describes what is needed to achieve NZE within the appliances sector using IEA's net zero roadmap. We then model the direct CO_2 emissions, electricity, and fuel consumption (EJ) of residential, commercial, and industrial appliances needed to achieve NZE in 2050. Finally, using Mepsy, CLASP models the impact of two scenarios—BAU and a scenario aligned with global appliance benchmarks—for six primarily residential appliances (space heating, water heaters, air conditioners, ceiling and portable fans, televisions, and refrigerator-freezers), industrial electric motors, and residential and commercial lighting (Table 3). We then compare the estimated emissions from both scenarios in 2050 to IEA's net zero targets for appliances in the same year. Following these three steps, CLASP assesses whether the appliances sector is on track to meet net zero goals.

In part two, CLASP estimates global appliance access, or adoption gaps, for the ten appliances essential for building resilience to climate change. These appliances differ from the eight appliances included in part 1 (Table 3). Many of the appliances needed to build climate resilience, like mobile phones, have a negligible impact on global emissions, but are vital to keeping people safe and connected during emergencies. For that reason, we expand the set of appliances studied to include low energy-consuming appliances. CLASP's analysis focuses at the individual household level and therefore does not include commercial appliances or industrial electric motors.

In both analyses, we find that current efforts are insufficient to reach NZE in 2050 and to meet universal appliance access, or adoption, targets. Greater ambition and commitment to both efficiency and access are needed.

TABLE 3. SUMMARY OF APPLIANCES INCLUDED IN SECTION 2

APPLIANCES ESSENTIAL TO CLIMATE CHANGE MITIGATION	APPLIANCES ESSENTIAL TO CLIMATE RESILIENCE AND SUSTAINABLE DEVELOPMENT
Section 2.1 models the future climate impact of the following residential, commercial, and industrial appliances: ▪ Residential space heating equipment ▪ Residential water heaters ▪ Residential air conditioners ▪ Residential ceiling and portable fans ▪ Residential televisions ▪ Residential refrigerator-freezers ▪ Commercial and residential lighting ▪ Industrial electric motor systems	Section 2.2 evaluates the appliance access/ownership gaps for ten residential appliances: ▪ Lighting ▪ Air conditioners ▪ Fans ▪ Refrigerators ▪ Heat pumps ▪ E-cooking ▪ Mobile phones ▪ Televisions ▪ Radios ▪ Solar water pumps

2.1 Existing Policies Exceed Net Zero

There is an urgent need to limit global warming to 1.5 °C [2.7 °F]. The IPCC projects that a shift from 1.5 °C of warming above pre-industrial levels to 2 °C [3.6 °F] would expose an additional 1.7 billion people to severe heat waves, raise the average sea level by an additional 10 centimeters (cm) [4 inches (in)], and expose hundreds of millions more people to climate-related risks and poverty.[47] Recent modeling from the World Meteorological Organization (WMO) finds we will surpass the 1.5-degree threshold between now and 2027.[48] It is therefore critical to understand what actions are needed to restrict warming to 1.5 °C and assess whether we are on the correct path.

APPLIANCES IN IEA'S ROADMAP

In 2021, the IEA published a landmark roadmap for reaching NZE by 2050, giving us a 50-50 chance of limiting warming to 1.5 °C. The analysis showed that it is possible to restrict warming to 1.5 °C while simultaneously meeting climate resilience and energy access goals.

However, the window to achieve NZE is narrowing. IEA updated the net zero roadmap in 2022. Results show that a faster-than-anticipated economic recovery from the Coronavirus disease (COVID)-19 pandemic has pushed global fuel-related emissions over 36 Gt CO_2 in 2021, the highest single-year increase ever and back to the historic high of 2019.[49] This development narrows the window of possibility for achieving net zero and increases the needed speed and ambition of transformative action.

To reach NZE, IEA's roadmap calls for complete decarbonization of the electric grid, the electrification of fossil-fueled end uses, and greatly improved energy efficiency. IEA expects the electricity sector to decarbonize before industry, buildings, and transportation.[50] Their Net Zero Emissions scenario shows that electricity sector emissions must fall from 14 Gt CO_2 in 2021, to 7 Gt in 2030, to 0 Gt in 2040. As many appliances are powered by electricity, this decarbonization of the electric system would reduce appliance emissions without any improvements to the appliances themselves. However, **CLASP's analysis finds that decarbonizing the electricity system is not enough to reach NZE in 2050.**

EFFICIENT APPLIANCES KEEP NET ZERO ALIVE

There is a limit to the amount of electricity that can be provided by carbon-free sources. In IEA's Net Zero Emissions by 2050 scenario, renewable electricity generation capacity expands fourfold from 2020 to 2030. This equates to a 15% compound annual growth rate—much higher than historical rates—and it is not realistic to expect more. Therefore, electric appliances will need to become more efficient to fit within this "renewable energy budget."

According to IEA, the energy consumption of the *current* stock of electric appliances (which we estimate at 70 EJ or 19,444 TWh in 2021) *could* be accommodated by renewable sources by 2030.[xix] However, the stock will grow. Additional efficiency improvements will therefore be needed to make room in the renewable electricity budget for:

1. Newly electrified appliances and transportation;
2. Providing first-time access and resilience; and
3. A growing and wealthier population.

Many appliances, and a majority of space and water heating equipment, are powered directly by fossil fuels, not by electricity, and would continue to have negative impacts regardless of electricity system decarbonization. Similar to emissions from electricity generation, IEA anticipates that direct emissions from fuel-burning appliances would need to be reduced to achieve net zero.

xix. IEA projects renewable generation to grow to 23,064 TWh in 2030 in its Net Zero Emissions by 2050 scenario. IEA, "IEA World Energy Outlook 2022: Tables for Scenario Projections," tbl. WORLD_Elec_NZE.

Using IEA's Net Zero Emissions by 2050 scenario, we estimate that appliances in 2050 may use up to 82 EJ of electricity and emit up to 0.1 Gt CO_2 directly. The electricity would be provided by renewable and other zero-carbon sources, while the remaining direct emissions would be captured, resulting in NZE. These twin appliance energy and emissions budgets (or allowances) are shown for intermediate years in Table 4.

To develop Table 4, CLASP estimated the indirect emissions from electricity consumption for appliances in both buildings and industry, assuming that motor systems consume 68% of industrial electricity. These indirect emissions from appliances would fall by approximately 50% by 2030 as the electricity system decarbonizes, and then to zero by 2040.[51] However, this electricity system transformation is only possible if the total electricity consumption increases by less than 20% (70 to 82 EJ) between 2021 and 2050.

TABLE 4. APPLIANCE ELECTRICITY AND EMISSIONS BUDGETS NECESSARY TO ACHIEVE THE IEA'S NET ZERO SCENARIO[52]

SECTOR	IMPACT	2021	2030	2040	2050
Buildings (Residential and Commercial)	Electricity Consumption (EJ)	45	48	54	57
	Indirect Emissions (Gt CO_2)	6	3	0	0
	Direct Emissions (Gt CO_2)	3.0	1.6	0.5	0.1
Industrial Electric Motor Systems	Electricity Consumption (EJ)	25	25	25	25
	Indirect Emissions (Gt CO_2)	5	3	0	0
	Direct Emissions (Gt CO_2)	0	0	0	0
Total	Electricity Consumption (EJ)	70	73	79	82
	Direct Emissions (Gt CO_2)	3.0	1.6	0.5	0.1

Appliance electrification is necessary to reduce impacts from direct fossil fuel combustion. A transition to heat pumps and other electric alternatives for space heating, water heating, cooking, and lighting will both reduce CO_2 emissions and cut down on air pollution. While it is possible to decrease space heating and cooling energy use through building envelope improvements, these are much harder due to the significantly longer lifetimes of buildings compared to appliances.

Second, IEA expects an increase of 2 billion people and a doubling of the world gross domestic product (GDP) by 2050.[53] This will lead to additional appliance uptake,[54] as will additional appliances and associated electricity consumption from providing access to people who currently lack appliances. However, as previously mentioned, total electricity consumption cannot increase much if there is hope of staying within the renewable electricity budget. We assume any electricity demand in excess of this budget would be supplied predominantly by fossil fuels.

In practice, this means that current electric resistance appliances for space and water heating must be replaced with heat pumps that are two to four times more efficient, which "makes room" in the budget, which then allows methane gas and oil users to also convert to heat pumps. For appliances that are already all-electric (cooling, refrigeration, domestic appliances and electronics, lighting, and industrial electric motor systems), efficiency improvements must accommodate millions of new users and growth in economic activity.[55]

Shoppers and staff conversing in front of wall of new room ACs. *Credit: Shutterstock*

So, while the amount of electricity consumed does not appear to change significantly from 2021 through 2050, dramatic efficiency improvements are masking substantial growth in the number and usage of appliances. Without ambitious new policies to drive efficiency improvements, direct emissions from appliances will continue while energy use will grow substantially, exceeding the renewable electricity budget and requiring continued use of fossil-fueled electricity.

Even if policies were aligned to CLASP's Global Benchmark Scenario, efficiency improvements would be insufficient and energy consumption would exceed the renewable electricity budget for residential and industrial motor systems by nearly 100 EJ in 2050, resulting in 7.2 Gt CO_2 in 2050.

The authors used Mepsy, CLASP's Appliances & Equipment Climate Impact Calculator, to model the potential reductions from efficiency and electrification policies for eight appliances responsible for a majority of appliance energy use[xx] and which have a substantial overlap with the ten essential appliances discussed in Section 1.2.[xxi] The eight appliances include:[56]

- Six primarily residential appliances: space heating, water heaters, air conditioners, ceiling and portable fans, televisions, and refrigerator-freezers;
- Industrial electric motors; and
- Residential and professional (commercial and outdoor) lighting.

The only commercial-sector appliance currently implemented in Mepsy is lighting; therefore, we are primarily comparing our results to IEA's Net Zero Emissions by 2050 energy budget for the residential sector and 68% of industrial electricity that we estimate powers motor systems.

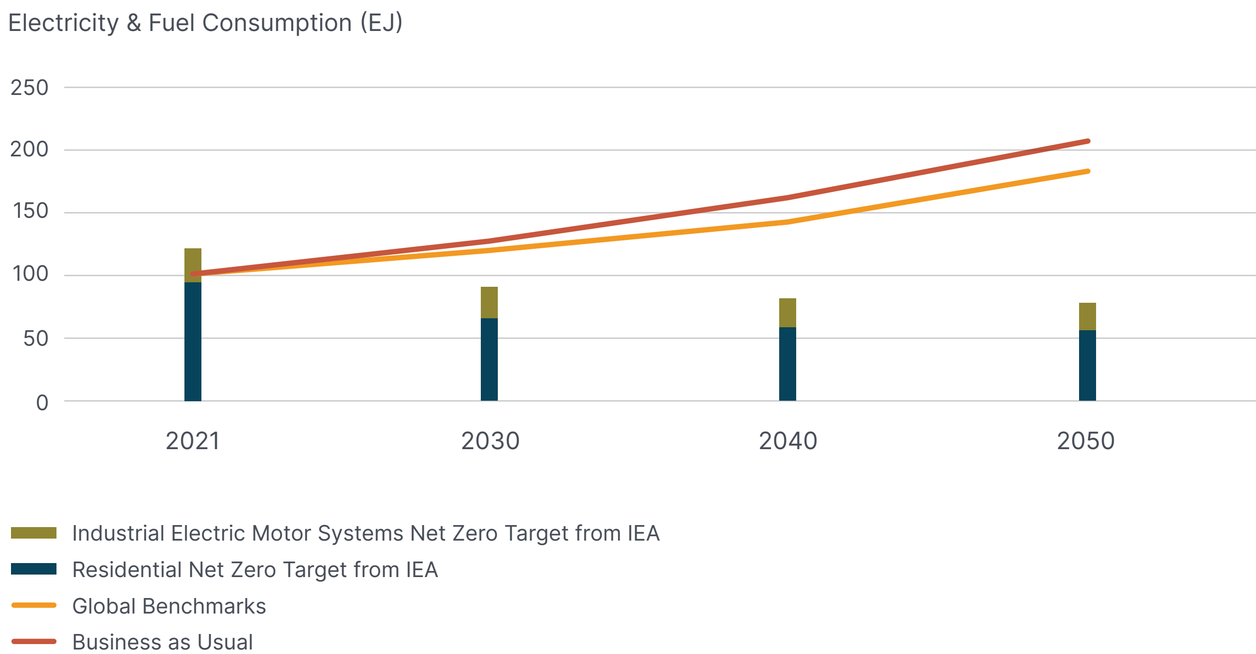
xx. Our review of residential and commercial end-use consumption surveys and modeled electricity use from industry in China, European Union, India, and the United States found that these eight are responsible for 75% energy use.

xxi. Cooking appliances, radios, cell phones, and solar water pumps are not included in Mepsy and were not modeled.

CLASP assessed the energy and CO_2 emissions reduction potential due to policy over the period 2021–2050. Figure 3 and Figure 4 show the modeled energy consumption and emissions, respectively, under a BAU scenario and a scenario modeling today's global benchmarks. Both scenarios take into account electricity system decarbonization in line with the Net Zero Emissions by 2050 scenario. However, any electricity consumption beyond the "renewable energy budget" is assumed to be supplied by primarily fossil-fueled generation[57] and any space and water heating that is not electrified will continue burning fossil fuels. In the BAU scenario, efficiencies are maintained at today's typical levels, while in the Global Benchmarks scenario, they are increased to some of the world's most stringent policies recommended by CLASP and other efficiency organizations, starting in 2025.[58] For air conditioners, refrigerators, and industrial motors, they are based on U4E's model regulations.[59] Some of these global benchmarks remain aspirational and have yet to be adopted in full by any government.

In Figures 3 and 4 below, CLASP compares budgets based on IEA's Net Zero by 2050 scenario for appliances to the two policy scenarios for both energy use (electricity and fuel consumption) and CO_2 emissions. The graph in Figure 3 shows that BAU and even some of the most ambitious policies in play today for residential and industrial appliances greatly exceed the energy budgets. Despite some improvement over BAU, the efficiency gains from aligning policies to global benchmarks will be nullified by growth in the number and use of appliances. They fail to take advantage of energy reductions achieved by heat pumps replacing electric resistance and fossil fuels for space and water heating.

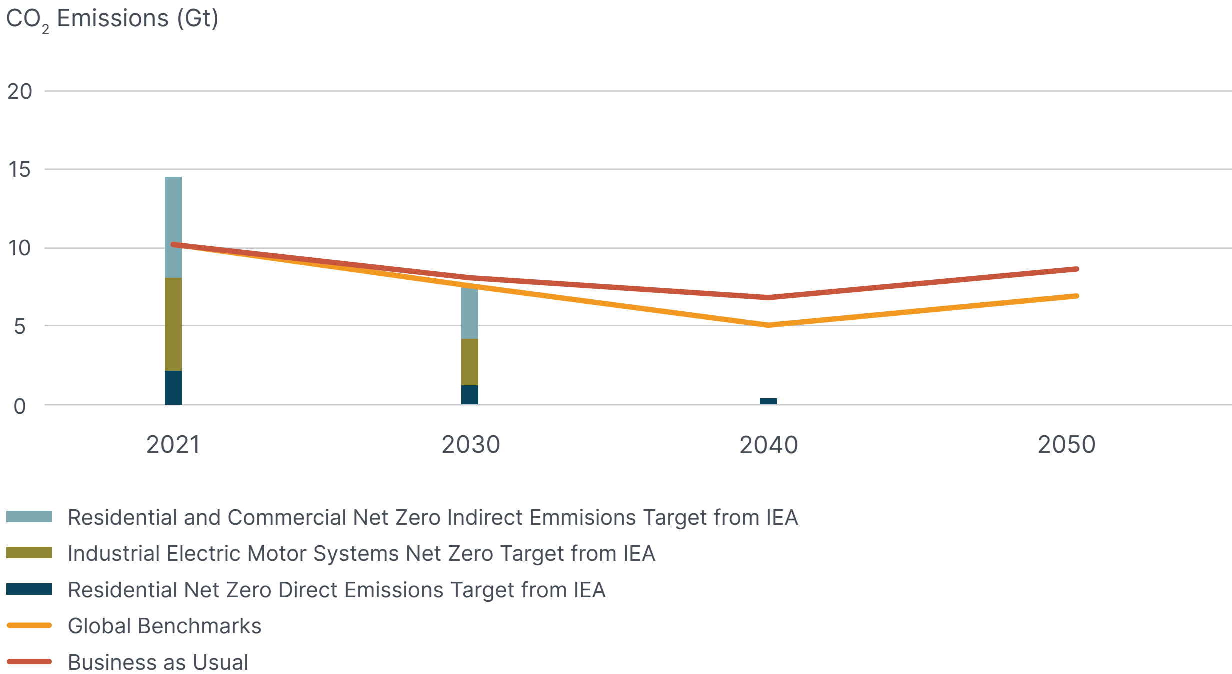
FIGURE 3. ELECTRICITY & FUEL CONSUMPTION UNDER BAU & GLOBAL BENCHMARKS SCENARIOS



Note: *Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2023-2025. Appliances include major residential appliances and industrial electric motors systems (lines). Results are overlaid with IEA's energy budgets for the relevant sectors (bars).*

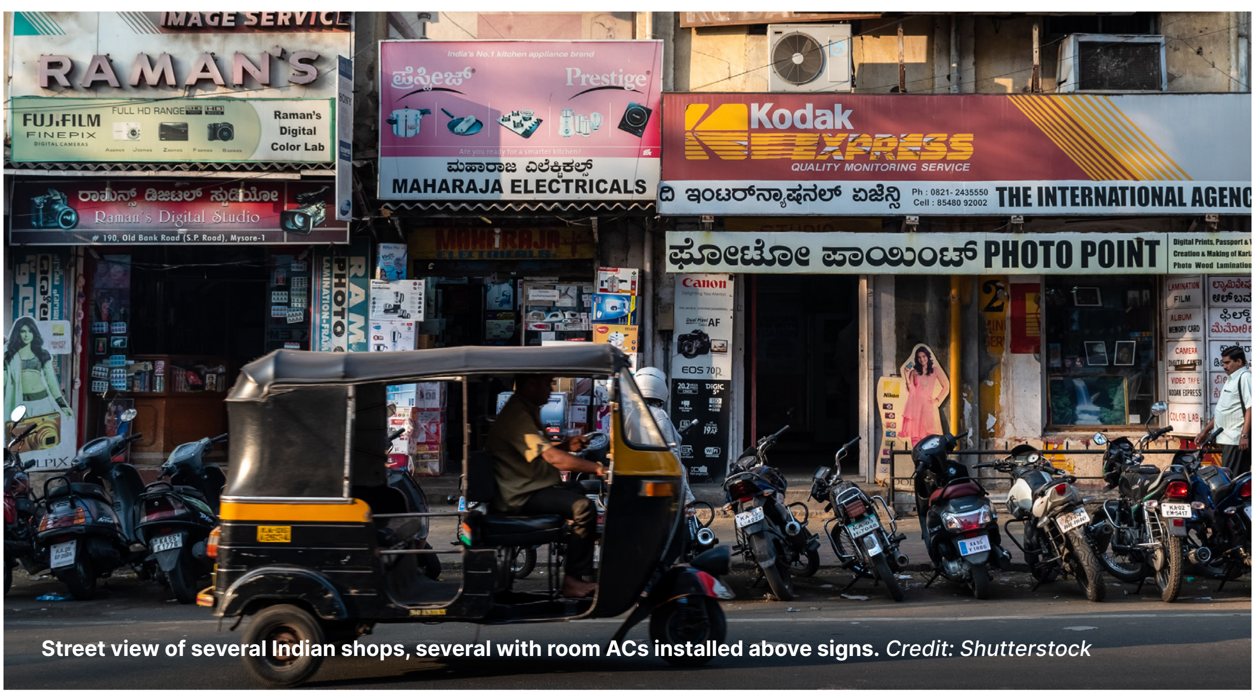
As a result of energy use (fuel and electricity) exceeding the budget and not fully electrifying, the emissions do not fall to 0.1 Gt by 2050 as required in the emissions budget in Figure 4, and even grow between 2040 and 2050, in line with growing energy use.

FIGURE 4. CO_2 EMISSIONS UNDER BAU & GLOBAL BENCHMARKS SCENARIOS



Note: *Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2023-2025. Modeled CO_2 emissions under BAU and today's best appliance efficiency policies for major residential appliances and industrial electric motors systems (lines); overlaid with IEA's Net Zero Emissions by 2050 trajectory for the relevant sectors (bars). Assumes electric grid decarbonization in line with Net Zero by 2050 Roadmap.*

In sum, the BAU and Global Benchmarks scenarios are off track to reach NZE in 2050 by 9.0 Gt and 7.1 Gt, respectively.



Street view of several Indian shops, several with room ACs installed above signs. *Credit: Shutterstock*

2.2 Large Access Gaps Persist

Adapting to a warming world will require appliances. However, many households and businesses do not have access to the appliances they need because they cannot afford them, modern appliances are not available in their area, or they do not have access to modern energy. At the same time, there is an urgent need to improve the efficiency of existing appliances and promote rapid decarbonization and reduced dependence on fossil fuels within the built environment by adopting electric heating and cooking solutions.

