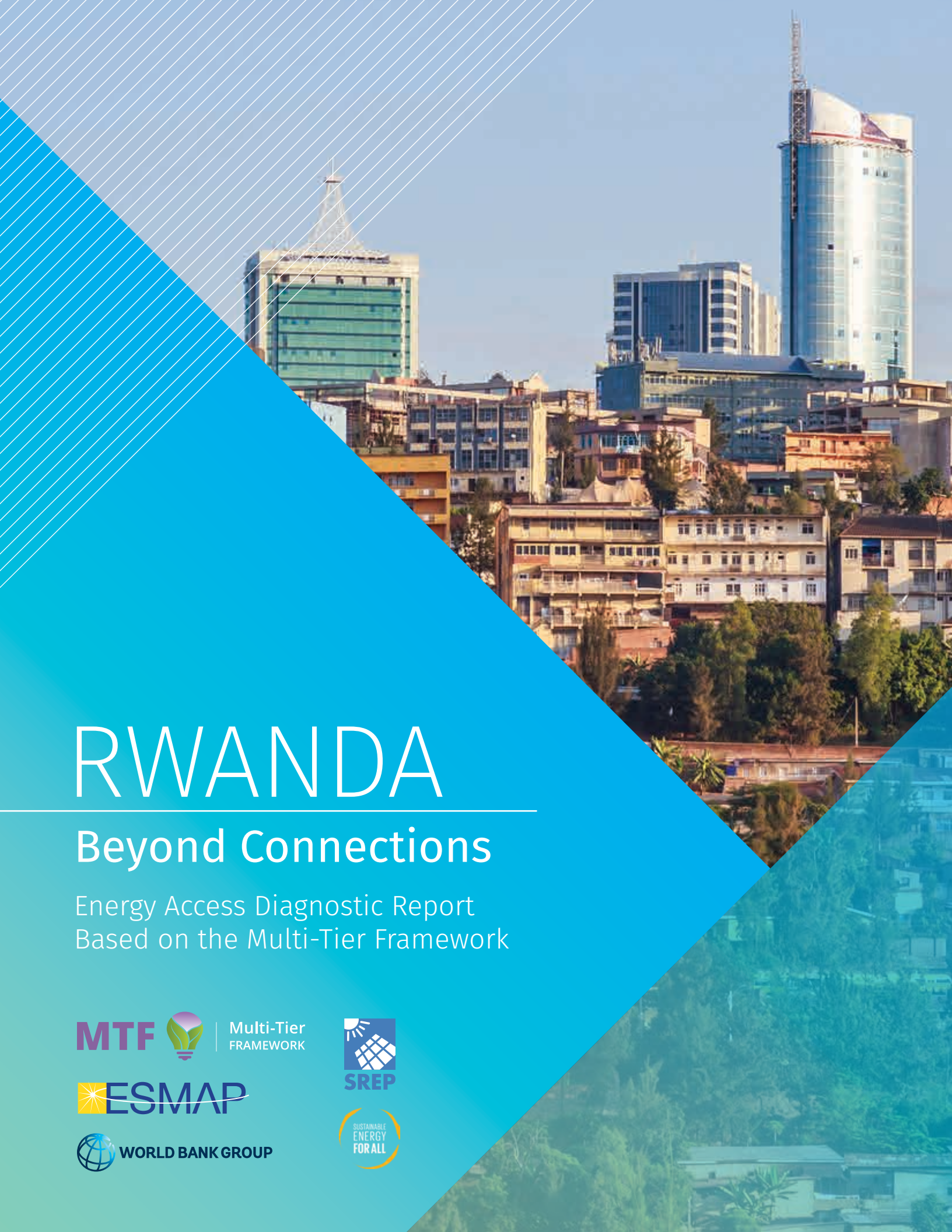

# RWANDA

## Beyond Connections

Energy Access Diagnostic Report
Based on the Multi-Tier Framework

MTF Multi-Tier FRAMEWORK

ESMAP

WORLD BANK GROUP

SREP

SUSTAINABLE ENERGY FOR ALL

# RWANDA

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### Energy Access Diagnostic Report Based on the Multi-Tier Framework