To understand the magnitude of current appliance access and ownership gaps, we used publicly available data sources to quantify the penetration of appliances in countries and estimated the number of people lacking access to each essential appliance type.[xxii] For lighting, air conditioners, fans, refrigerators, mobile phones, televisions, and radios, we focus on the need and benefits of first access. For heat pumps and e-cooking, we focus on the need and benefit of a shift to electric alternatives. For solar water pumps, we cover both smallholder farmers benefiting from mechanized (rather than manual) irrigation for the first time or switching away from polluting diesel. Despite the different circumstances of people accessing appliances for the first time or switching to efficient alternatives, the two scenarios share benefits: lower fuel costs, lower pollution, and lower GHG emissions.

Man setting up solar water pump. *Credit: CLASP*

xxii. The data and methodology used to estimate appliance access gaps are detailed in a separate document, Annex A: Appliance Access Gap Methodology.

CLASP's analysis finds large access or ownership gaps exist for all ten appliances. Table 5 shows the percentage of the population without access to each appliance.[xxiii] For four of the ten appliances assessed, we estimated access rates for 162 countries, which make up the vast majority of the global population. In some cases, estimating global appliance access for all countries was not appropriate or not possible due to a lack of data (see heat pumps, televisions, lighting, and solar water pumps). In these cases, we assessed access as a percentage of the subset of the global population for which data were available. For example, we were only able to estimate heat pump access for 25 countries, instead of 162; therefore, the data presented for heat pumps reflect access in those specific countries, rather than access globally.

TABLE 5. GLOBAL APPLIANCE OWNERSHIP/ACCESS (LATEST YEAR AVAILABLE)

APPLIANCE	BASE POPULATION* (BILLIONS)	POPULATION THAT OWNS APPLIANCE (BILLIONS)	POPULATION THAT DOES NOT OWN APPLIANCE (BILLIONS)	PERCENT OF POPULATION THAT OWNS APPLIANCE	PERCENT OF POPULATION THAT DOES NOT OWN APPLIANCE
Lighting	7.7	7.0	0.7	91%	9%
Air Conditioners and Fans	2.4	1.2	1.2	50%	50%
Refrigerators-Freezers	7.7	6.0	1.7	78%	22%
Heat Pumps	2.4	0.8	1.6	34%	66%
E-Cooking	7.3	1.1	6.2	15%	85%
Solar Water Pumps	2.1	0.0	2.1	1%	99%
Mobile Phones	7.7	5.8	1.9	76%	24%
Televisions	7.7	6.7	1.0	87%	13%
Radios	3.2	0.9	2.3	28%	72%

**Population varies based on data availability. Refrigerator, television, lighting, and mobile phone access gap data are available for 162 countries, e-cooking data are available for 148 countries, radio data are available for 51 countries, heat pump data are available for 25 countries, and solar water pump data are available for 13 countries. Air conditioner and fan data are available for 66 countries and were provided by Sustainable Energy for All. Please see Annex A: Appliance Access Gap Methodology for the complete list of countries and original data sources.*

Appliance access, or ownership gaps, at the country level for the ten appliances listed in Table 5 above are shown in Figures 5-13. Each country is shaded according to the size of the access gap:

- Countries with small access gaps are shaded in dark blue.
- Countries with large access gaps are shaded in red.
- Countries shaded in gray are those for which data are not available.

The data and methodology used to estimate appliance access gaps are detailed in Annex A: Appliance Access Gap Methodology.

xxiii. To estimate the number of people or households that lack access to a specific appliance, we multiply the total households/population in a given country by the proportion without access. This represents the appliance access gap in that country. We supplement any missing data (for countries, recent years, or both) through regression and other modeling, resulting in a worldwide view of access gaps for essential appliances.

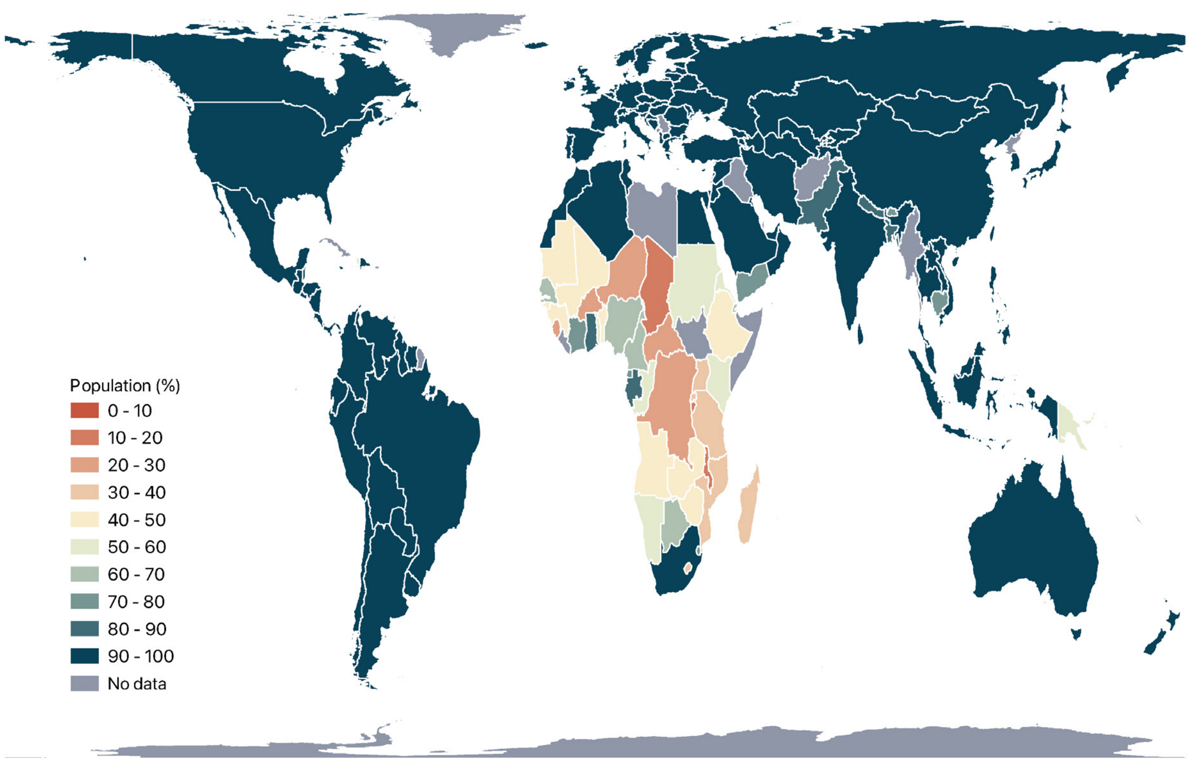
LIGHTING

Universal access to modern energy services is one of three priorities under SDG 7. This goal has prioritized energy services that meet Tier One electricity access according to the World Bank's Energy Sector Management Assistance Program (ESMAP) and Sustainable Energy for All's (SEforALL) Multi-Tier Framework, which is sufficient to power basic task lighting.[60] While progress has been made to close energy access gaps, particularly in India, the number of people without access to energy services actually increased in 2022.[61] In this analysis, we use access to electricity as a proxy for access to **lighting,** ignoring lanterns and kerosene lamps, which are not considered modern appliances.[62]

Based on these assumptions, we estimate that 8% of the global population (675 million people) lacked access to lighting in 2021.[63] The largest access gaps for lighting occur in sub-Saharan Africa.[xxiv] Of the 675 million people without access to electricity, nearly 83% (566 million people) reside in sub-Saharan Africa.[64] Unfortunately, steady progress in electrification has been offset by population growth. As a result the number of people without access has remained stagnant.[65] Within sub-Saharan Africa, South Sudan, Burundi, and Chad have the largest access gaps, with 92%, 90%, and 89% of the population lacking access to electricity and task lighting, respectively (Figure 5).

Within many countries, there is a sharp divide in electricity access between urban and rural communities. According to the latest Energy Progress Report, electrification has occurred at a faster pace in rural areas than in urban areas since 2010.[66] Unfortunately, access gaps in rural environments remain large because access rates in rural areas started from very low levels. Closing lighting access gaps in rural communities will require a better understanding of electricity uses and greater mobilization of financing to make access to electricity and lighting more affordable and infrastructure more resilient.[67]

FIGURE 5. RESIDENTIAL ELECTRICITY & LIGHTING ACCESS (2021)



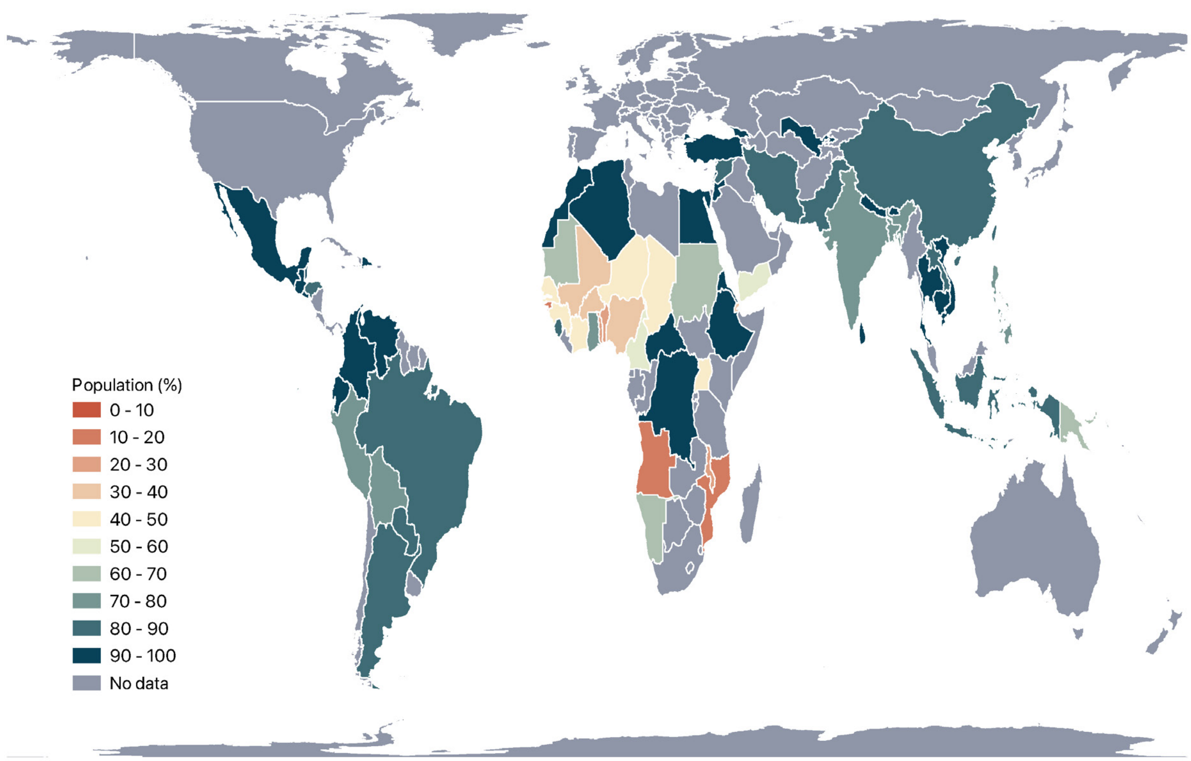
xxiv. This analysis groups countries into regions and sub-regions according to classifications designated by the United Nations Statistics Division. Available here.

AIR CONDITIONERS & FANS

Air conditioners and fans supply critical cooling services that provide thermal comfort by lowering the ambient temperature of a space and increasing airflow. A more comfortable environment decreases the risks of heat-related health complications and can improve productivity.[68,69] Fans are already ubiquitous in hot and humid countries, including India[70] and Indonesia,[71] but as incomes and global temperatures rise, they may be replaced with air conditioners. The IEA estimates that by 2050, as much as two-thirds of the world's population could own an air conditioner; if efficiency is not prioritized, energy demand for space cooling will more than triple.[72]

CLASP estimates that 1.2 billion people are at high risk due to a lack of access to air conditioners and fans (Figure 6), based on a sample of 66 countries assessed in SEforALL's 2022 report *Chilling Prospects: Tracking Sustainable Cooling for All.*[73] Most of the 1.2 billion at risk are the urban and rural poor. These communities often do not have access to electricity, live below the poverty line, and/or live in buildings with poor ventilation and construction. The largest access gaps occur in Southern Asia (422 million), sub-Saharan Africa (375 million), and Eastern Asia (158 million).

FIGURE 6. RESIDENTIAL AC & FAN ACCESS, HIGH-RISK POPULATION (2022)[74]



Note: *SEforALL's Chilling Prospects report explored global cooling-access gaps among 54 high impact countries and the high-temperature regions of 22 countries not considered high impact. It disaggregates between populations at high risk due to a lack of access to cooling (the rural and urban poor), those at medium risk (the lower-middle-income population) and those at low risk (the middle-income population). This map shows cooling access for high risk populations in high impact and non-high impact countries.*

REFRIGERATORS

Modern **refrigeration** has changed the way households secure, prepare, and store food, liberating women and children from household drudgery by reducing the time needed to shop for groceries and prepare food. Evidence from the US shows that the diffusion of refrigerators, washers, and other durable household appliances contributed to a 70% decline in the time spent on housework between 1900 and 1975, and helped propel women into the workforce.[75] Access to a refrigerator frees up additional time for those responsible for meal preparation, unlocking new opportunities for productive or leisure activities.

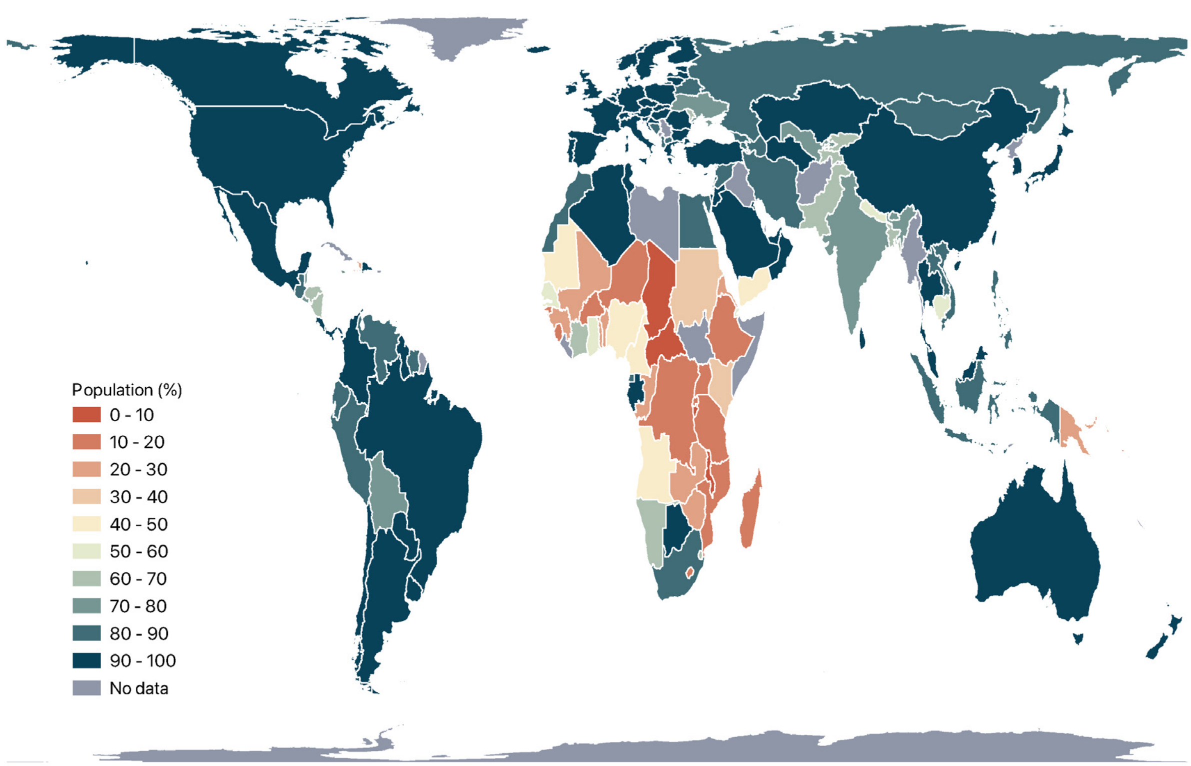
Refrigerators are also used by small businesses to generate more income through the sale of cold drinks and perishable items. A survey of solar off-grid refrigerator customers in Kenya, Tanzania, and Uganda found that 45% of customers were interested in using their fridge to generate more income, including 18% of customers who purchased their refrigerator to sell cold drinks.[76] Beyond household and productive use, refrigerators provide vital cooling services from vaccine storage to post-harvest loss reduction for perishable agricultural goods. This report assesses refrigerator access for products suitable for domestic and light commercial use only.

CLASP estimates that 75% of the global population has access to a refrigerator. There is a large divide in refrigerator access between sub-Saharan Africa and the rest of the world (Figure 7). An estimated 60% of the population in sub-Saharan Africa does not have access to a refrigerator (822 million people). Within the sub-region, Mauritius, Gabon, Botswana, Equatorial Guinea, and South Africa have the highest rates of refrigerator ownership, with 85% or more of the population in each country having access.

As with other appliances, the total *number of people* without access to a refrigerator in Asia is similar to sub-Saharan Africa despite the latter having lower access *rates*, due to Asia's much larger population. We estimate that 770 million people in Asia do not have access to a refrigerator, with the largest gaps occurring in South Asia (25% without access, 494 million people) and Southeast Asia (14% without access, 85 million people).

In Oceania, 7 of the 8 million people without access to a refrigerator reside in one sub-region, Melanesia. An estimated 68% of the population in this sub-region, which includes Papua New Guinea, lack access to a refrigerator.

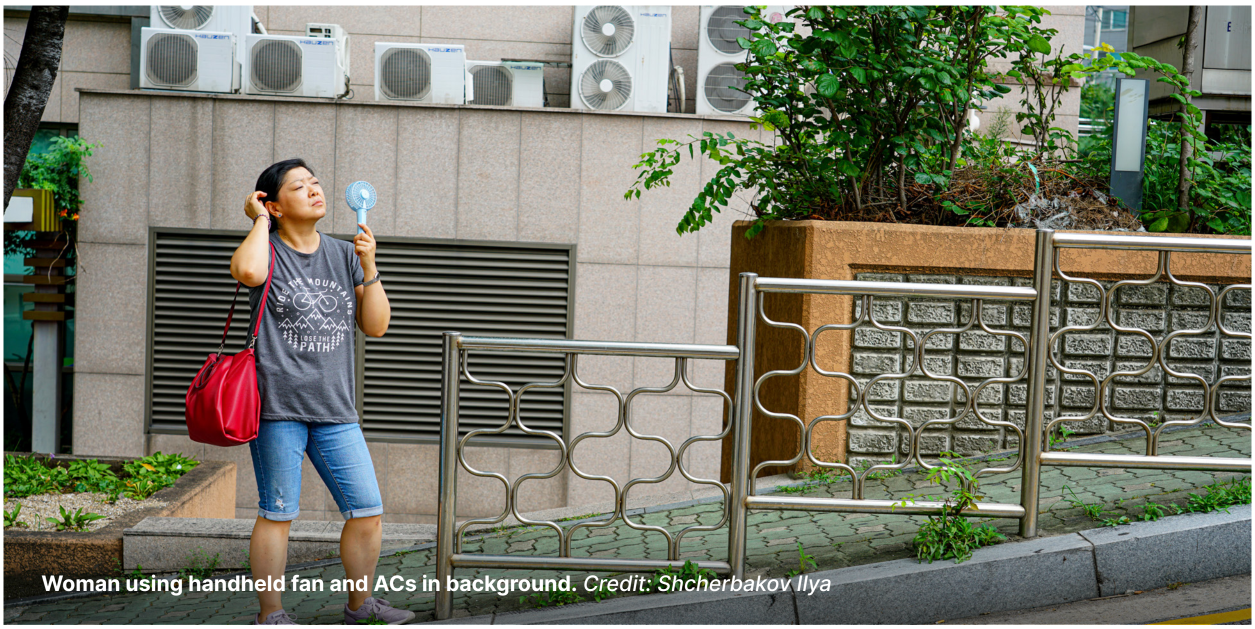
FIGURE 7. RESIDENTIAL REFRIGERATOR ACCESS (2022)



HEAT PUMPS

Heat pumps are a super-efficient way to provide heating and cooling services. Heat pumps used to heat and cool spaces take ambient energy from the air, such that they can move three to five units of heat for every unit of electricity they consume.[77] They are a critical component to building decarbonization, electrification, and NZE goals. The IEA's latest Net Zero Roadmap states that, by 2045, half of global heating demand must be met by heat pumps. Fuel switching via efficient heat pump adoption will be critical in the Global North and key markets like China, where there is a demand for both heating and cooling services and a need to rapidly decarbonize building-related emissions.

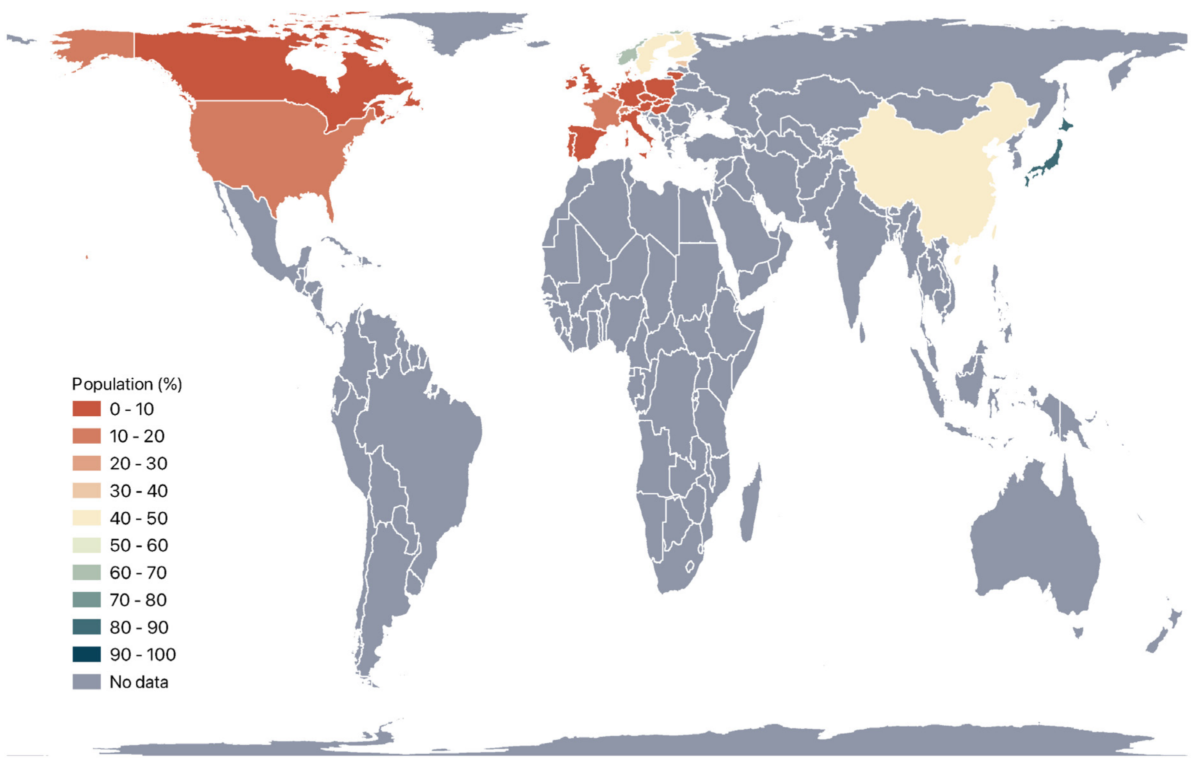
Heat pumps are not a new technology and have been available in many countries for decades. However, uptake of the technology across parts of East Asia, Europe, and North America remains low. Among the 25 countries for which we have data, we estimate that 33% of people use a heat pump to heat their home (Figure 8). This estimate is heavily skewed by Japan, Norway, Sweden, and China where 90%, 60%, 43%, and 42% of the population own the technology, respectively. Many of these countries have made a concerted effort to deploy energy-efficient heat pumps.


Woman using handheld fan and ACs in background. *Credit: Shcherbakov Ilya*

In 1991, Japan sought to reduce its dependence on fossil fuels by increasing electricity generation and improving the energy efficiency of appliances.[78] Over 15 years, 15 million residential heat pumps were deployed for space heating and cooling, and 35,000 heat pump water heaters were deployed over ten years.[79] Today, Japan is one of the largest markets for heat pumps and the second largest market for heat pump water heaters, with shipments of the latter reaching 500,000 units in 2020.[80]

Adoption of efficient heat pumps remains low across North America and most of Europe, though the rate of adoption is accelerating. We estimate that in 2022, 14% of the population in North America, and 7% of the population in Europe used heat pumps. In an effort to decarbonize their economies and reduce dependence on fossil fuels, both regions have put forth efforts to deploy heat pumps at scale. In the US, the Inflation Reduction Act provides rebates of up to $8,000 USD to households to purchase and install a heat pump.[81] In the European Union (EU), the energy crisis sparked by the Russian invasion of Ukraine is pushing multiple countries to meet electrification targets earlier than originally planned. Expanding policies and incentives to increase market penetration of heat pumps will be essential to accelerating heat pump ownership to meet global adoption targets by 2045.

FIGURE 8. RESIDENTIAL HEAT PUMP ADOPTION (LATEST YEAR AVAILABLE)



Note: *We show the latest year for which data are available between the years 2018 and 2022.*

ELECTRIC COOKING

Adopting modern cooking fuels in regions with low clean cooking access and transitioning from fossil fuel to electric cooking in regions with high rates of clean cooking access offer several climate, resilience, and sustainable development benefits. In this section, we assess the proportion of households that have adopted electricity as their primary cooking fuel.

In regions where woodfuels are the dominant cooking fuel, access to clean cooking fuels can help curb deforestation and black carbon emissions, both of which contribute to climate change.[82] Emissions from nonrenewable wood fuels for cooking make up nearly 2% of global emissions (1 Gt CO_2e per year).[83] A lack of clean cooking contributes to 3.7 million premature deaths annually, with women and children most at risk.[84] A transition to clean cooking would help advance a number of SDGs, with substantial benefits to public health. Additional benefits would come in the form of reduced drudgery from fuel collection for women and children, potentially freeing up time for education and income-generating activities.[85]

In regions where the majority of households already have access to clean cooking fuels, a transition to electric appliances would deliver additional health benefits and help drive electrification and decarbonization efforts. Evidence from the US suggests that gas cooking appliances contribute to poor indoor and outdoor air quality (see Section 1).[86]

CLASP advocates for a worldwide transition to e-cooking solutions. While clean cooking technologies like improved biomass stoves and fossil fuel cooking appliances substantially reduce exposure to household air pollution, they still produce emissions that contribute to poor air quality.[87,88] Electric cooking appliances, in contrast, do not directly emit harmful air pollutants like nitrogen oxides (NOx), carbon monoxide (CO), or fine particulate matter.

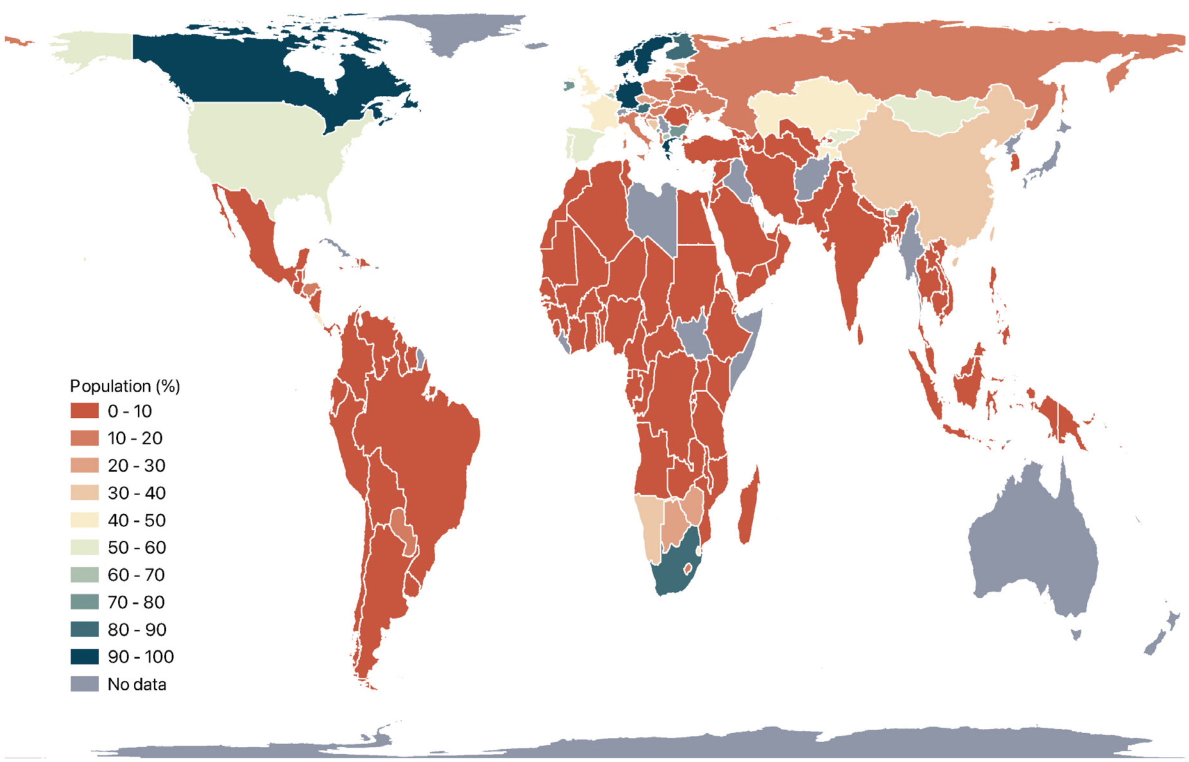
The social and economic barriers to widespread e-cooking adoption are not to be understated. User preferences and cultural cooking practices have a strong influence on households' preferred cooking appliances and fuels. Cooking methods vary across regions and require different appliance-fuel combinations (fuel stacking).[89,90,91] We recognize that a complete transition to e-cooking may not be possible. For example, a person may use a rice cooker, microwave oven, and an outdoor barbeque when preparing a single meal. However, setting a clear target for widespread adoption of e-cooking appliances and electricity as the primary cooking fuel can help align efforts to electrify buildings and ensure the health benefits of a clean energy transition are maximized.

Agnes Kalyonge, Kenyan food blogger and usability testing participant using her electric pressure cooker.
Credit: CLASP

CLASP estimates that only 16% of the global population use e-cooking appliances as their primary appliance for cooking. Use is highest in Western Europe and North America, where 72% and 60% of the population primarily cook with electricity, respectively (Figure 9). Within these sub-regions, use of e-cooking appliances is highest in Norway (100%), Sweden (98%), Denmark (97%), Germany (97%), Greece (93%), and Canada (91%).[92]

Use of e-cooking remains low across Latin America and the Caribbean, Africa, and much of Asia, often driven by a lack of access to electricity and clean cooking appliances. In Latin America and the Caribbean, 98% of the population (63 million people) does not have access to e-cooking. Within Africa, 236 million people across North Africa (98% of the population) and 989 million people in sub-Saharan Africa (93% of the population) lack access to e-cooking. Asia has the largest share of the global population without access to e-cooking. An estimated 1.9 billion people in Southern Asia (99% of the population), 598 million people in Southeast Asia (99% of the population), and 987 million people in East Asia (66% of the population) lack access to e-cooking. In these sub-regions, most households without modern cooking access rely on biomass (e.g., wood and animal dung), while some house-holds rely on kerosene.[93,94]

FIGURE 9. RESIDENTIAL E-COOKING ADOPTION (LATEST YEAR AVAILABLE)



Note: *We show the latest year for which data are available. In most cases, that is 2020.*

SOLAR WATER PUMPS

Approximately 95% of farmland in Sub-Saharan Africa and 60% in South Asia is rainfed—relying on unpredictable weather patterns. **Solar water pumps**—a clean, modern irrigation solution—have the potential to increase yields by two- to threefold, depending on crop and climate.[95]

We assessed solar water pump access in 13 countries:[xxv] Côte D'Ivoire, Ethiopia, India, Kenya, Malawi, Mozambique, Nigeria, Rwanda, Sierra Leone, Uganda, Tanzania, Zambia, and Zimbabwe. For each country, we estimated the number of non-subsistence smallholder farmers that lack a reliable connection to the main power grid and assumed that all could benefit from access to solar water pumps.[96] We focus on solar versus grid-connected electric pumps because solar pumps are:

- More reliable in areas with inconsistent access to the grid;[97]
- Less expensive to run, with zero operation and low maintenance cost, making for an effective investment;[98]
- Easier to install without the help of a technician;[99] and
- Are lower-carbon (unless the local electricity grid is powered by renewable sources).

We found that less than 1% of smallholder farmers in 12 of the 13 countries assessed had access to a solar water pump (Figure 10). The largest access gaps are in India (23 million people), Ethiopia (8 million people), Nigeria (5 million people), Uganda (2 million people), and Kenya (2 million people).

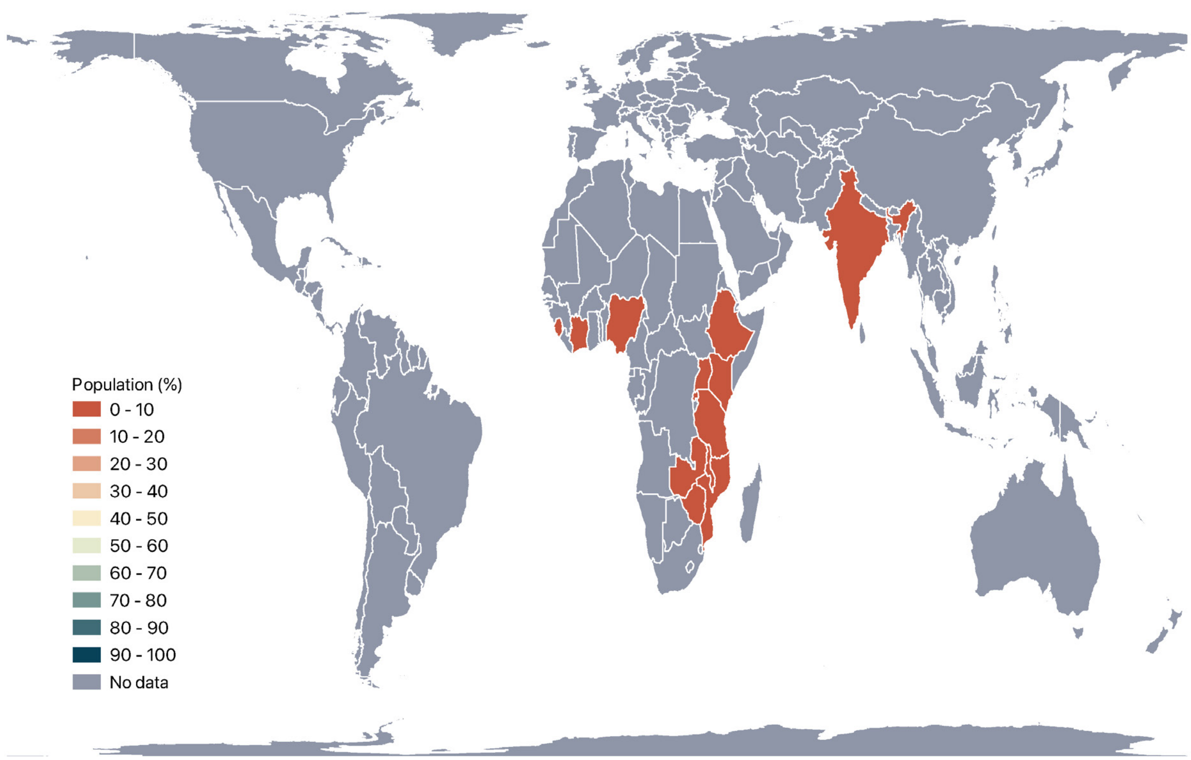
Kenyan man posing with his solar water pump. *Credit: CLASP*

xxv. While there are global datasets of un-irrigated land area (see: Food and Agriculture Organization of the United Nations (FAO), "AQUASTAT", https://www.fao.org/faostat/en/#data/WCAD), it is challenging to estimate the sufficiency of rainfall and the number of smallholder farmers that would benefit from a water pump without detailed market study, hence the more limited data for this appliance.

Most efforts to expand access to pumped irrigation include incentives for fossil fuel-, electric-, and solar-powered pumps. For example, India has used subsidies to rapidly deploy mechanized water pumping solutions to benefit farmers and the agricultural sector, including solar water pumps. However, solar water pumps make up only a small fraction of the total installed pumps in India. It is estimated that of the 30 million irrigation systems installed, 70% are electric, 29% are diesel, and 1% are solar.[100] In 2019, the Indian government launched the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM) scheme, which provides a 60% subsidy for solar water pumps and aims to install 2.75 million pumps by 2022.[101] As of July 2023, over 900,000 irrigation pumps had been installed, 120,000 of them solar water pumps.[102]

Solar water pumps are commercially available but have not yet reached scale. Government and donor intervention is required to help the market reach maturity. Programs are needed that target new business models, access to finance, affordability, and low customer awareness of solar water pump technology.

FIGURE 10. SOLAR WATER PUMP ACCESS (LATEST YEAR AVAILABLE)



Note: *We show the latest year for which data are available between 2018 and 2022.*

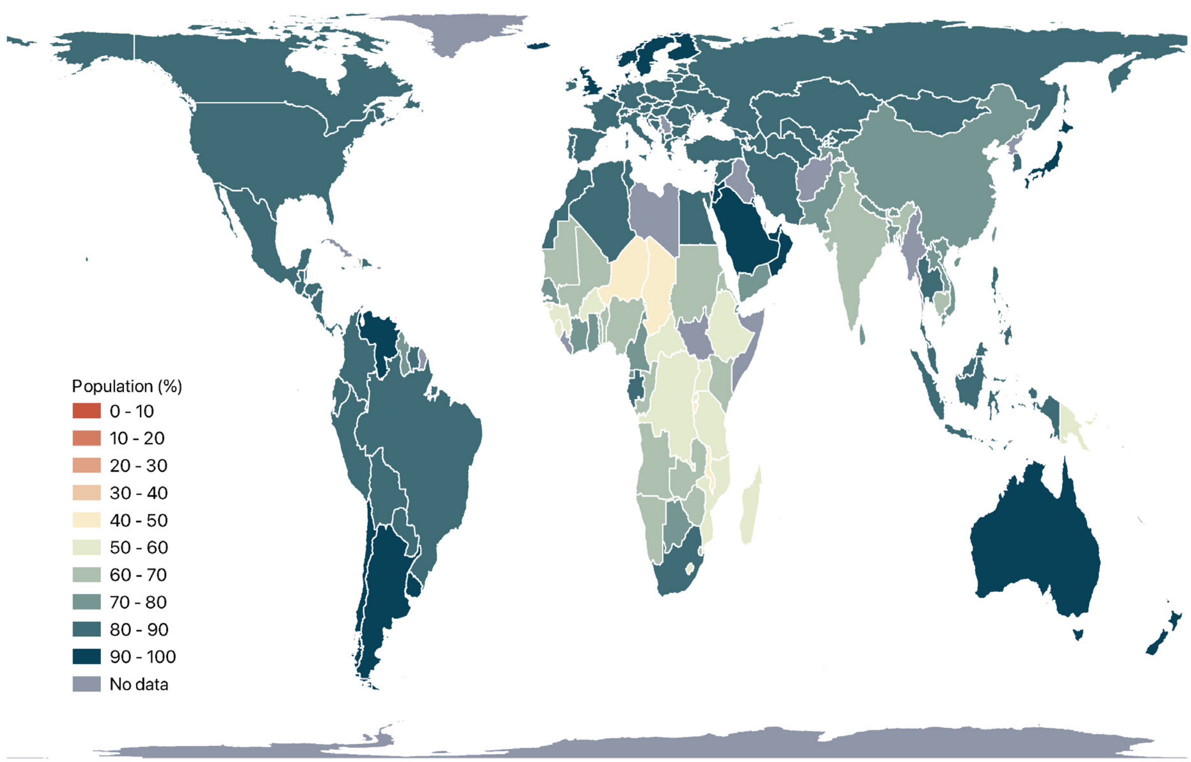
MOBILE PHONES

Mobile phones are critical enablers of sustainable development, allowing people to access vital information and essential services like financial access and healthcare. Bridging mobile phone access gaps helps close the digital divide[xxvi] and enables access to banking and formal credit systems, thereby expanding access to energy and other appliances. Services such as pay-as-you-go financing, which allow customers to pay for solar energy and appliances in installments, have helped make access to modern energy services more affordable and accessible for households with no or limited access to the grid.

Mobile phone ownership is the highest among the ten appliances included in our analysis. An estimated **76% of the population (5.8 billion people) own a mobile phone.** The relatively low cost of mobile phones coupled with the rapid expansion of mobile and data networks have enabled millions of people in emerging economies to bypass fixed-line telephones altogether through technology leapfrogging.

Despite the rapid diffusion of mobile phones, a digital divide remains, particularly in Africa and Asia (Figure 11). In Africa, 35% of the population (475 million people) do not own a mobile phone. Within Africa, the majority of people without a mobile phone reside in Sub-Saharan Africa, 424 million people. In Asia, 26% of the population do not own a mobile phone. However, because of Asia's large population, the total number of people without access to a phone in Asia, 1.2 billion people, represents 63% of the global population without mobile phone access.

FIGURE 11. INDIVIDUAL MOBILE PHONE ACCESS (2022)



xxvi. Digital divide refers to the gap between those that have and do not have access to modern information and communications technology, like a computer and the internet.