*Written by: Bryan Bonsuk Koo, Dana Rysankova, Elisa Portale, Niki Angelou, Sandra Keller, Gouthami Padam*

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# ABBREVIATIONS

| | |
|---|---|
| **ESMAP** | Energy Sector Management Assistance Program |
| **ICS** | improved cookstove |
| **kW** | kilowatt |
| **kWh** | kilowatt-hour |
| **LPG** | liquefied petroleum gas |
| **MTF** | Multi-Tier Framework |
| **RISE** | Regulatory Indicators for Sustainable Energy |
| **SHS** | solar home system |
| **SLS** | solar lighting system |
| **SREP** | Scaling Up Renewable Energy Program in Low Income Countries |
| **W** | watt |
| **WTP** | willingness to pay |

# NUMERICAL HIGHLIGHTS

## ACCESS TO ELECTRICITY

- The government of Rwanda has successfully accelerated growth in access to electricity: the access rate increased from 10% in 2010 to 13% in 2012[1] to 28.6% in 2016[2] to 43% in 2018.[3] The Rwandan government has set a target to achieve 100% electrification by 2024 (52% through grid connections and 48% through off-grid solutions), according to the National Strategy for Transformation, which was approved in 2017.
- As of 2016, 28.6% of households have access to at least one source of electricity: 23.5% of households have access through the grid, and 5.1% have access through off-grid solutions, mostly solar.[4]
- 26.8% of households households have been assessed as having basic access to electricity supply. The remaining 73.2% have no electricity source, rely on dry-cell batteries, or have a grid or off-grid electricity supply that does not provide basic energy service (able to light the house and charge phones and available for at least 4 hours a day and 1 hour in the evening).
- 81.3% of electrified households have at least 8 hours of electricity supply a day, including at least 3 hours in the evening.
- 77.4% of urban households are connected to the grid, compared with 15.6% of rural households.
- 49.6% of electrified households receive electricity 23 hours a day, 7 days a week.
- 91.7% of grid-connected households experience more than four electricity disruptions a week.
- 20.9% of grid-connected households face voltage issues—such as low or fluctuating voltage.
- Average monthly household consumption of electricity is 20.8 kWh nationwide, 29.2 kWh in urban areas, and 9.9 kWh in rural areas.
- 66.8% of rural grid-connected households use only very low–load appliances (mostly for lighting and phone charging).

[1] Global Tracking Framework, 2017.
[2] Based on Multi-tier energy access Tracking Framework survey in 2016
[3] As of 2016, when the MTF data were collected, the overall electrification rate, including grid connections and off-grid solutions was 28.6%. However, since then, the electrification rate in Rwanda has increased very rapidly about 43%, 31% from grid and 12% from off-grid solutions, according to Ministry of Infrastructure in January 2018. MTF data have already informed the government of Rwanda of policy decisions such as a change in connection policy introduced May 2017; validated technical design of the Renewable Energy Fund, and contributed to the development of the government program of energy sector reform that is supported by the Energy Development Policy Operation series.
[4] As of 2016 when the MTF data was collected, overall electrification rate including on- and off-grid was 28.6%. However, since then, the electrification rate in Rwanda has been increased very rapidly and the electrification rate in Rwanda is about 43%, 31% from on-grid and 12% from off-grid solutions according to Ministry of Infrastructure in January 2018. MTF data has already informed government of Rwanda of policy decisions such as change in connection policy introduced May 2017; validated technical design of the Renewable Energy Fund; and contributed to the development of the government program of energy sector reform that are supported by the Energy Development Policy Operation series.

- The main barriers that prevent households from gaining connectivity to the grid are the high connection fee (54.7% of households) and distance from the grid infrastructure (36.5% of households).
- 23.9% of unconnected households are willing to pay full price upfront for an off-grid solar device that allows them to reach Tier 1 for access to electricity, and 30.3% are willing to pay full price with a 6- or 12-month payment plan.
- 9.2% of households that use an off-grid solar solution acquired it with a payment plan, and 90.8% paid upfront.
- Phone charging (42.3%) is the most common additional service used by households that updated their off-grid solar solution, followed by radio (19.7%) and television (12.9%).

## ACCESS TO MODERN ENERGY COOKING SOLUTIONS

- 99.6% of households cook with biomass, and a third of those households use an improved cookstove as their primary stove. Only 0.4% of households use clean fuels as their primary cooking fuel. None of the sampled households use an electric stove as their primary stove.
- Stove stacking (using multiple cookstoves) occurs in 6.6% of households. For the majority of households that use more than one cookstove, the additional stove is lower performing than the primary stove.
- 76.5% of households spend over 7 hours a week to acquire (through collection or purchase) and prepare cooking fuel, and 38.4% of households spend up to 5 minutes per meal preparing the stove.
- 35.3% of households stated that their primary cooking fuel is only sometimes or rarely available
- 72% of households are willing to pay full price for an improved biomass stove upfront or in six monthly installments.
- Households that use a three-stone stove exclusively spend 25% more time acquiring and preparing fuel than households that use an improved biomass stove exclusively do.

### GENDER ANALYSIS

- Nationwide, 25.7% of households are headed by women.
- Only 21.1% of female-headed households have access to any source of electricity, compared with 31.2% of male-headed households.
- For 60.7% of female-headed households and 52.4% of male-headed households the main barrier that prevents them from connecting to the grid is the high connection cost.
- Of female-headed households that access electricity through an off-grid solar solution, 47.9% use a solar lighting system, and 52.7% use a solar lantern.
- 63.2% of female-headed households and 43% of male-headed households are willing to pay for an off-grid solar solution that allows the household to reach Tier 1 for access to electricity.
- Just 13%–15% of household appliance purchase decisions are made by women alone, and 17%–33% of purchase decisions are made jointly.
- 12.4% of women age 15 or older experienced cough in the last 14 days, compared with 3.6% of men age 15 or older.
- In rural areas women spend an average of 80 minutes a day acquiring fuel, compared with 40 minutes for men, and 28 minutes a day preparing fuel, compared with 19 minutes for men.
- 82.6% of female-headed households are willing to pay upfront or with a 6- to 12-month payment plan for an improved cookstove if the price is reduced to 1,000 Rwandan francs.
- Women alone make the decision for 49.7% of cookstove purchases, including 85.6% of clean fuel stove purchases.

## POLICY HIGHLIGHTS

### ACCESS TO ELECTRICITY

- Rwanda's greatest challenge is to provide access to at least basic electricity supply (Tier 1 or above) to households without any access (Tier 0).
- The Rwandan government aims to achieve universal access by 2024 (52% through grid connections and 48% through off-grid solutions), according to the National Strategy for Transformation, which was approved in 2017. While the ultimate goal may be for all

households to be in Tier 5, this goal is likely to take time. In the interim, a combination of grid and off-grid solutions should be promoted.

- Grid expansion is likely to be cost-effective in urban areas, where grid infrastructure already exists and where households tend to have higher consumption and use higher load appliances, while off-grid solutions are likely to be cost-effective in rural areas, where households tend to be farther from the grid and consume very little electricity, primarily for lighting and phone charging, or at best for low-load appliances, such as a television. RISE indicators show that policymakers have historically prioritized grid extension over off-grid solutions.[5]
- Although access to electricity using an off-grid solar solution is only 5.1%, this penetration rate was achieved in a short timeframe: most households report that they acquired their first off-grid product within the last 3 years. Off-grid solutions are thus a promising approach for providing access to at least basic electricity supply to unelectrified households.
- Willingness to pay for a grid connection and off-grid solar devices can be enhanced by spreading payments over time. Other financing mechanisms that boost households' ability to pay may be required to connect households that are unwilling to pay a connection fee even with a payment plan.
- The causes of low electricity consumption and low ownership of appliances (such as ability to pay the tariff, lack of productive uses, unavailability of or inability to pay for appliances, and being unaccustomed to electricity use) among grid-connected households should be analyzed, and adequate measures should be implemented to boost the use of grid electricity.
- To improve access to electricity among grid-connected households, Rwanda needs to improve Reliability, Quality, and Availability. Increasing evening Availability from 3–4 hours to over 4 hours and solving voltage problems would move most households in Tier 3 to a higher tier, and reducing power disruptions to less than four per week and increasing daily Availability from 16–23 hours to over 23 hours would move households in Tier 4 to Tier 5.
- Availability and Capacity keep households with an off-grid solar solution in lower tiers for access to electricity, but solar solutions can provide households with over 23 hours of electricity a day, allowing them to reach Tier 5 for daily Availability. To reach a higher tier for access to electricity, households with an off-grid solar solution will need to upgrade to a larger system (or eventually connect to a mini-grid or the grid).
- The key to upgrading off-grid solar solutions (and thus moving households with an off-grid solar solution to a higher tier) will be to ensure that households can pay for them, including spreading the payments over time, and that the devices perform well.