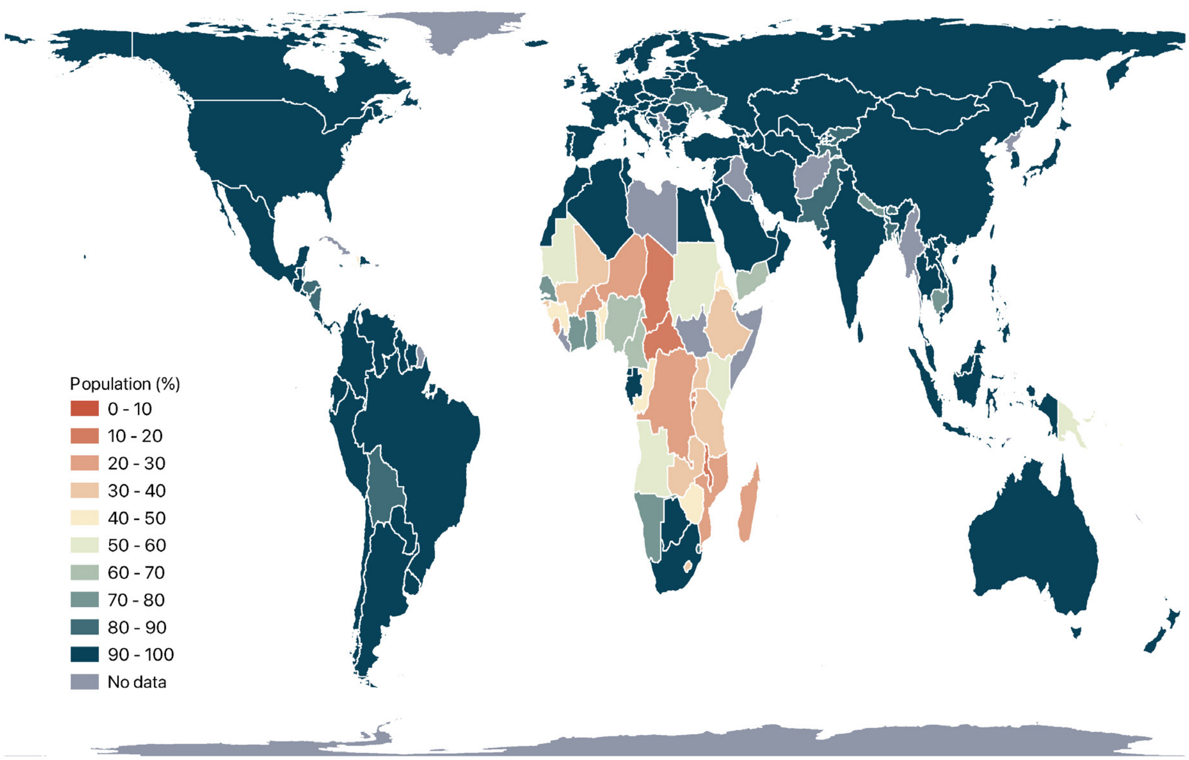
TELEVISIONS

Televisions are among the most popular household appliances that promote stronger family relationships, educate and create awareness on current issues, and can potentially reduce stress levels when used for entertainment.[103] When a household gains access to electricity, televisions are often one of the first appliances they purchase. In areas disconnected from the electric grid, energy-efficient televisions can help drive energy access by catalyzing market growth and reducing the total cost of solar home systems by allowing use of photovoltaics and batteries with less capacity than would be required for standard TVs.[104]

Compared to mobile phones, there is a stark divide in television ownership between sub-Saharan Africa and the rest of the world (Figure 12). Globally, 87% of the population has access to a television. However, in sub-Saharan Africa, that figure drops to just 47%. We estimate that 594 million people in Africa do not have access to a television. Within the sub-region of sub-Saharan Africa, the largest access gaps persist in Central and Southern Africa.

Within Asia, the Southern, Central, and South-Eastern sub-regions have the largest access gaps with 11%, 8%, and 6% lacking access, respectively. The total number of people without access to a television in these sub-regions is considerable, totaling 264 million people or 44% of the global population without access.

FIGURE 12. RESIDENTIAL TELEVISION ACCESS (2022)

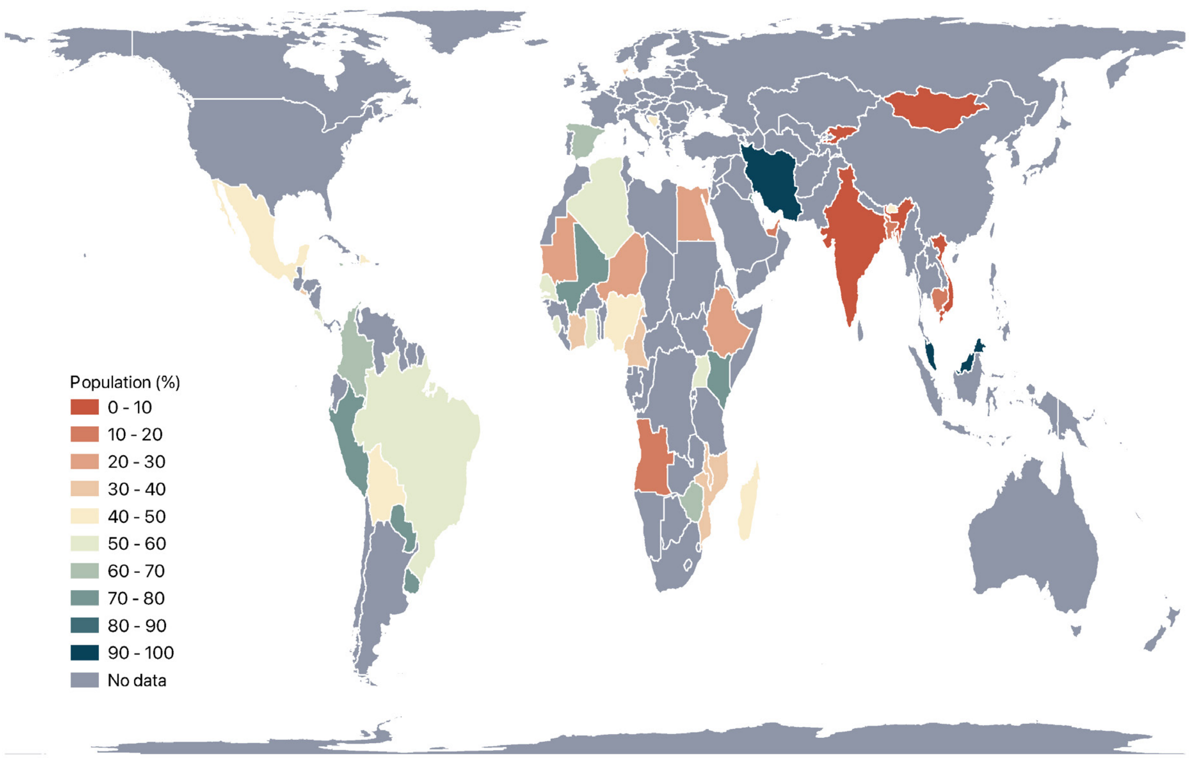


RADIOS

While **radios** do not make up a significant share of global energy demand, they are important appliances for distributing information to the public. Despite the proliferation of televisions, cell phones, and social media apps, many adults around the world still turn to radio broadcasts for news, information, and entertainment. In 2021, 80% of South Africans aged 18 or older reported listening to the radio within the last week.[105] Similar trends have been reported in the US, where 82% of the population aged 12 or older reported listening to the radio on a weekly basis.[106]

Limited data on radio access exists. **Of the 52 countries for which we were able to estimate access rates, 28% of households had access to a radio** (Figure 13). Vietnam, Kyrgyzstan, Mongolia, India, and Bangladesh had the largest access gaps with 99%, 98%, 98%, 95%, and 87% of the population lacking access to a radio, respectively.[107] India, Bangladesh, Nigeria, Brazil, and Vietnam have the largest access gaps by population; these five countries make up nearly 20% of the population without access to a radio. However, low access rates may indicate the technology has been superseded by other media. With the expansion of mobile phones, televisions, and the internet, people may turn to broadcast and digital media for news, information, and entertainment.

FIGURE 13. RESIDENTIAL RADIO ACCESS (LATEST YEAR AVAILABLE)



Note: *We show the latest year for which data are available. In most cases, that is 2021.*

FACING CLIMATE HAZARDS

There is an urgent need to close appliance access gaps. The planet is already experiencing the negative effects of climate change. 2023 is on track to be one of the warmest years on record. The effects of global warming are everywhere, from the massive wildfires in North America,[108] to catastrophic drought in East Africa,[109] deadly floods in Asia,[110] and record-breaking heat waves across the Northern Hemisphere.[111] The frequency of climate hazards and number of people affected is expected to increase as the planet warms.

The problem of access is particularly acute where people are most exposed to climate hazards. We selected two important climate hazards—exposure to extreme heat and agricultural drought risk—and overlaid those hazards with cooling and solar water pump access data at the national level.

There is a high degree of overlap between appliance access gaps and exposure to climate hazards. Many of the countries with the largest appliance access gaps are also those most at risk to the dangers of climate change.

There is a high degree of overlap between appliance access gaps and exposure to climate hazards. Many of the countries with the largest appliance access gaps are also those most at risk to the dangers of climate change.

In other words, appliances are lacking from exactly those communities that most need them and the adaptation/resilience benefits they deliver.

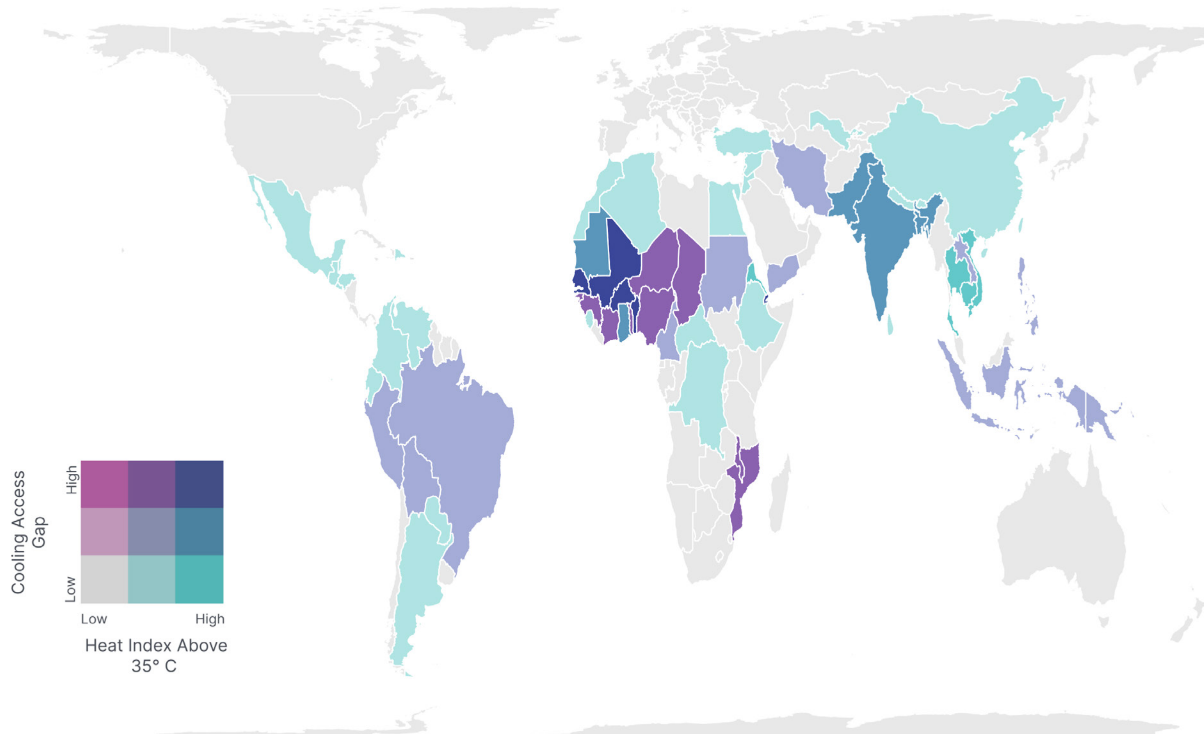
Girl in Rajasthan state sitting on cushion, refrigerator with India star label behind her.
Credit: Hemis / Alamy Stock Photo

Air Conditioners & Fans

The World Health Organization (WHO) estimates that 12,000 people lose their lives annually due to extreme heat waves and projects that figure could rise to 255,000 annually by 2050 without adaptation measures.[112]

Figure 14 compares the percentage of the population without access to an air conditioner or fan[xxvii] to the number of days the daily mean Heat Index[xxviii] rose above 35 °C [95 °F] in 2020. In the map, magenta (pink) shading is used to show the population proportion that lacks access to cooling, while cyan (blue) shading is used to show the prevalence of extreme heat. Darker shading indicates countries with larger access gaps, more extreme heat, or both. We find that populations in West Africa, South Asia, and Southeast Asia are most at risk because they are exposed to a high number of days of extreme heat and have limited access to cooling appliances.

FIGURE 14. COOLING ACCESS & HEAT RISK (2022)



Note: *Map shows the population at high risk due to a lack of cooling access[113] compared to the number of days the Heat Index was above 35 °C.[114] Cooling access data were sourced from: SEforALL. "Chilling Prospects: Tracking Sustainable Cooling for All."*

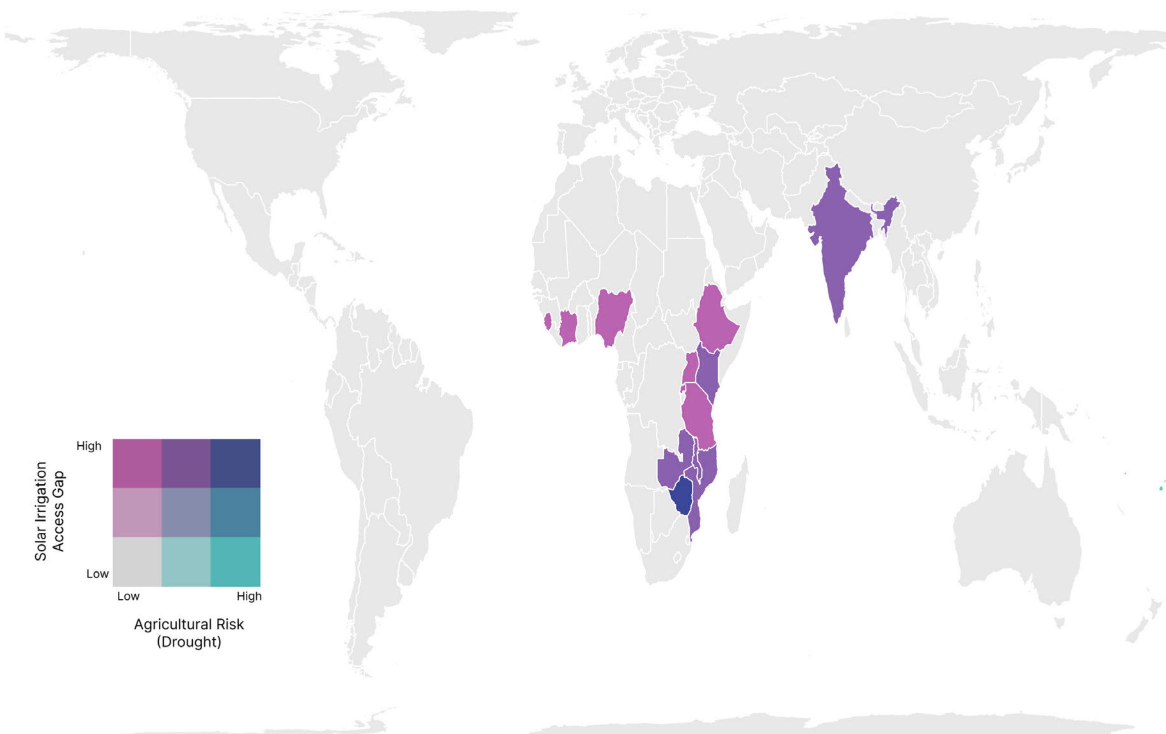
xxvii. Data were sourced from Sustainable Energy for All's Chilling Prospects: Tracking Sustainable Cooling for All report. To estimate cooling access gaps, we used the percentage of the population at high risk due to a lack of cooling access. High risk populations were defined as households that do not have access to electricity, live below the poverty line, live in buildings with poor ventilation and construction, do not have access to a refrigerator and agricultural and medical cold chains. This population largely include the rural and urban poor.

xxviii. A Heat Index is a measure of how it feels once humidity is factored in with air temperature.

Solar Water Pumps

Climate change will increase the intensity of drought, posing a number of risks to global food security.[115,116] Figure 15 overlays projected hazards due to heat and drought on top of solar water pump access gaps. It shows that the farmers in six of the 13 countries studied have large solar water pump access gaps and have medium or high vulnerability to agricultural drought, highlighting the crucial role solar water pumps can play in building climate resilience[xxix] in these economies.[117,118]

FIGURE 15. SOLAR WATER PUMP ACCESS & AGRICULTURAL DROUGHT RISK (2018-2022)[xxx]



Note: *This map shows a percentage of households that do not own a solar water pump (blue, years: 2018-2022) with total agricultural drought risk (2022).*

xxix. While some solar water pumps will replace diesel pumps (e.g., there are over 20 million off-grid smallholder farmers in India and 8.8 million diesel pumps), they would still improve resilience by increase incomes.

xxx. Data only available for the following countries: India, Ethiopia, Nigeria, Uganda, Kenya, Mozambique, Malawi, Sierra Leone, Rwanda, Zambia, Zimbabwe, and the United Republic of Tanzania. Solar water pump access rates were modeled by CLASP. Agricultural risk data are sourced from: Meza, Isabel, Stefan Siebert, Petra Döll, Jürgen Kusche, Claudia Herbert, Ehsan Eyshi Rezaei, Hamideh Nouri, et al. "Global-Scale Drought Risk Assessment for Agricultural Systems." Natural Hazards and Earth System Sciences 20, no. 2 (March 2, 2020): 695–712. https://doi.org/10.5194/nhess-20-695-2020.

03 Net Zero Heroes: Efficient Appliances

CEO of GreenScene Rekik Bekele standing in front of solar water pump, Ethiopia. *Credit: CLASP | Duncan Moore*

03

Inefficient appliances and large appliance access gaps severely hinder efforts to lower emissions and build climate resilience. Sections 1 and 2 of this report highlight the urgent need to radically reduce the negative impacts of inefficient appliances while simultaneously expanding the positive impacts from more efficient appliances to everyone.

Efficient appliances are a climate solution that uniquely sits at the nexus of climate mitigation and adaptation. Efficient appliances lower final energy demand and resulting emissions in a cost-effective manner and can expand access through lower operating costs. Unfortunately, appliance efficiency is often ignored in favor of other mitigation solutions, and therefore has not been utilized to its full potential. As a result, appliance emissions are expected to exceed what is needed to achieve NZE in 2050 by 9 Gt CO_2.

This section presents a series of ambitious efficiency targets that would put appliances on a pathway to NZE by 2050 and help close critical appliance access gaps.

CLASP advocates for urgent climate action focused on ten "Net Zero Heroes"—the appliances essential for reducing GHG emissions and building climate resilience globally.

> **CLASP advocates for urgent climate action focused on ten "Net Zero Heroes"—the appliances essential for reducing GHG emissions and building climate resilience globally.**

Women using solar water pump. *Credit: Futurepump*

THESE TEN APPLIANCES[xxxi] ARE:

- LED lighting
- Air conditioners
- Comfort fans
- Refrigerator-freezers
- Heat pump space heating
- Heat pump water heaters
- Industrial motors
- Electric cooking
- Televisions
- Solar water pumps

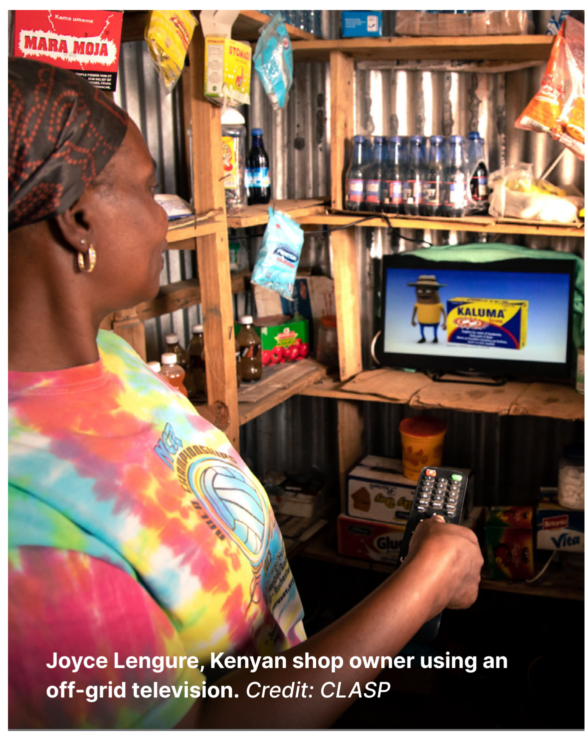
Appliances currently account for roughly 40% of all energy-related CO_2 emissions. Promoting the Net Zero Heroes by achieving the targets set forth in this section would deliver significant CO_2 reductions by 2050.

Achieving the efficiency targets for all ten Net Zero Heroes would avoid 9.2 Gt of CO_2 in 2050 relative to BAU. Achieving CLASP's Net Zero Hero targets would also improve the quality of life for millions of people by helping households and communities stay comfortable and connected during emergencies and natural disasters, reap the health and wellness benefits of enhanced food security, unlock opportunities for income generation, and foster more equitable outcomes for marginalized groups.

Meeting Net Zero Hero appliance efficiency targets would expand access to critical appliances to hundreds of millions of people while reducing exposure to climate risks through improved access to cooling technologies, enhanced food and water security, and new income-generating activities.

> **Meeting Net Zero Hero appliance efficiency targets would expand access to critical appliances to hundreds of millions of people while reducing exposure to climate risks.**

This section is divided into two parts. Part one introduces the ten Net Zero Heroes, presents targets for each, and forecasts climate mitigation impacts of meeting those targets. Part two quantifies the additional adaptation, resilience, and sustainable development benefits of meeting the efficiency targets shared in part one.



Joyce Lengure, Kenyan shop owner using an off-grid television. *Credit: CLASP*

xxxi. CLASP's ten Net Zero Heroes differ from the ten climate appliances essential to building climate resilience in Sections 1 and 2. The Net Zero Heroes are the ten appliances most critical to reducing the energy demand and GHG emissions needed to achieve NZE by 2050. However, many Net Zero Heroes are also critical climate resilience and adaptation benefits, particularly for households gaining access to these products for the first time.

3.1 Mitigation Potential

Achieving the CO_2 emissions reductions necessary to reach NZE by 2050 and limit global warming to 1.5 °C will require ambitious appliance policies and regulations, implemented promptly, and revised frequently.

As discussed in Section 2.1, new, ambitious efficiency policies are necessary to reduce appliance electricity consumption and make room within the renewable electricity budget for the electrification of fossil-fueled end uses, providing access and resilience, and accommodating future population and economic growth. BAU, and even some of the best policies in play today, are insufficient to stay within the emissions budget and achieve net zero.

CLASP calls for a concerted effort and renewed focus on ten energy end-uses—the Net Zero Heroes. The energy efficiency of these Net Zero Heroes must be greatly increased this decade. Table 6 identifies a specific energy efficiency target for each end-use that, if met, will allow appliances to remain within the budgets for both energy and emissions, resulting in significant CO_2 reductions compared to today's best policies.[xxxii]

TABLE 6: NET ZERO HEROES: TARGETS & MODEL IMPACTS

End-use	Target	2040 mitigation relative to BAU	2050 mitigation relative to BAU
LED LIGHTING	▪ Completely phase out fluorescent and incandescent lighting by 2025 ▪ Double the luminous efficacy of new LEDs by 2030 to take advantage of rapid technological improvement	0.2 Gt CO_2	0.03 Gt CO_2
AIR CONDITIONERS	▪ Double the efficiency of new units by 2030 ▪ Transition to low-GWP refrigerants in accordance with the Kigali Amendment to the Montreal Protocol	0.8 Gt CO_2	1.1 Gt CO_2

xxxii. As some of the Net Zero Hero targets do not begin until 2030, the modeled impacts include today's best policies as a stepping stone between now and 2030.

COMFORT FANS	TARGET ▪ Require permanent-magnet motors in new table, ceiling, and pedestal fans by 2025	2040 MITIGATION RELATIVE TO BAU 0.04Gt CO_2 2050 MITIGATION RELATIVE TO BAU 0.03Gt CO_2
REFRIGERATOR-FREEZERS	TARGET ▪ Double the efficiency[xxxiii] of new units by 2030[119]	2040 MITIGATION RELATIVE TO BAU 0.1Gt CO_2 2050 MITIGATION RELATIVE TO BAU 0.2Gt CO_2
HEAT PUMPS	TARGET ▪ Stop sales of fossil fuel equipment to fully transition stock to heat pumps by 2050	2040 MITIGATION RELATIVE TO BAU 1.2Gt CO_2 2050 MITIGATION RELATIVE TO BAU 1.8Gt CO_2
HEAT PUMP WATER HEATERS	TARGET ▪ Stop sales of fossil fuel equipment to fully transition the stock of storage water heaters to heat pumps and solar thermal by 2040	2040 MITIGATION RELATIVE TO BAU 0.2Gt CO_2 2050 MITIGATION RELATIVE TO BAU 0.3Gt CO_2
ELECTRIC MOTORS	TARGET ▪ Double the efficiency[xxxiv] of new industrial motor systems (controls, motor, and motor-driven equipment) by 2030[120] ▪ Greatly accelerate the replacement rate of existing stock by 2030 to achieve full replacement by the most efficient motors (IE5) by 2035	2040 MITIGATION RELATIVE TO BAU 3.4Gt CO_2 2050 MITIGATION RELATIVE TO BAU 5.1Gt CO_2

xxxiii. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

xxxiv. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

ELECTRIC COOKING

TARGET

- Fully transition to electric cooking worldwide[xxxv]

2040 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

TELEVISIONS

TARGET

- Require European Union (EU) Tier 3 efficiency levels everywhere by 2025

2040 MITIGATION RELATIVE TO BAU

0.03 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.02 Gt CO_2

SOLAR WATER PUMPS

TARGET

- Fully transition to electric water pumping for irrigation[xxxvi]

2040 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

0.4 Gt CO_2

TOTAL

2040 MITIGATION RELATIVE TO BAU

6.7 Gt CO_2

2050 MITIGATION RELATIVE TO BAU

9.2 Gt CO_2

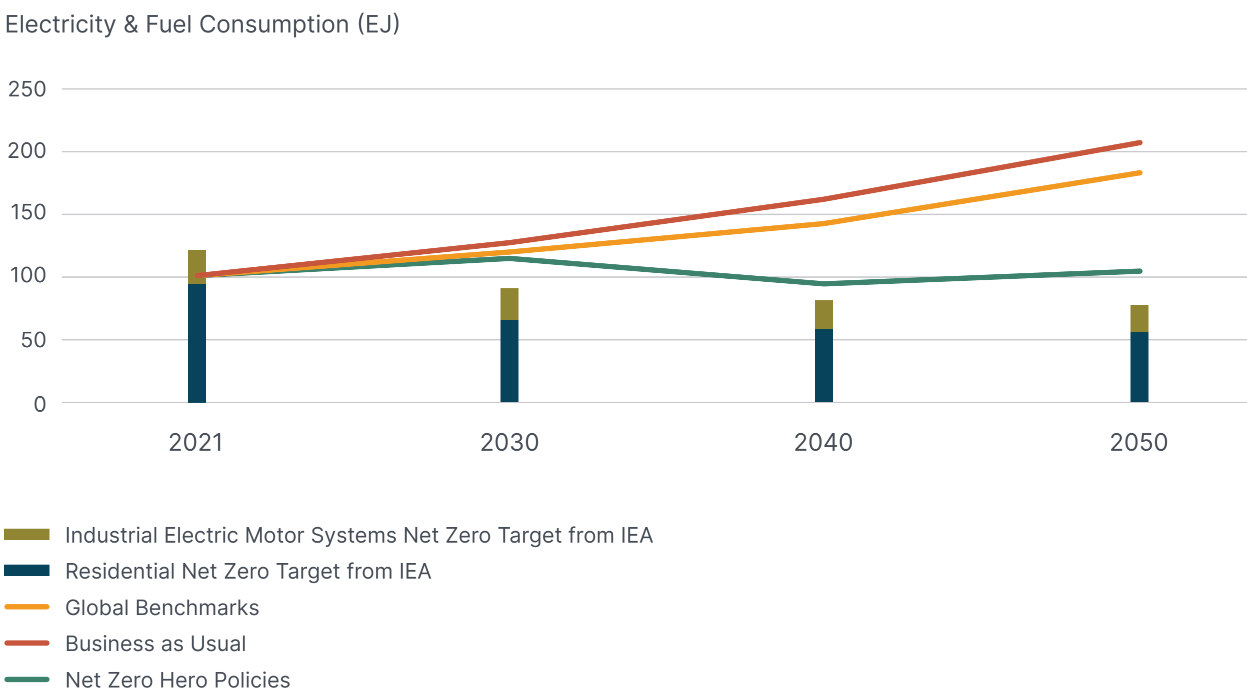
xxxv. For electric cookers, the benefits shown here are in the year the target (a full transition) is achieved. The mitigation potential provided is a conservative estimate. The CO_2 reductions represent the emissions that could be mitigated annually from reduced fuelwood harvest in 84 countries, sourced from the Clean Cooking Alliance's report, Accelerating Clean Cooking as a Nature-Based Climate Solution. Likewise, the mitigation potential does not include CO_2 reductions from transitioning from fossil fuels to electricity nor the reductions in methane emissions from leaks in gas infrastructure because other GHG emissions were not included in the scope of this analysis.

xxxvi. For solar water pumps, the benefits shown here are in the year the target (a full transition) is achieved. The mitigation potential provided is a conservative estimate. The 0.4 Gt potential represents the avoided CO_2 emissions that we would expect in a single year if the access gap were closed with solar water pumps rather than diesel pumps in 11 countries. It does not include the additional emissions reductions that would be achieved by transitioning the existing stock of diesel irrigation pumps to solar-powered or electric water pumps. If we were to expand our analysis to include all countries and the replacement of diesel pumps with solar or electric pumps, the mitigation potential would be significantly higher.

In Figure 16 below, we graph the energy for the appliances analyzed in Mepsy under the Net Zero Hero scenario as well as the Global Benchmarks and BAU scenarios, analyzed earlier. While the energy consumption starts out the same across all scenarios in 2021, the energy in the Net Zero Hero Policies scenario starts diverging after 2030 and stays within 25% of the budget based on the IEA Net Zero Emissions by 2050 scenario. In contrast, the energy consumption continues to climb in the BAU and Global Benchmarks scenarios.

While this energy consumption does exceed the budgets, we assumed that the excess could be further mitigated through behavioral change or additional efficiency improvements (discussed below) such that the eventual energy consumption would fall within the budget. For example, IEA expects behavior change to be a large share of the transition to NZE, contributing about half as much in the transition off of methane gas as efficiency does.[121]

FIGURE 16. ELECTRICITY & FUEL CONSUMPTION UNDER BAU, GLOBAL BENCHMARKS & NET ZERO HERO SCENARIOS

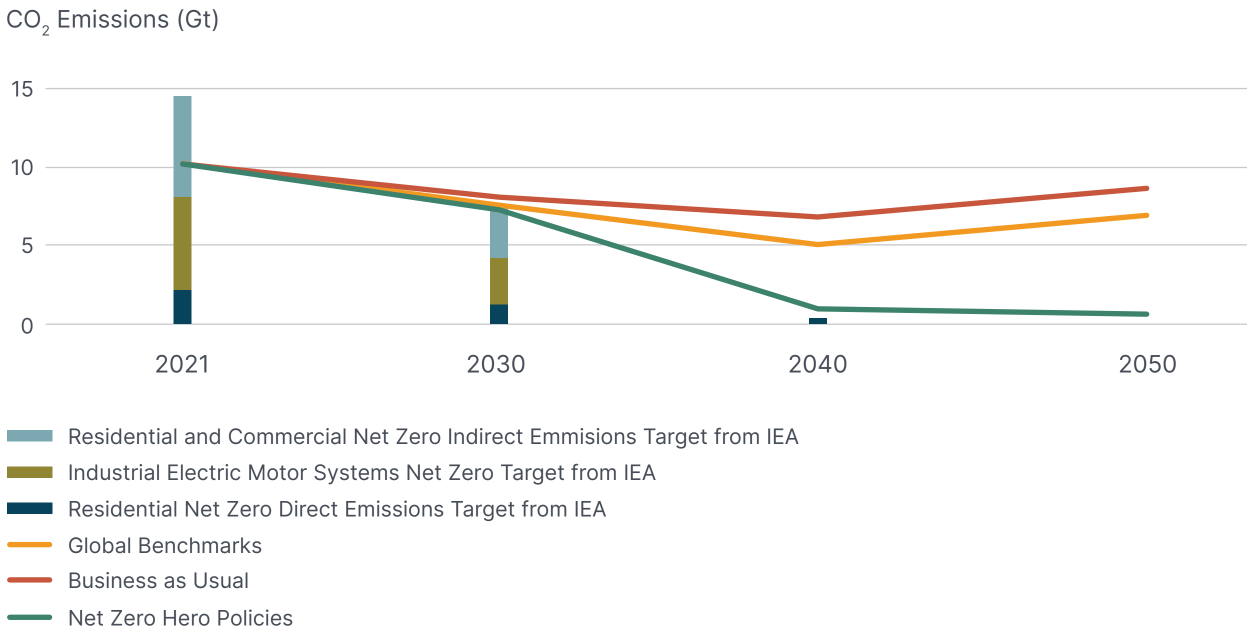


***Note:** Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2025-2030. Modeled electricity and fuel consumption under BAU, Global Benchmarks, and Net Zero Heroes appliance efficiency policies for major residential appliances and industrial electric motors systems (lines); overlaid with IEA's energy budgets for the relevant sectors (bars).*

In contrast, because of continuing high energy demand under the BAU and Global Benchmarks scenarios, a significant portion of the demand cannot be met by renewables or mitigated through other means, resulting in continued indirect emissions past 2040.[xxxvii] As a result, Figure 17 shows the size of these emissions along with those from any unelectrified fossil fuels. It is clear that we can only reach NZE if we increase ambition beyond even some of the most ambitious policies adopted today.

xxxvii. We assume that any energy consumption beyond that in the Net Zero Heroes cannot be met with renewables. The IEA's Net Zero Roadmap requires renewable energy capacity to triple by 2030. This is an ambitious target. Annual capacity additions have risen an average of 11% between 2015 and 2020.

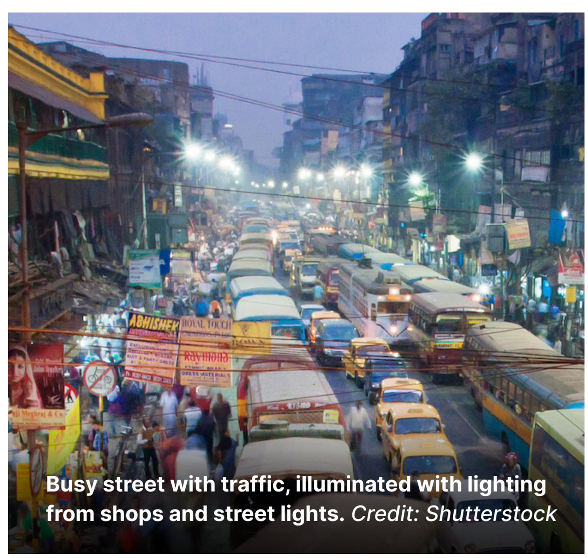
FIGURE 17. CO_2 EMISSIONS UNDER BAU, GLOBAL BENCHMARKS & NET ZERO HEROES SCENARIOS



Note: *Modeled CO_2 emissions from appliance efficiency policies for major residential appliances and industrial electric motors systems (lines); overlaid with IEA's Net Zero Emissions by 2050 trajectory for the relevant sectors (bars). Assumes electric grid decarbonization in line with the Net Zero by 2050 Roadmap. Modeled using Mepsy for 162 countries and eight appliances, with adoption in 2025-2030.*

Only the Net Zero Heroes program outlined in Table 6, characterized by a doubling of the efficiency of some products and urgent electrification of others, can sufficiently drive down energy use and emissions. Further ambition beyond what we have seen to date will be needed to achieve this agenda, both in terms of the frequency and stringency of policy updates and the use of complementary policies, including those that yield behavioral changes and building envelope improvements.

First, it will be important for countries to revise policies frequently to cement efficiency gains and continue taking advantage of technological improvement. Once an efficiency policy is adopted, manufacturers have to redesign some of their products to meet it. When these new products enter the market, policymakers should reevaluate whether further gains are possible. For example, in one country that CLASP recently analyzed, all the air conditioners on the market are twice as efficient as the minimum standard, meaning that the standard is not serving its function and should be revised. Another country revises its air-conditioner policies every two to four years to keep up with market efficiency improvements, but is nevertheless behind the world's best MEPS levels.[122] In other words, frequent updates must be paired with ambition to meet net zero targets.



Busy street with traffic, illuminated with lighting from shops and street lights. *Credit: Shutterstock*

Two people cooking fresh vegetables in pan on induction stove. *Credit: Shutterstock*

CLASP has modeled a series of such revisions in a country with a fast-growing economy, and found that it would be possible to meet a 50% energy reduction (an efficiency doubling) for new AC, refrigerators, industrial motor systems, and lighting by 2030. This would be consistent with the country's commitments under the Product Efficiency Call to Action (see Section 2.1), as well as contribute to achieving NZE by 2050. Efficiency policies would be revised every two to five years, leveraging resources such as U4E model regulations and IEA's policy ladders[123] to maintain pace and ambition.

The policies noted above would result in CO_2 mitigation once the stock turns over. However, to start reducing CO_2 emissions *before* 2030, the doubling efficiency and decarbonization policies would have to be complemented by additional policies and programs such as:

- Incremental efficiency requirements prior to 2030 (e.g., 25% reduction in energy in 2025);
- Incentives for early replacement (especially for long-lived products such as heating and air conditioning, and commercial and industrial equipment such as motors);
- Programs targeting other components of the system (e.g., efficiency gains from incremental improvements in motor efficiency are relatively small; much larger gains can be achieved by using variable speed drives and more efficient end-use components, such as pumps, compressors, and fans, as well as by digitization);
- Labeling or purchasing guidelines that encourage even higher efficiencies for a subset of customers, which can help drive investment into higher efficiency and pave the way for subsequent standards revisions.

Section 4 summarizes a range of policy options available to governments, donors, and other market actors to both improve the efficiency of appliances and promote the production and sale of more efficient models.

3.2 Adaptation, Resilience & Development Potential

Yet another reason to make appliance efficiency a priority now is that people urgently need access to appliances and the resilience and adaptation benefits they deliver. One sure way to make appliances accessible to more people is to make them more affordable. Improving efficiency is an effective way to drive down lifecycle costs, making appliances more affordable. Later in this section, we will present evidence that this mechanism works and estimate what impact improved efficiency could have on affordability and access.

Older woman standing in front of fan in a home. *Credit: Unsplash*

ENERGY EFFICIENCY DRIVES APPLIANCE ACCESS

Climate mitigation potential is reason enough to focus on improving the efficiency of appliances, but improved efficiency can also lead to greater climate resilience and adaptation by improving affordability and, thereby, bringing appliances within reach of more people.

Energy efficiency catalyzes access to appliances by lowering running costs as well as first costs.

The evidence connecting increased efficiency with improved affordability is compelling. It is well established that more efficient appliances cost less to operate due to their lower electricity or fuel consumption. This is a central tenet of most appliance standards programs, which are designed to reduce energy consumption and save consumers money on their utility bills (see Section 4).

Increased efficiency not only reduces energy costs; it can also drive down the total cost of ownership (TCO), i.e., first cost plus operating cost. A comparison of the estimated incremental prices of appliance standards in the US found that these costs were routinely overestimated. When developing standards for nine products,[xxxviii] the US government predicted a manufacturer selling price increase of $148 USD; the actual average was a *decrease* in price by $9 USD.[124] A similar analysis found that product prices often decrease over time, even as efficiency improves. For example, the average (quality-adjusted) price of a new refrigerator in 2015 was actually 35% *lower* than it was in 1987, despite large improvements in efficiency.[125] Similar price trends have been reported for the same period for clothes washers (45% lower) and dishwashers (30% lower).[126]

A 2018 study sought to determine the optimal levels of energy conservation (efficiency) standards for refrigerators and freezers in Uganda. The researchers calculated the TCO of baseline units and more efficient units and found that standards could reduce the TCO by $173 USD for freezers, $35 USD for refrigerators, and $21 USD for refrigerator-freezers. The researchers concluded that implementing standards and making refrigeration products more affordable in Uganda, where the average household spends 22% of its annual income on energy, would help to expand access to these appliances.[127]

This same dynamic is also at play in off-grid contexts, where the energy system must be sized to meet the requirements of the connected appliances. Efficiency for Access compared the costs of purchasing and operating efficient and inefficient solar-powered refrigerator-freezers using price data collected between 2017 and 2019. When considering the purchase price of the appliance, together with the solar energy system needed to power it, they found that the efficient refrigerator-freezers were between $300 USD and $900 USD less expensive than inefficient models, depending on the size of the food compartment and other features.[128] Even though the energy-efficient solar refrigerator-freezers are more affordable than inefficient models, they remain out of reach for many low-income families. Additional interventions, such as the consumer financing options discussed in Section 4.3, are needed to ensure that all families can access refrigerator-freezers. Nevertheless, energy efficiency remains a necessary ingredient in expanding access to refrigeration to off-grid populations.

Man gesturing toward water tank and hose in rural India. *Credit: CLASP*

xxxviii. The nine standards included: refrigerators, clothes washers (2x), electric water heaters, non-electric water heaters, central ACs (3 tons), room ACs, commercial ACs (15 tons), and ballasts.

ENABLING A JUST ENERGY TRANSITION

Achieving the efficiency targets in Section 3.1 (see Table 6) for the Net Zero Heroes is not only critical for climate mitigation, but it will also yield huge benefits for the health and wellbeing of people all over the world. We identified some of the other benefits (beyond climate mitigation), including climate resilience, adaptation, health, environmental, economic, and human development benefits, that would accrue from reaching the Net Zero Heroes Targets. These other benefits are described briefly below and summarized in Table 7.

Air conditioners and refrigerator-freezers: Doubling the efficiency of new units by 2030 would make these important cooling appliances more affordable. We adapted SEforALL's analysis and estimated that these efficiency improvements would make air conditioners accessible to 123 million more people and refrigerators accessible to 262 million more people. In addition, these efficiency improvements would enable millions of consumers to save money on their electricity bills. For more detail, see our Spotlight on Cooling Appliances.

Electric cookers and solar water pumps: We quantified the adaptation, resilience and other human development benefits from expanding access to solar water pumps and enabling universal access to electric cooking. Details are provided in the Spotlight on Electric Cooking and the Spotlight on Solar Water Pumps.

LED lighting, space heating, water heating, and cooking: A full transition to LED lighting would eliminate toxic mercury pollution from the production, breakage, and disposal of fluorescent lighting. A transition from fossil fuel-powered equipment to heat pumps for space heating and water heating and to electric cooking appliances would eliminate methane leakage from these end uses and reduce air pollution. See our Spotlight on Air Pollution for more on how appliance efficiency can help to reduce air pollution levels and improve human health.

Electric motors: Improved electric motor efficiency in industry is associated with increases in industrial competitiveness and productivity and with improved quality control.[129]

LED lighting, comfort fans, and televisions: As with air conditioners and refrigerators, a sustained focus on improving the availability of good-quality, energy-efficient, and affordable LED lighting, comfort fans, and televisions will also serve to increase access to these three Net Zero Heroes. It would also allow consumers to save money on their electricity bills, an especially important benefit for low-income households.

Woman installing LED lightbulb. *Credit: Shutterstock*

In Section 3.1, we identified an efficiency target for each Net Zero Hero and quantified the climate mitigation potential for each. In Table 7 we show the same targets again and summarize some of the other benefits of meeting these targets.

TABLE 7. NET ZERO HEROES: TARGETS & OTHER BENEFITS

LED LIGHTING

TARGET

- **Completely phase out fluorescent and incandescent lighting by 2025**
- **Double the luminous efficacy of new LEDs by 2030 to take advantage of rapid technological improvement**

OTHER BENEFITS

- Eliminate mercury pollution from production, breakage, and disposal of fluorescent lighting
- Reduce waste due to longer LED lifetimes

AIR CONDITIONERS

TARGET

- **Double the efficiency of new units by 2030**
- **Transition to low-GWP refrigerants in accordance with the Kigali Amendment to the Montreal Protocol**

OTHER BENEFITS

- 123 million people with first access[xxxix]
- 116 million people with improved thermal comfort
- 93 million people with improved health and wellbeing

COMFORT FANS

TARGET

- **Require permanent-magnet motors in new table, ceiling, and pedestal fans by 2025**

xxxix. For air conditioners and refrigerator-freezers, we extended SEforALL's analysis to forecast the number of households benefiting from first access and assumed an average household size of 3.74 persons to estimate the number of people benefiting.

REFRIGERATOR-FREEZERS

TARGET

- **Double the efficiency[xl] of new units by 2030[130]**

OTHER BENEFITS

- 262 million people with first access
- 39 million people with improved quality of life
- 26 million people with improved food security and nutrition

HEAT PUMP SPACE HEATERS

TARGET

- **Stop sales of fossil fuel equipment to fully transition stock to heat pumps by 2050**

OTHER BENEFITS

- Eliminate methane leakage from space heating
- Reduce outdoor air pollution from space heating

HEAT PUMP WATER HEATERS

TARGET

- **Stop sales of fossil fuel equipment to fully transition the stock of storage water heaters to heat pumps and solar thermal by 2040**

OTHER BENEFITS

- Eliminate methane leakage from water heating
- Reduce outdoor air pollution from water heating

ELECTRIC MOTORS

TARGET

- **Double the efficiency[xli] of new industrial motor systems (controls, motor, and motor-driven equipment) by 2030[131]**
- **Greatly accelerate the replacement rate of existing stock by 2030 to achieve full replacement by the most efficient motors (IE5) by 2035**

OTHER BENEFITS

- Improved industrial competitiveness, productivity, and quality control

xl. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

xli. A doubling of efficiency would mean a 50% reduction in the average energy consumption of new units.

ELECTRIC COOKERS

TARGET

- **Fully transition to electric cooking worldwide**[xlii]

OTHER BENEFITS

- 3.7 million premature deaths avoided annually
- 0.7 million fewer children with asthma
- Improved respiratory and heart health
- Time savings and reduced deforestation by eliminating the need to gather firewood
- Eliminate methane leakage from cooking

TELEVISIONS

TARGET

- **Require European Union (EU) Tier 3 efficiency levels everywhere by 2025**

SOLAR WATER PUMPS

TARGET

- **Fully transition to electric water pumping for irrigation**[xliii]

OTHER BENEFITS

- 98 million people with improved food security
- 15 million smallholder farmers with yield increases >30%
- 0.85 million new jobs in the agricultural sector
- $100 USD billion in fuel cost savings annually

Note: *For electric cookers and solar water pumps, the benefits shown here are in the year the target (a full transition) is achieved. For air conditioners and refrigerator-freezers, we extended SEforALL's analysis to forecast the number of households benefiting from first access and assumed an average household size of 3.74 persons to estimate the number of people benefiting. Additional detail can be found in the Spotlight on Air Conditioners and Refrigerators.*

Source: *CLASP analysis.*

To support those most affected by climate change and end energy poverty, CLASP advocates for an expanded definition of energy access that includes ten essential appliances critical to building resilience. To date, most efforts to build climate resilience within the energy sector have focused on expanding access to the 2.9 billion people that lack access to clean cooking solutions, and the 675 million people that lack access to electricity.[132]

Expanding the focus of the existing energy access agenda from new connections and kWh to include access to appliances and equipment would unlock the development impacts of expanded power supply. At the same time, the energy efficiency community must broaden its priorities from climate mitigation and avoided CO_2 emissions to include appliance access and climate adaptation and resilience.

xlii. For electric cookers, the benefits shown here are in the year the target (a full transition) is achieved.

xliii. For solar water pumps, the benefits shown here are in the year the target (a full transition) is achieved. The mitigation potential provided is a conservative estimate. The 0.4 Gt potential represents the avoided CO_2 emissions that we would expect in a single year if the access gap was closed with solar water pumps rather than diesel pumps in 13 countries. It does not include the additional emissions reductions that would be achieved by transitioning the existing stock of diesel irrigation pumps to solar-powered or electric water pumps. If we were to expand our analysis to include all countries and the replacement of diesel pumps with solar or electric pumps, the mitigation potential would be significantly higher.

04 Taking Proven Solutions to Scale

Building with ACs stretching up toward sky. *Credit: Shutterstock*

04

The solutions needed to accelerate the adoption of efficient appliances critical to reducing emissions, expanding access, and enhancing adaptive capacity are proven, scalable, cost-effective, and widely used.

Energy efficiency policies can halve the energy consumption of major appliances, including refrigerators, televisions, and washing machines,[133] and decrease appliance prices over time.[134] Complementary efforts in research and development (R&D) funding, financing and financial incentives, bulk procurement requirements, awards, and informational tools have been critical to driving market uptake of efficient appliances. These solutions target the market at different stages of development and work collectively to transition it into a new paradigm centered around net zero-ready appliances (Table 8).

TABLE 8. SUMMARY OF APPLIANCE EFFICIENCY POLICIES & MARKET DEVELOPMENT PROGRAMS

TYPE OF POLICY OR PROGRAM	EXAMPLES
Market Clearing	MEPS limit the maximum amount of energy an appliance can consume, clearing out the most inefficient products in a specific market.
Market Growth	Appliance labeling programs, incentives, bulk procurement requirements, and awareness raising efforts work to lower economic, market, and information barriers to drive the sale of efficient appliances, which in turn help create economies of scale to improve overall appliance efficiency.
Market Innovation	R&D funding, awards and competitions, and endorsement labels help drive innovation and increase the availability of high-efficiency appliances on the market.

> Appliance efficiency policies like standards and labeling are proven, scalable, and cost-effective with benefits outweighing costs at a ratio of four to one.

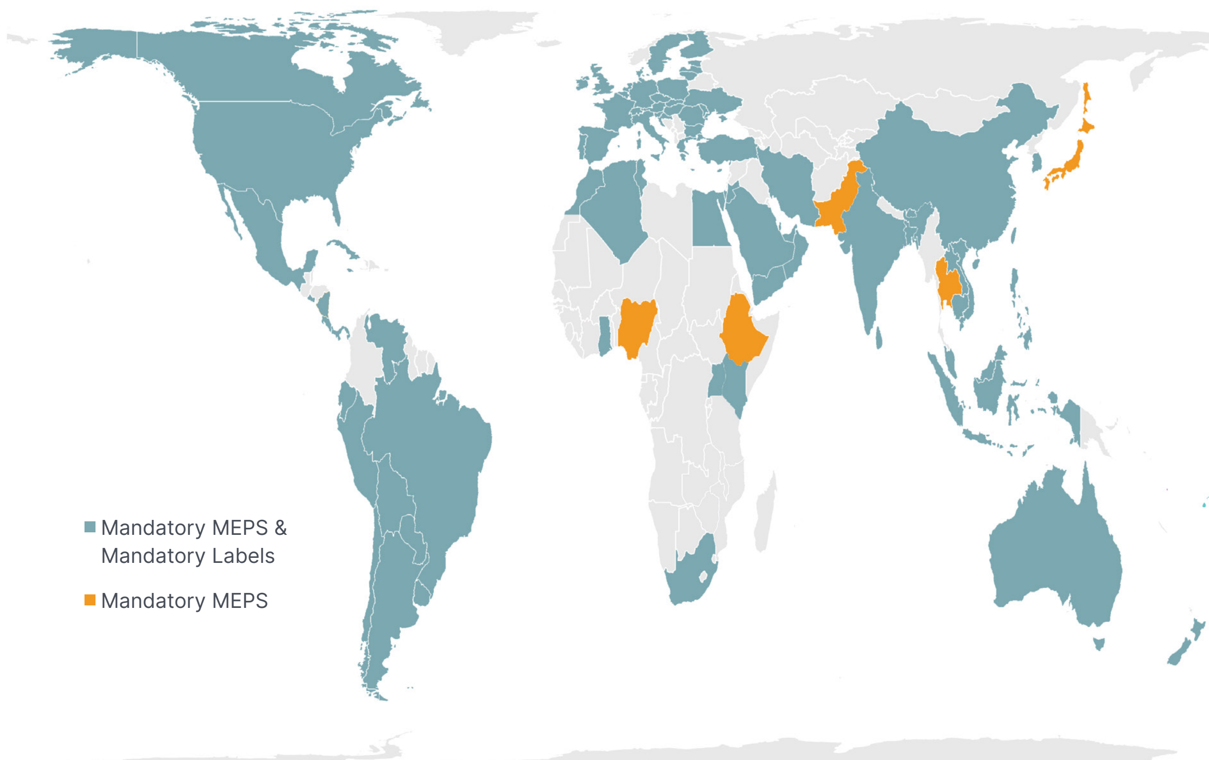
Appliance efficiency policies like standards and labeling are proven, scalable, and cost-effective with benefits outweighing costs at a ratio of four to one.

In this section, we introduce the major types of policies and programs that have been used to improve the energy efficiency and quality of appliances throughout the world. We also provide examples and case studies of those solutions and highlight valuable takeaways that governments, development institutions, donors, and others can use to replicate the interventions in other contexts.

4.1 Policies

Appliance energy efficiency policies are one of the most cost-effective solutions to reduce emissions and should be a cornerstone in any climate mitigation strategy. There are 86 countries with mandatory MEPS and labels for appliances (Figure 18),[135] while over 120 countries employ appliance standards and labeling programs in some capacity.[136] Data from the CLASP Policy Resource Center[xliv] shows that there are more than 1,500 policies worldwide covering 13 broad product categories.

FIGURE 18. MANDATORY MEPS & LABELING REQUIREMENTS FOR APPLIANCES[137]



xliv. The CLASP Policy Resource Center features a dynamic Appliance & Equipment Policy Tracker that shows at a glance the broad variety of product types that are addressed by appliance efficiency policies.

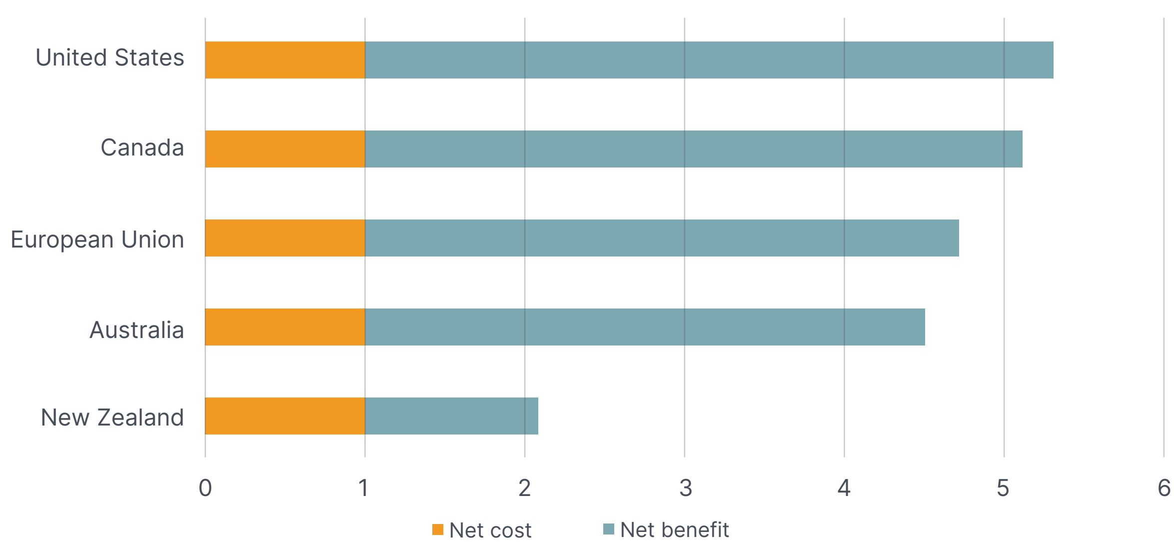
Longstanding appliance energy efficiency programs with the largest product coverage have cut total electricity consumption by roughly 15%, with most of the reductions in the residential sector.[138] Examples include:

- **China:** China has 73 appliance efficiency policies. Between 2005 and 2020, these policies cut electricity use by more than 2,500 TWh cumulatively (170 TWh per year) and have avoided 100 Mt of CO_2 emissions per year.[139]
- **European Union:** Efficiency policies in the EU cover 31 appliances.[140] In 2020, the EU cut energy use by 1,039 TWh—a 10% reduction from BAU—primarily resulting from EU Ecodesign and Energy Labeling measures.[141] Additionally in 2020, the EU's Ecodesign and mandatory labeling program cut emissions by 311 Mt CO_2.[142] See the case study titled _Evolving the EU Energy Label: Shaping Consumer Choices and Market Transformation_ for more.
- **India:** India has efficiency policies for 34 appliances—14 mandatory and 20 voluntary. Standards and labeling mechanisms saved 9.95 GWh in fiscal year 2020-21[143] and avoided 7.86 Mt of CO_2.[144]
- **United States:** In the US, efficiency policies cover 60 appliances.[145] Between 1987 and 2020, appliance efficiency policies in the US have saved a cumulative 20,749 TWh of energy. In 2020 alone, these policies avoided 343 Mt CO_2.[146,147]

Beyond energy savings, appliance efficiency policies deliver large cost savings to households. In the US, the typical household saves more than $320 USD per year on their energy bills because of standards.[148] In Brazil, refrigerators are often the appliance that contributes most to the electricity bills of low-income households.[149] Recent revisions to Brazil's labeling policies are expected to reduce consumers' electricity bills by 18.4 billion BRL [$3.6 billion USD] and cut CO_2 emissions by 9.7 Mt in 2030. See the case study titled, _Cooling Down Costs: Updated Energy Labels Save Brazilian's Money_ for more.

Appliance energy efficiency policies deliver cost-effective carbon mitigation wins, with benefits outpacing costs by four to one (Figure 19).[150] Studies analyzing marginal abatement costs for various climate interventions have shown that energy efficiency investments broadly deliver carbon savings at a negative cost.[151] CLASP's review of the costs required to administer long standing appliance standards and labeling programs found that large quantities of CO_2 can be abated for at, or well below, $1 USD per ton.[152] To date, 43 countries directly reference appliance efficiency policies like standards and labels in their NDCs to the Paris Climate Agreement, and institutions like the World Bank have committed to intensifying support for efficiency policies in middle-income countries.[153,154]

FIGURE 19. COST-BENEFIT RATIO FOR LONGSTANDING APPLIANCE EFFICIENCY STANDARDS & LABELING PROGRAMS[155]



Appliance efficiency policies play an important role in building resilience to climate change while reducing stress on the grid during periods of peak energy demand. As the climate warms, people will need access to run appliances like fans and air conditioners longer and more frequently to keep cool. At the same time, this rising demand will place incredible stress on the power grid, which can lead to consequential service disruptions. In Pakistan, fans are a vital lifeline to families during the warm summer months and are known to constitute over 33% of the total load on the grid. In 2016-17, CLASP and SAMA^Verte collaborated with the government of Pakistan and the provincial government in Punjab to create a voluntary label for fans aimed at reducing energy consumption. This project provides valuable insights for governments looking to initiate or enhance appliance efficiency programs, underscoring that opting for a mandatory label approach significantly increases the likelihood of success. See the case study titled, *Empowering Efficiency: Lessons from Pakistan's Energy Labeling Journey* for more.

Beyond standards and labels, appliance efficiency policies focused on quality assurance can protect customers' investments and ensure that products are of high quality and will perform as advertised. Programs like VeraSol support test methods and quality standards for off-grid appliances, conduct appliance testing and build global test laboratory capacity, and certify and maintain a database of quality of solar appliances. To date, the program has certified 60 million solar appliances, benefitting 180 million people.[156]

Strong appliance efficiency policies can have a transformative impact on markets by phasing out inefficient or harmful technologies. MEPS may be used as a tool to drive further electrification or transition away from products requiring the use of climate-polluting or environmentally hazardous materials such as high-GWP refrigerants or highly toxic mercury.

In China, appliance efficiency policies have helped to transition the market to more efficient air conditioners and push the market toward lower-GWP refrigerants like R-32. In 2020, China adopted world-leading MEPS for room air conditioners and combined two previous separate regulations into a single label based on a technology-neutral seasonal performance metric. The market share of variable-speed ACs in China increased from 53% in 2017 to 95% in 2022. Meanwhile, most fixed-speed ACs have been phased out from the domestic market. In addition, products meeting the highest energy efficiency level (grade 1) have rapidly increased their market share from 19% to 56%, and the lower-GWP refrigerant R-32 also increased its market share significantly.

See the case study titled, ***Revolutionizing Cooling and Climate: China's Pioneering AC Efficiency Standards*** for more.

Despite their proven track record, cost effectiveness, and numerous benefits, rapid action is needed to accelerate the pace of policy making for appliances. Appliance electricity consumption continues to grow and is largely driven by increasing numbers of buildings and expanding ownership and use of energy-consuming devices in emerging economies.[157] This report finds that even the strongest policies in place today are not sufficient to reach NZE by 2050 (see Section 2). To get on track, most of the appliances sold in 2035 and beyond must match today's best available technology (see Table 5).[158] This would require significant investments in appliance efficiency and a rapid increase in the rate of policymaking in nearly all global economies. Additionally, investments in policy compliance programs are required to support effective policy implementation and lock in the benefits of adopting clean energy technologies and energy efficiency and quality standards. Resources like CLASP's Compliance Toolkit can serve as a helpful starting point for policymakers.

Two women using electric pressure cooker, trying food. *Credit: CLASP*

4.2 Research & Development

R&D programs are designed to directly stimulate the creation of new technology and drive continuous improvement in the efficiency of energy-consuming products. In many cases, dedicated investment in unproven technologies with high-impact potential is warranted to drive markets for more innovative, high-performing, and energy-efficient technologies.

There are many examples of successful R&D programs. In India, the Department of Science and Technology co-sponsored the Global Cooling Prize to support the development of groundbreaking high-efficiency room air conditioners.[159] The two winning teams showcased air conditioners with a climate impact that was five times less than conventional models and have a plan for bringing their prototype models to market by 2025.[160] The Jamaican and Trinidadian governments co-sponsor the Caribbean Climate Innovation Centre, which operates an incubator and an accelerator for start-up companies developing new climate-friendly technologies, including energy-efficient technologies.[161] To date, the center has invested more than $800,000 USD in their clients and helped form over 100 startups.[162] In the US, the Federal Government invests in R&D for energy efficiency, with the Advanced Research Projects Agency-Energy (ARPA-E) focusing on high-risk, high-reward projects, and the Department of Energy's Building Technologies Office focusing on more low-risk, low-reward projects.[163,164]

R&D programs can be implemented by a multitude of stakeholders beyond governments. One example includes the Efficiency for Access R&D fund, which aims to accelerate innovation in off- and weak-grid appliances. Since 2018, the fund has awarded 39 companies over £5.5 million GBP in funding to support off-grid appropriate technologies ranging from solar refrigerators to egg incubators.[165]

Female farmers interacting with crops in Tanzania. *Credit: Feed The Future Mboga na Matunda*

4.3 Financing & Incentives

Financing schemes and financial incentives help the private sector and consumers overcome cost barriers of efficient appliance ownership by lowering upfront costs or by spreading them out over time. Financing can take many forms, from loans to leasing to performance contracting or third-party financing, and is often administered by governments, development banks, and other financial institutions to increase the manufacture and sale of energy-efficient appliances. Lease-to-own arrangements are typically offered by the private sector. Utilities can also play a critical role in countries where they are regulated in a way that incentivizes them to invest in energy efficiency by offering financing programs for energy-efficient appliances to their customers. Research by CLASP and the Consultative Group to Assist the Poor (CGAP) found that utility-enabled financing can benefit both customers and providers, unlock latent demand for electricity, and improve customers' perceptions of their electric utilities.[166]

Man loading fresh produce into cold room. *Credit: New Leaf Dynamics*

Ghana's ECOFRIDGES Green On-wage (GO) financing mechanism is one example of a successful appliance financing program that has supported the purchase of over 1,300 energy-efficient air conditioners and nearly 1,600 refrigerators. To lower the financial barrier to purchasing a new, efficient appliance for consumers, the program offered a credit facility with flexible repayment terms at 0% interest for 12 months to eligible customers. To ensure the supported products met minimum energy and environmental performance criteria, eligible refrigerators were required to have a five-star energy rating and use R-600a refrigerants, while eligible air conditioners needed to have at least a three-star rating and use R-32 refrigerant. Since the program's inception, the financing facility has deployed over $1 million USD in financing, reduced energy demand by 25 MWh, and avoided over 20,0000 tons of direct and indirect CO_2 emissions.

See the case study titled, *Keeping it cool: How Ghana's ECOFRIDGES GO initiative cuts energy costs and emissions* for more.

Financial incentives to accelerate the deployment of efficient appliances come in many forms, ranging from upstream incentives for manufacturers to downstream incentives for consumers. Governments have employed financial incentives for appliances since the 1970s, but other stakeholders, like utilities or international development institutions, can also issue this assistance. The most common incentives are rebates or subsidies, tax incentives, and results-based financing (RBF). Energy efficiency standards and labels can serve as a foundation for incentive programs because they provide a verified baseline for judging enhanced performance. It is possible to design an effective incentive program without underlying standards if there is a suitable test procedure to identify high-efficiency products.

For households living near or below the global poverty line of $2.15 USD per day, an appliance represents a significant investment. **Financial incentives represent an important mechanism to make appliances more affordable for low-income customers.** SunCulture, a solar water pump provider, has partnered with the French electric company EDF and Bboxx to implement a government subsidy that will halve the cost of pumps for 5,000 smallholder farmers in Togo.[167] This 50% subsidy, coupled with tax exemptions, is part of a national effort to help make solar energy more affordable and end energy poverty. The partnership between SunCulture, Bboxx, and EDF leverages each partner's strengths, allowing SunCulture's pumps to be equipped with Bboxx's platform for remote monitoring and management and pay-as-you-go financing model, while leveraging EDF's hands-on experience from sales and installation in West and Central Africa.

RBF mechanisms offer a market-driven solution that can help make effective use of resources. RBF is an umbrella term referring to any program or intervention that provides rewards to individuals or institutions after defined results are achieved and verified. While it is not a silver bullet, RBF has been employed as one solution to expand access to appliances in countries with high energy and appliance access gaps. For example, the Efficiency for Access Coalition has paired RBF with the Global Lighting and Energy Access Partnership (Global LEAP) Awards, a competition to identify high-performing and energy-efficient off-grid-appropriate appliances. Companies selected for Efficiency for Access's financing support are identified through the Global LEAP Awards, ensuring that the products incentivized are energy-efficient and of good quality. Since 2016, the program has incentivized the sale of nearly 290,000 fans, televisions, refrigerators, solar water pumps and electric pressure cookers (EPCs), benefitting over 1.2 million people.

4.4 Bulk Procurement

Bulk procurement and other procurement strategies by institutional purchasers, including governments, utilities, and international development institutions can accelerate market transformation. When making appliance and equipment purchases, these institutions can set efficiency and other related criteria to encourage manufacturers to scale up production of technologies that meet those criteria, while also decreasing the per-unit cost due to economies of scale. Harnessing the power of routine purchasing for internal uses by the government and other institutional buyers (i.e., for government offices, public schools, universities, hospitals, street lighting, water and other utilities, military/defense facilities, and other state-owned enterprises) can also be a powerful way to stimulate the market for energy-efficient products while setting an example for corporate buyers and individual consumers. These approaches highlight ways that bulk and government procurement can help make new technologies more mainstream and cost-competitive.

India's Unnat Jyoti by Affordable LEDs for All (UJALA) scheme is a successful appliance-focused energy efficiency program with strong policy backing from the government. Launched in 2015, the program is one of the world's largest lighting replacement programs for domestic consumers which promotes the use of energy-efficient LED bulbs to replace traditional incandescent and compact fluorescent lamp (CFL) bulbs. The program is implemented by the state-owned Energy Efficiency Services Limited (EESL) and is funded through public-private partnerships. By procuring in bulk, EESL was able to make LED bulbs more affordable to consumers through a demand aggregation model. LED bulbs are distributed to households at subsidized rates, making them affordable and accessible to all. From 2012 to 2016, LED retail market prices dropped from roughly 800 Indian Rupees (INR) per LED bulb to 200 INR per LED bulb—one of the fastest LED price reductions in the world.[168] As of June 2023, the program had distributed over 368 million LED bulbs, mitigating 38 million tons of CO_2 per year and saving households 192 billion INR [$2.3 million USD] on their energy bills.[169] See the case study titled, *Lighting a Billion: The UJALA Program's Transformational Impact in India* for more.

Hanging lightbulbs. *Credit: Goodcat; Shutterstock*

4.5 Promotional Tools

Promotional tools like awards and informational resources offer another pathway to overcome information barriers and drive technological innovation.

Awards identify and promote top-performing products and, when widely promoted and well-recognized, awards can help improve awareness of these products among consumers and retailers. In turn, the award outcomes can influence manufacturers' product design decisions.

One example of awards competitions is the Off-Grid Cold Chain Challenge (OGCCC). The OGCCC identifies best-in-class cold chain equipment in emerging markets. The competition adopted a field-testing component to collect real-time data on energy consumption and performance of emerging cold storage equipment. Results from multiple rounds of competition demonstrate growth in the number of companies providing such cooling solutions, as well as improvement in the design and performance. The data collected through field testing have helped identify gaps in lab and field performance and give companies the information they need to improve product design. The OGCCC has also highlighted the need to establish more robust quality and performance benchmarks for off-grid cold storage equipment. See case study titled, *Fresh Food & Reduced Emissions: The Global LEAP Off-Grid Cold Chain Challenge's Impact on Food Security & Market Growth* for more.

Informational tools, like qualification lists, mobile apps, and online tools, help individual consumers identify energy-efficient products, as well as guide bulk procurement. For example, online databases, like the VeraSol Product Database, can help buyers and distributors of off-grid solar appliances identify high-performing products that meet international quality standards or have been tested to standardized test methods.

Aerial view of a ColdHubs storage room in Nigeria. *Credit: Global LEAP Awards*

4.6 Solutions in Action

Several ongoing initiatives recognize the transformative potential of appliances and provide platforms for mobilizing to realize this potential. We identified ten examples of such initiatives and wrote profiles of each to accompany this paper. The profiles, which can be accessed from Table 9, include key facts about these initiatives, including who leads and who is involved, what are their goals, and how they intend to reach those goals.

While the efforts profiled here are ambitious, they are not by themselves sufficient to achieve the change we seek. Additional investment is needed. These initiatives will have to be replicated, and some may need to be strengthened to align with the efficiency targets set forth in Section 3.1. In the following section, we lay out our recommendations for action.

Woman standing near solar panel in rural India. *Credit: CLASP*

TABLE 9. INITIATIVES & PROGRAMS LEADING THE WAY, FULL PROFILES LOCATED IN ANNEX B

INITIATIVE OR PROGRAM	LEAD INSTITUTION(S)	TECHNOLOGIES ADDRESSED
Clean Lighting Coalition	CLASP	▪ Lighting
Super-Efficient Equipment and Appliance Deployment (SEAD) Initiative	Clean Energy Ministerial, Energy Efficiency Hub	▪ Residential air conditioning ▪ Lighting ▪ Residential refrigerators and freezers ▪ Industrial electric motor systems
Clean Cooling Collaborative	ClimateWorks Foundation	▪ Air conditioning ▪ Fans
Ayrton Fund	United Kingdom (UK) Foreign, Commonwealth & Development Office UK Department for Business, Energy & Industrial Strategy	▪ Fans ▪ Air conditioning ▪ Walk-in cold storage ▪ E-cooking
Efficiency for Access	CLASP, Energy Saving Trust	▪ E-cooking ▪ Fans ▪ Lighting ▪ Refrigerators/freezers ▪ Solar water pumps ▪ Televisions ▪ Walk-in cold storage ▪ Other productive use appliances
Productive Use Appliance Financing Facility	CLASP	▪ Solar water pumps ▪ Electric pressure cookers (EPCs) ▪ Refrigerator-freezers ▪ Walk-in cold storage ▪ Fans ▪ Mills
REPowerEU	European Commission	▪ Heat pumps
US Inflation Reduction Act	US Department of Energy US Internal Revenue Service US Environmental Protection Agency	▪ Heat pumps
United for Efficiency	UN Environment	▪ Lighting ▪ Refrigeration ▪ Room air conditioners ▪ Distribution transformers ▪ Electric motors
Clean Cooking Alliance	UN Foundation	▪ E-cooking

05 Conclusion & Recommendations

Three generations of Indian women looking at all of room ACs with India Star Label. *Credit: Shutterstock*

5.1 Conclusion

Energy-efficient appliances are proven, cost-effective climate solutions that enable governments to limit global warming, improve resilience, and achieve their sustainable development objectives. But the global community has not taken full advantage of this opportunity. Emissions from inefficient appliances are projected to significantly surpass the IEA's Net Zero by 2050 targets, jeopardizing efforts to achieve the goals of the Paris Climate Agreement. Meanwhile, billions of people around the world still lack access to appliances that are increasingly vital as temperatures rise, hindering a just energy transition.

Fortunately, a clear pathway to planet- and people-friendly appliances exists. CLASP has identified the ten appliances that should form the basis of an urgent global push—the Net Zero Heroes—and provided ambitious efficiency targets for each.

The Net Zero Heroes include LED lighting, air conditioners, comfort fans, refrigerator-freezers, heat pump space heaters, heat pump water heaters, electric motors, electric cookers, televisions, and solar water pumps. Chosen for their climate mitigation potential, they also offer significant resilience benefits, from cooling to information access, and are closely linked to a number of SDGs.

Getting appliances on track to meet global net zero goals will require governments to push harder on efficiency than ever before. CLASP's new targets for the Net Zero Heroes are ambitious, yet achievable, but only if swift action is taken. Many of these goals significantly exceed current global benchmarks, which are not strong enough to prevent an overshoot of the mid-century net zero goal even if they were universally adopted. As a result, proven policies, programs, and initiatives will need to scale at unprecedented rates.

By taking immediate action to focus narrowly on Net Zero Hero targets and align efforts across nations and sectors, we can achieve rapid transformation of the appliance sector, creating a better world for all.

TJemaa el-Fnaa Market in Morocco at night fall. *Credit: Shutterstock*

5.2 Recommendations

CLASP calls on all actors to align their efforts with the Net Zero Hero targets and do their part to ensure initiatives for Net Zero Heroes are funded, implemented, and scaled at a rate never seen before. Concerted action is required. Achieving the targets for all Net Zero Heroes will require governments, manufacturers, and others to act with speed and focus. In many cases, governments and others may face trade-offs between actions for the Net Zero Heroes and other appliance efficiency solutions. With little time left to meet Net Zero Hero targets (see Table 6), it is imperative to prioritize Net Zero Hero targets even if it leads to a delay in other solutions.

Improved efficiency can also lead to greater climate resilience and adaptation by improving affordability, thereby bringing appliances within reach of more people. To support a just energy transition, CLASP also advocates for broadening the climate adaptation and energy access agendas to include and prioritize appliances. This would require acknowledging the critical role of appliances in climate-resilient development at global climate forums and expanding the focus of the existing energy access agenda, including access targets for appliances and equipment along with new connections and kilowatt hours (kWh). Additional analysis is needed to identify, assess, and calibrate appliance access goals and map the pathways to closing existing access gaps.

GOVERNMENTS

- **Increase the stringency of appliance policies and the frequency of revision at the speed and scale needed to achieve Net Zero Hero Targets.** Appliance policies such as minimum energy performance standards (MEPS) and energy labels are critical tools. Adopting the levels recommended in United for Efficiency (U4E)'s Model Regulation Guidelines and CLASP's World's Best MEPS is a good start, but will not be enough. Governments will have to redouble their efforts and go much further to reach CLASP's Net Zero Hero targets, outlined in Table 6.
- **Bring other measures to bear.** CLASP recommends a suite of policies and market development programs that work to clear the market of the most inefficient products (via MEPS), promote the adoption of efficient appliances (via comparative labels, financing and financial incentives, bulk procurement, and awareness-raising efforts), and drive technology innovation (via research and development funding, awards and competitions, and endorsement labels). Governments will need an "all of the above" approach to drive efficiency improvements and electrification at the speed and scale necessary to achieve the targets in Table 6.
- **Plan, track, and measure.** Develop roadmaps with specific, time-bound targets for appliance efficiency improvement and enhanced access to efficient appliances. Parties to the United Nations Framework Convention on Climate Change (UNFCCC) should incorporate appliance efficiency into their Nationally Determined Contributions (NDCs) and Net Zero Roadmaps. Countries with significant energy access deficits should integrate access to efficient appliances into their national electrification plans, clean cooking strategies, and sustainable economic development plans. Regular data collection about appliance ownership and usage should be utilized to help governments track which interventions are supporting households and the marketplace, and inform additional action. Market surveillance should be used to confirm compliance with policies.
- **Maximize the multiple benefits of efficient appliances by taking an intersectional approach to designing ambitious plans and policies.** Appliance-focused measures can deliver important equity, health, economic, environmental, climate, and energy security benefits simultaneously. Policies designed with only one of these as a goal risk missing out on the others. Stakeholders will need to

come together across sectors (e.g., health, development, agriculture, and environmental justice) to set goals consistent with the targets in Table 6 and design policies and programs to reach them.

- **Collaborate internationally to stop the dumping of inefficient appliances.** Regional harmonization of standards and cooperation on market surveillance across borders can help block substandard appliances. These efforts benefit all countries in the region. Appliance-exporting countries should go further and discourage the production of all appliances that do not meet domestic efficiency, refrigerant, or other requirements. Uniform guidance across importing and exporting markets can send clear signals to manufacturers that inefficient appliances are no longer acceptable.
- **Expand the capacity of local manufacturers to produce efficient appliances.** In some countries, training and technology transfer will be needed to ensure Net Zero Heroes can be manufactured domestically. Where appliance manufacturing provides jobs, such measures could be indispensable to obtaining broad support for appliance policies and effecting a just energy transition.

MANUFACTURERS & DISTRIBUTORS

- **Produce only appliances and equipment that meet Net Zero Hero targets and avoid dumping low quality products in lower income markets.** Appliance manufacturers should stop producing appliances that do not meet minimum standards in their countries of origin and exporting them to markets that have less stringent standards. They should instead use their influence to promote the sale of more efficient appliances across the globe. For greater impact, manufacturers can join forces through industry associations and global initiatives such as U4E, EP100, and the We Mean Business Coalition. Such efforts can help companies achieve their own NZE and other climate targets.
- **Steer consumers toward the Net Zero Heroes.** Distributors' stocking decisions have enormous influence on what consumers buy. Distributors also influence how appliances are labeled and presented in stores and online. Appliance distributors should work in concert with manufacturers and governments to shift consumers' purchases toward high-efficiency appliances and accelerate the phase-out of fossil-fueled appliances.

TVs on display in shop. *Credit: Shutterstock*

DONORS & FINANCIAL INSTITUTIONS

- **Increase funding for appliance efficiency and access programs.** All actors from both the public and private sectors will need to do more to accelerate the pace of progress. Energy supply has benefitted from subsidies for many years. Financial support on the demand side will be needed for everything from appliance policy development and technology transfer to market surveillance and consumer financing. Efficient appliances sit squarely at the nexus of climate mitigation and adaptation and can deliver benefits for people and the planet simultaneously. Appliance programs should be funded accordingly.
- **Leave no one behind.** Governments and development partners must deploy end-user subsidies and concessional financing to ensure everyone can access energy-efficient appliances, as a just energy transition demands. Consumer financing plays a critical role in lowering the first-cost barrier, especially for low-income consumers and those living beyond the reach of the electric grid. Stimulating demand for efficient appliances is just as important in rural electrification efforts as ensuring that the electricity supply is sufficient, reliable, and sustainable. Financing that enables rural households to purchase and operate good-quality appliances will lead to an increase in electricity demand, which in turn improves the economics of further investment in grid extension and distributed renewable energy.

CIVIL SOCIETY ORGANIZATIONS

- **Advocate for efficient, affordable appliances.** Efficient appliances deliver important benefits to consumers. Policymakers, manufacturers, and others need to know that these benefits matter to consumers, especially to low-income consumers who struggle most with high energy costs and low access to energy services. Consumer, energy, environmental, and health advocates must argue vigorously for ambitious, people-centered climate action and hold decision makers accountable for meeting the targets in Table 6.

Woman looking in fridge. *Credit: Shutterstock*

Aerial night shot of Jakarta Indonesia. *Credit: Shutterstock*

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Annex A: Appliance Access Gap Methodology

CLASP used a two-step methodology to estimate access to the ten essential appliances in its Net Zero Heroes paper. We first used public databases to search for relevant data (Section 1). Then, as the data were incomplete in either space or time, we supplemented it with regression analysis (Section 2). The result was a comprehensive mapping of access gaps for most of the essential appliances across most of the world's countries in 2022, as presented in Section 2.2 of Net Zero Heroes.

1. DATA SOURCES

CLASP first utilized publicly available databases that collect survey results of appliance "penetration," representing the percentage of households in a country (or for mobile phones, the percentage of individual adults) that own an appliance. The appliance access gap is the additive inverse of the penetration (1 – penetration) or the number of households that lack the appliance.

Penetration is a number between 0% and 100%. This is in contrast to appliance "ownership", which is the total number of appliances in a country divided by the number of households and can be greater than 100% if households on average own more than one of a particular appliance. Even when ownership of an appliance in a country is less than 100%, ownership cannot be used to estimate penetration, as households with more than one appliance may "mask" households with zero appliances. For example, 100% ownership could mean universal access (100% penetration), or it could mean that half the households have two of a particular appliance while the other half have none (50% penetration).

The need to only focus on penetration limited the number of databases we were able to use. In cases where databases were missing a significant number of countries, we sought data from others. When multiple databases had data for the same country and appliance, we chose the more recent database to estimate penetration in that country. Table 1 provides an overview of the data sources used and the number of country estimates we were able to compile for each appliance.

TABLE 1: DATA SOURCES FOR ESTIMATING APPLIANCE ACCESS GAPS

ESSENTIAL APPLIANCE	PENETRATION DATA SOURCES	NUMBER OF COUNTRIES WITH DATA IN THE SOURCE	NUMBER OF COUNTRIES WITH USABLE DATA	STRATEGIES USED TO SUPPLEMENT
Lighting	World Bank[1]	262	162	None
Air Conditioners and Fans	SE4All Chilling Prospects[2]	76	66	None
Refrigerator-Freezers	DHS STATcompiler[3]	77	71	Regression
Heat Pumps	European Heat Pump Association[4] Country Surveys[5,6,7,8]	25	25	None
E-cooking	WHO Energy Database[9] Country Surveys[10,11,12]	179	148	None
Solar Water Pumps	CLASP and Dalberg Solar Water Pump Market Sizing[13,14,15]	13	13	None
Televisions	DHS STATcompiler[16]	77	72	Regression
Mobile Phones	ITU DataHub[17] Pew Research[18]	114	72	Regression
Radios	DHS STATcompiler[19] ITU DataHub[20]	56	52	None

2. SUPPLEMENTING DATA SOURCES

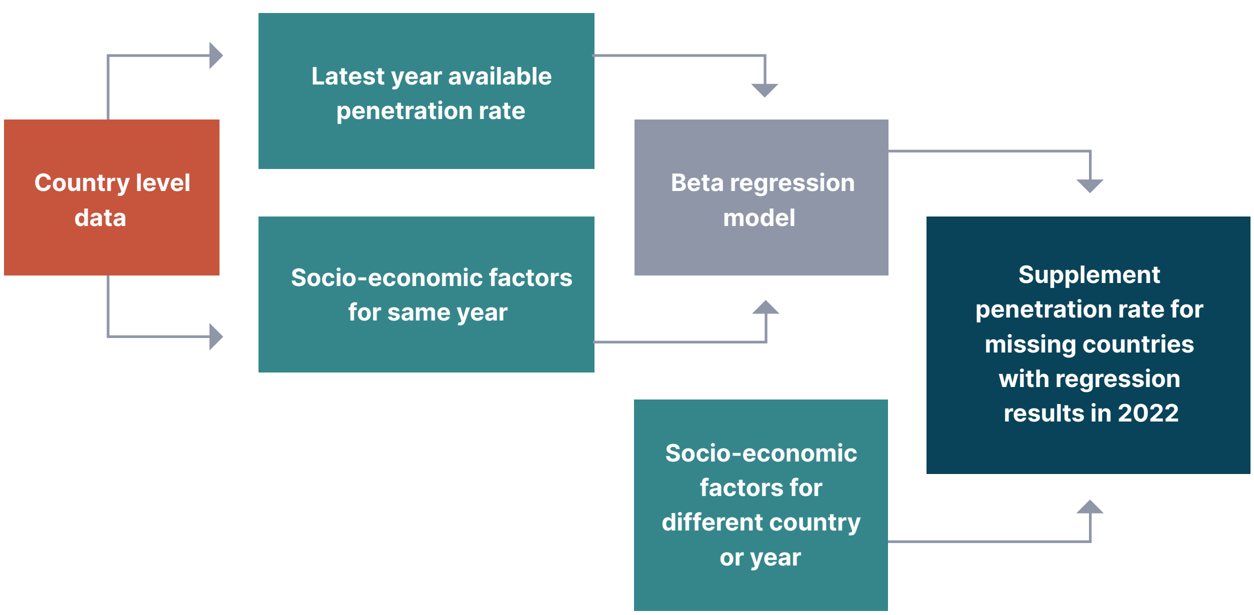
Even with the databases listed above, some countries were still missing as surveys had not been conducted in all countries or had not been conducted recently. Therefore, CLASP supplemented the data sources listed in the previous section using regression analysis to fill in missing data.

2.1. REGRESSION ANALYSIS OVERVIEW

Regression analysis is a statistical technique used to understand how changes in one or more independent variables are associated with changes in the dependent variable. Prior research has consistently identified a robust correlation between household income and the penetration of major household appliances. National electrification and urbanization levels also matter, but less than income for expensive or luxury products.[21] Therefore, CLASP developed regression models that correlate penetration for a particular appliance (dependent variables) with the above socio-economic factors (independent/driver variables) for the same countries and for the latest year available. We then used these models to close data gaps for countries that were missing from the surveys in Section 1 and project the penetration to the year 2022. Figure 1 illustrates the general approach.

There are a variety of regression models that can be used. Typically, the data are transformed using a logistic (s-shaped) function, and then a linear regression is used. Instead, we used a beta regression model due to its reputation for better accommodating dependent variables that assume values between 0 and 1, such as appliance penetration, and producing more evenly distributed errors.[22]

FIGURE 1: GENERAL APPROACH TO SUPPLEMENTING AVAILABLE DATA THROUGH REGRESSION MODELING



2.2. DRIVER VARIABLES

To ensure an accurate estimation of appliance penetration for 2022 across a diverse set of countries, it is critical that driver variables are accessible at the country level worldwide. The variables and their sources are listed in Table 2.

Unfortunately the independent variables were not available for all the years. For example, the UN provides urbanization every 5 years, so we linearly interpolated during the 4 years in between to ensure data completeness. Similarly, household size data is only available for years when a survey was conducted in a particular country, prompting us to use linear interpolation to ensure we had data during the in-between years. Finally, the household size, GDP, and electrification variables were only available until 2020 or earlier. For these variables, we projected values to 2022 based on historical data as follows: electrification and household size linearly extrapolated based on historical trends, while GDP was exponentially extrapolated based on the IMF GDP growth rates. After generating complete data series for the independent variables over 1950–2022, we proceeded to develop regressions for mobile phones, televisions, and refrigerator-freezers as follows.

TABLE 2: INDEPENDENT VARIABLES USED IN THE REGRESSION MODEL

VARIABLE	SOURCES	YEARS
Gross Domestic Product (GDP)	World Bank Gross Domestic Product, Purchasing Power Parity (constant 2017 international $)[23]	1990-2020
	IMF Real GDP Growth[24]	2020–2022
Population	UN Population Division[25]	1950-2100
Household Size	UN Population Division Household Size and Composition 2019[26]	1960–2018
Electrification	World Bank Access to Electricity (% of the population)[27]	1990–2020
Urbanization	UN Population Division World Urbanization Prospects 2018 (% of the population residing in urban areas)[28]	1950–2050

2.3. REFRIGERATOR-FREEZER ANALYSIS

CLASP's model of refrigerator-freezer penetration incorporates average household income, electrification, and urbanization. The results (Table 3) show a relatively high R^2 at 0.77 (socio-economic variables explain 77% of the variability in refrigerator-freezer penetration across time and countries).

TABLE 3: REFRIGERATOR-FREEZER BETA REGRESSION MODEL

SYMBOL	VARIABLE	BETA MODEL COEFFICIENT
	Constant (ln γ in logistic model)	-3.42
a_1	Monthly Household Income Coefficient	4.59×10^{-4}
a_2	Electrification Rate Coefficient	2.31
a_3	Urbanization Rate Coefficient	1.79
	Multiple R^2/Pseudo R^2	0.77
	RMS Error (percentage points)	2.1

2.4. TELEVISION ANALYSIS

According to CLASP's previous research, the household TV penetration rate is mostly related to the national household income level and electrification rate. Therefore, the beta regression model was built based on these two variables. The results show that electrification has the most significant impact on the household TV penetration rate in a specific country. Table 4 shows the beta model results, including coefficients and a root-mean-square error of 1.4 percentage points.

TABLE 4: TV BETA REGRESSION MODEL

SYMBOL	VARIABLE	BETA MODEL COEFFICIENT
	Constant (ln γ in logistic model)	-2.32
a_1	Monthly Household Income Coefficient	4.71×10^{-4}
a_2	Electrification Rate Coefficient	3.13
	Multiple R^2/Pseudo R^2	0.80
	RMS Error (percentage points)	1.4

2.5. MOBILE PHONE ANALYSIS

Through trial and error, CLASP found that population, urbanization, and electrification, had the most significant relationship to phone penetration rate, resulting in a 0.52 R^2 correlation coefficient. Among all the variables, electrification had the biggest coefficient value at 0.84 (the bigger the coefficient, the bigger the impact of the explanatory variable on penetration).

TABLE 5: MOBILE PHONE BETA REGRESSION MODEL

SYMBOL	VARIABLE	BETA MODEL COEFFICIENT
	Constant (ln γ in logistic model)	-1.41
a_1	Population Coefficient	$-1.84 * 10^{-7}$
a_2	Urbanization Rate Coefficient	0.46
a_3	Electrification Rate Coefficient	0.84
	Multiple R^2/Pseudo R^2	0.52
	RMS Error (percentage points)	1.4

2.6. ANALYSIS OF OTHER APPLIANCES

For the remaining appliances, we either did not have to supplement the data through regression because the datasets were substantially complete, or we were unable to do so. Our estimate of access gaps is, therefore, an undercount and additional millions of people are likely experiencing access gaps in countries for which we were not able to develop estimates.

- **Lighting:** we presumed that penetration was the same as the electrification rate, as lighting is the first appliance procured by households after gaining access to electricity. As the electrification data set was complete, we did not have to supplement it.
- **E-cooking:** the dataset was similarly complete.
- **Air conditioners and fans** and **heat pumps:** We were unable to find a global dataset, but we did find data estimates across most hot and cold countries, which would be the countries where access to these appliances would be necessary.
- **Solar water pumps:** we had initial data for so few countries, and the usefulness of solar water pumps depends much more on local context than the other household appliances. Therefore, we presented the limited data we had without attempting to supplement it.
- **Radio:** we were unable to develop a satisfactory beta regression model. The model had high errors and a low correlation coefficient, indicating that the socio-economic variables did not meaningfully explain the penetration, and sure enough, surveys show that radio penetration in many countries has been falling with time even as income has been rising. We, therefore, again relied on the survey data only and did not use regression to supplement it.

Annex A: End Notes

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Annex B: Initiatives & Programs Leading the Way

UKaid from the British people | AYRTON FUND

Lead Institutions

UK Foreign, Commonwealth and Development Office (FCDO)

UK Department for Business, Energy & Industrial Strategy (BEIS)

Technologies

Fans

Air conditioning

Walk-in cold storage

Electric cooking

Other appliances

AYRTON FUND

The Ayrton Fund, supported by the UK government with a commitment of up to £1 billion, aims to accelerate the clean energy transition in developing countries. With a focus on research, development, and demonstration (RD&D) of innovative clean energy technologies and business models, the fund seeks to make clean energy options more affordable, accessible, and attractive in developing countries, in alignment with Sustainable Development Goals 7 (Affordable and Clean Energy) and 13 (Climate Action). Managed jointly by the Foreign, Commonwealth and Development Office (FCDO) and the Department for Business, Energy & Industrial Strategy (BEIS), the fund supports various themes, including lower-cost clean energy supplies, efficient demand management, and smart delivery systems. The fund will operate from April 2021 to March 2026.

In its first year, the fund supported 16 clean energy RD&D platforms and programs including:

Low Energy Inclusive Appliances (LEIA): This FCDO program focuses on improving the efficiency, availability, and affordability of electrical appliances and solar technologies for off-grid and weak-grid settings.

Modern Energy Cooking Services (MECS): This FCDO program, involving leading UK universities and innovators, advances research on clean cooking solutions, facilitating the transition from biomass to cleaner cooking fuels in developing countries.

Transforming Energy Access (TEA): This FCDO platform facilitates the testing and scale-up of innovative technologies and business models.

Climate Compatible Growth (CCG): This FCDO platform generates evidence and global public goods to aid countries in developing and implementing economic strategies and plans.

Clean Energy Innovation Facility (CEIF): This BEIS program promotes the commercialization of clean energy technologies in developing countries, focusing on themes such as industrial decarbonization, sustainable cooling, smart energy, and energy storage.

Global Challenges Research Fund (GCRF): Administered by UK Research and Innovation (UKRI), this BEIS fund supports researchers and innovators, both in the UK and internationally, in addressing crucial issues faced by developing countries, including access to clean energy.

CLEAN COOKING ALLIANCE

Lead Institutions

United Nations Foundation

Technologies

Electric cooking

The Clean Cooking Alliance (CCA) is dedicated to promoting clean cooking solutions and reducing the negative impacts of traditional cooking practices. It is aligned with SDG 7, which aims to ensure universal access to modern energy services (including clean cooking) by 2023. By addressing the health, environmental, and social challenges associated with cooking, the CCA aims to improve the lives of millions of people around the world.[1]

CCA has a three-pronged strategy:[2]

- **Investment:** mobilizing funding and resources to support the scale-up of clean cooking solutions
- **Innovation:** developing and promoting new technologies and business models
- **Advocacy:** integrating clean cooking into national development agendas and policies

CCA develops partnerships with myriad stakeholders, including governments, philanthropies, and private companies. Through these partnerships, CCA has been able to leverage resources, expertise, and networks to scale up interventions and drive systemic change. Two examples are Haiti's Cookstoves and Clean Energy Market Project[3] and Nepal's Country Action Plan (CAP) for Transforming the Cookstoves and Fuels Market.[4]

CCA has provided more than $25 million USD in support to companies across the clean cooking industry.[5] It has invested $17.8 million USD in research on the impacts of household air pollution and the benefits of clean cooking.[6] More than 5,000 women entrepreneurs, youth, and educators have been trained, and CCA's demand creation and behavior change campaigns have reached more than 40 million people in 8 countries.[7]

CLEAN COOLING COLLABORATIVE

Lead Institutions

ClimateWorks Foundation

Technologies

Air Conditioning

Fans

The Clean Cooling Collaborative (formerly Kigali Cooling Efficiency Program (K-CEP)) is an initiative of ClimateWorks Foundation focused on transforming the cooling sector and making efficient, climate-friendly cooling accessible for all. The Collaborative catalyzes organizations, companies, and governments to bring efficient, climate-friendly cooling policies, financing, and technology solutions to the world. The Collaborative estimates that cooling-focused efforts could avoid 100 Gt CO_2e by 2050 while also closing the cooling access gap.[8]

Optimizing and improving mechanical cooling technologies, including air conditioners, is a major focus. Through its network of implementing partners, the Collaborative is working to improve test procedures, strengthen minimum energy performance standards, implement demand flexibility more widely, and improve affordability. All of these efforts are aimed at achieving a rapid transformation of room air conditioner markets.

The Global Cooling Prize demonstrated that such a transformation is achievable. The winning prototypes met the ambitious target of having *at least five times less climate impact* than the standard room air conditioners available when the competition launched in 2018. According to the prize administrators, "When scaled, such technologies could prevent 75 Gt of CO_2e emissions cumulatively between now and 2050 and mitigate over 0.5 °C of global warming by the end of the century."[9] The competition was initiated by RMI, the Government of India, and Mission Innovation.

Lead Institutions

CLASP

Technologies

Lighting

CLEAN LIGHTING COALITION

The Clean Lighting Coalition (CLiC) is CLASP's global campaign calling for the phase-out of toxic, mercury-containing fluorescent lighting in favor of efficient LEDs through the Minamata Convention on Mercury. CLiC engages national governments, provides robust evidence demonstrating the feasibility of an LED transition, and mobilizes more than 300 advocates in over 70 countries worldwide.

A global LED transition is vital to protecting human and environmental health from the dangers of mercury – a dangerous neurotoxin that can pollute water and land. Phasing out fluorescent lamps is also critical to meeting global climate targets. LED lamps are twice as energy efficient as fluorescent alternatives – lowering global energy demand and associated emissions. Mercury-free LEDs also have life spans two to three times longer than fluorescent lamps, resulting in less e-waste.

In 2022, CLiC supported key decision makers at the Minamata Convention COP4 to adopt an amendment proposed by the Africa Region to phase out compact fluorescent lamps by 2025. At COP5 the following year, CLiC continued its engagement with the 147 Parties to the Convention to accelerate the global transition to LED lighting - achieving a phase out of all fluorescent lamps globally by 2027. The decisions effectively end the mercury-added lighting industry for good and offers significant climate benefits, including (cumulatively from phase out dates to 2030):

- Avoid 2.963 gigatonnes of CO_2 emissions
- Save $1.23 trillion USD on electricity bills
- Eliminate 193 tonnes of mercury pollution, both from the light bulbs themselves and from avoided mercury emissions from coal-fired power plants

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Lead Institutions

CLASP

Energy Saving Trust

Technologies

Electric cookers

Fans

Lighting

Refrigerators/freezers

Solar water pumps

Televisions

Walk-in cold storage

Other productive use appliances

EFFICIENCY FOR ACCESS

Efficiency for Access is a global coalition supported by UK aid and IKEA Foundation that promotes high-performing appliances that provide clean energy access to the world's poorest populations. It is jointly coordinated by CLASP and Energy Saving Trust and aims to accelerate the growth of off-grid appliance markets to improve livelihoods, reduce carbon emissions, and support sustainable development. Established in 2018, it has grown to comprise 76 organizations, including donors, investors, and industry stakeholders, mobilizing over £280 million in funding for off-grid-appropriate appliances.

The coaltion's flagship program, Low-Energy Inclusive Appliances (LEIA), focuses on research and innovation to make household and light-industrial electrical appliances more affordable, efficient, and accessible in developing countries. LEIA's activities include market stimulation (Global LEAP Awards), quality assurance (VeraSol), R&D support (Efficiency for Access R&D Fund), and student competitions (Efficiency for Access Design Challenge). LEIA is funded by FCDO and by IKEA Foundation.

LEIA has facilitated the sale of over 2.7 million solar appliances, benefiting around 12 million people. It has also supported over 500 off-grid appliance companies, disbursing £4 million in R&D grants, resulting in 38 completed projects, 31,000 beneficiaries, and the creation of over 900 jobs.

Lead Institutions

CLASP

Technologies

Solar water pumps

Electric pressure cookers

Refrigerators/freezers

Walk-in cold storage

Fans

Mills

PRODUCTIVE USE APPLIANCE FINANCING FACILITY

Access to affordable and energy-efficient productive use appliances can deliver significant economic, health, education, and quality of life benefits while lowering carbon emissions. Despite their transformative potential, productive use appliance sales are extremely low, and affordability is the biggest barrier to market growth.

CLASP's Productive Use Appliance Financing Facility is a groundbreaking initiative funded by the Global Energy Alliance for People and Planet (GEAPP) and supported by Nithio that makes quality-assured productive use technology more affordable in emerging markets. The Facility, which launched in 2022, provides procurement subsidies, consumer financing, capacity-building small grants, and technical assistance for eligible appliance distributors, allowing companies to lower costs for customers while investing in long-term growth.[10]

The Facility operates across the off-grid, mini-grid, and grid-connected (utility) sectors, initially in the Democratic Republic of the Congo, Ethiopia, Kenya, Nigeria, Sierra Leone, and Uganda. It supports the sales of six main appliance technologies, selected because of their relative maturity and potential to drive development impact: walk-in cold rooms, refrigerators, electric cookers, fans, mills, and solar water pumps.[11] The Facility represents a crucial step towards ensuring that all communities have access to affordable and sustainable energy solutions, helping to create a more just and equitable world for all.

European Commission

Lead Institutions

European Commission

Technologies

Heat pumps

REPOWEREU

About 50% of all the energy consumed in the EU today is used for heating and cooling, and more than 70% of heating and cooling is still based on fossil fuels, mostly natural gas.[12] The EU's ambition, as expressed in the Fit for 55 proposals of 2021, is to reduce net GHG emissions at least 55% by 2030 and achieve climate neutrality by 2050.[13] To hit these targets, heating must be electrified.

The need to electrify heating became even more urgent with the February 2022 Russian invasion of Ukraine. In response, the European Commission established the REPowerEU Plan in May 2022 to shift Europe away from fossil gas and oil use more quickly than previously contemplated. The plan aims to stimulate even faster uptake of individual heat pumps in buildings and of large-scale heat pumps in district heating and cooling networks.

The REPowerEU Plan calls for a doubling of the current deployment rate of individual heat pumps, resulting in a cumulative 10 million units deployed from 2022 to 2027.[14] A number of policy changes will be needed to reach this ambitious target, and success will require a concerted effort on the part of multiple EU agencies and individual member states.

SUPER-EFFICIENT EQUIPMENT AND APPLIANCE DEPLOYMENT INITIATIVE

Lead Institutions

Clean Energy Ministerial

Energy Efficiency Hub

Technologies

Residential Air Conditioning

Lighting

Residential Refrigerators and Freezers

Industrial Electric Motor Systems

The Super-efficient Equipment and Appliance Deployment (SEAD) Initiative is a project of the Clean Energy Ministerial, a group of 29 energy ministers working in concert to accelerate the transition to renewable energy.[15] The SEAD Initiative focuses on deploying efficient appliances to "reduce energy use, bills, and emissions."[16]

In 2021, SEAD together with the UK Government, IEA, and CLASP organized the Product Efficiency Call to Action. Timed to coincide with the UNFCCC COP26 in Glasgow, the Call to Action sought to galvanize action around appliance efficiency by challenging countries to double the efficiency (or halve the energy use) of four common types of appliances and equipment by 2030: residential air conditioning, lighting, residential refrigerators and freezers, and industrial electric motor systems. Together, these four appliances and equipment are responsible for the majority of global electricity use.

While 14 countries signed the pledge,[17] further work remains: current signatories should take action to implement new policies (standards, labeling, or incentives) and make plans to update them in order to meet the efficiency doubling goals. CLASP's initial review of policies found that the signatories have not yet made significant improvements to their MEPS, but doubling is still possible if countries adopt an aggressive policy revision schedule and levels in line with IEA's energy performance ladders prior to 2030.[18,19,20,21]

UNITED FOR EFFICIENCY

Lead Institutions

U.N. Environment

Technologies

Lighting

Refrigeration

Room air conditioners

Distribution transformers

Electric motors

United for Efficiency (U4E) is a global effort led by UN Environment that helps developing countries and emerging economies to move their markets toward more energy-efficient appliances and equipment. The initiative works by:[22]

- Informing policy makers of the potential environmental, financial, and economic savings of a transition to high-efficiency products
- Identifying and promoting global best practices in transforming markets
- Offering tailored assistance to governments to develop and implement national and regional strategies and projects to achieve a fast and sustainable market transformation

U4E carries out projects at the regional, multi-country, and country levels. Projects bring together U4E founding partners CLASP, International Copper Association, NRDC, UNDP, and UN Environment with national governments, academic institutions, manufacturers, and other national and international organizations. U4E has ongoing projects in Southeast Asia, the Caribbean, Eastern and Southern Africa, Latin America, and elsewhere.[23]

U4E has created a number of publications including country savings assessments, model regulation guidelines, and green public procurement guidelines to quantify the benefits of a transition to energy-efficient appliances and equipment and provide stakeholders with specific guidance for realizing these benefits.

U4E aims to help countries reduce electricity consumption by up to 20% and, by 2030, achieve a 1.25 Gt reduction in CO_2 emissions.[24]

Lead Institutions

US Department of Energy

US Internal Revenue Service

US Environmental Protection Agency

Technologies

Heat pumps

UNITED STATES INFLATION REDUCTION ACT

On August 16, 2022, US President Joseph R. Biden signed the Inflation Reduction Act (IRA) into law, allocating $369 billion USD in funding for emissions-reducing climate and clean energy provisions. The IRA will have a significant impact on emissions reductions, job creation, and public health, and is the most significant federal climate and clean energy legislation in US history. It is projected that the IRA's provisions could cut greenhouse gas (GHG) emissions 37–43% below 2005 levels by 2030, putting the US's Paris Agreement Nationally Determined Contribution of 50% reduction within reach.[25]

One focus of the IRA is heat pumps for space heating. Several financial incentives including tax credits and rebates encourage individuals to voluntarily retrofit their homes with energy-efficient appliances and other upgrades. As participation is voluntary, and financial incentives may fund numerous types of efficient alternatives, the precise impact of the IRA on the residential sector is hard to estimate. The US Energy Information Administration (EIA) estimated a 2 percentage point increase in heat pump penetration, or 2.5 million new installations,[26,i] while RMI estimated 7.2 million installations from the tax credits alone.[27]

Further incentives for heat pumps may be provided through the Home Owner Managing Energy Savings (HOMES) program, which will incentivize $4.3 billion USD of whole-home energy retrofits, as well as a Greenhouse Gas Reduction Fund (GHGRF) that designated $7 billion USD to supporting the deployment of zero-emissions technology in low-income and disadvantaged communities.[28] Implementation of the IRA now moves to the states, which will develop programs to utilize this funding.

Programs in US states and other countries seeking to drive further heat pump adoption should seek to address all the market barriers to heat pump adoption through incentives, equitable pricing, and regulations, as well as overall coordination and communication.[29]

i. CLASP calculated the number of anticipated heat pump installations based on 2020 RECS data and EIA's assumed 2 percentage point increase in heat pump market share.

Annex B: End Notes

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