[5] RISE results for Rwanda can be viewed at: http://rise.worldbank.org/country/rwanda

## ACCESS TO MODERN ENERGY COOKING SOLUTIONS

- Rwanda faces a double challenge in improving access to modern energy cooking solutions: a high percentage of households that still use highly polluting three-stone and traditional stoves and a very low percentage of households that use clean fuels. The ultimate objective should be to provide all households access to cooking solutions that are clean, efficient, convenient, affordable, safe, and available (Tiers 4 and 5), but in the interim improved biomass stoves could be an immediate solution to move households in Tier 0 to Tiers 1–3.
- The government of Rwanda should develop a comprehensive national program to scale up access to modern energy cooking solutions. While such a program would need to involve stakeholders from a wide variety of positions, roles, and levels, there is no substitute for high-level political, technical, and financial support from national leaders and agencies. This high-level support is a key success factor that requires time to build and continuous engagement to maintain.
- Disseminating improved biomass stoves to the large percentage of households that express willingness to pay for these solutions would likely include a combination of supply measures (such as support for stove manufacturers and distributors by, for example, establishing working capital facilities) and demand measures (such as consumer awareness campaigns and consumer financing options). Given the low penetration of improved biomass stoves in rural areas, rural households in particular, should be targeted.
- Health-related consumer awareness campaigns would be critical for promoting clean fuel stoves and improved biomass stoves.
- Given the important health benefits that clean fuels deliver, ways to expand their small share, particularly in more affluent urban areas, should be explored. A strategy to do so should be accompanied by a strategy to minimize the parallel use of biomass stoves (in particular, three-stone and traditional stoves). Potential supply constraints should be analyzed and removed accordingly, particularly for higher income urban households that can afford clean fuels.
- Allowing a stove to be paid for in installments appears to be an effective way to increase households' ability to pay for an improved biomass stove without resorting to upfront cost subsidies, which are often unsustainable. Offering a six-month payment plan was especially effective in increasing willingness to pay among rural households.

## GENDER ANALYSIS

- A gender gap exists in access to electricity and modern energy cooking solutions. Female-headed households have lower access rates for both grid and off-grid electricity: 20% of female-headed households have access to any source of electricity, compared with 31% of male-headed households, so more female-headed households (80.3%) than male-headed households (70.9%) are in Tier 0. More female-headed households (57.7%) than male-headed households (51.8%) use a three-stone stove as their primary stove. In addition, female-headed households are less likely to be willing to pay for a grid connection or an off-grid solar solution.
- Gender-targeted financing mechanisms are required to increase grid connections for female-headed households and to enable female-headed households to benefit equally from off-grid solar solutions. More female-headed households (69.5%) than male-headed households (40.1%) are not willing to pay for a grid connection at full price upfront, full price with a down payment and 24-month payment plan, or half price upfront. Thus, gender-targeted subsidies for a grid connection and improved biomass stoves could significantly improve access to the grid and use of improved biomass stoves. The cost to connect to the grid is the main constraint for 60.7% of female-headed households and 52.4% of male-headed households.[6]
- Gender-targeted subsidies for improved cookstoves could significantly improve access to such stoves. Because female household members spend more time collecting and preparing cooking fuels and spend more time in the cooking space, they would benefit most from switching to an improved biomass stove.
- Cookstove-related campaigns and dissemination efforts should be adequately tailored to both a male and female audience. Nationwide, more female household members (49.7%) than male household members (40.3%) make the decision to purchase appliances.

[6] The government of Rwanda has introduced a policy to help households pay for a connection by removing the upfront of cost of a connection fee and spreading it across the payment period.

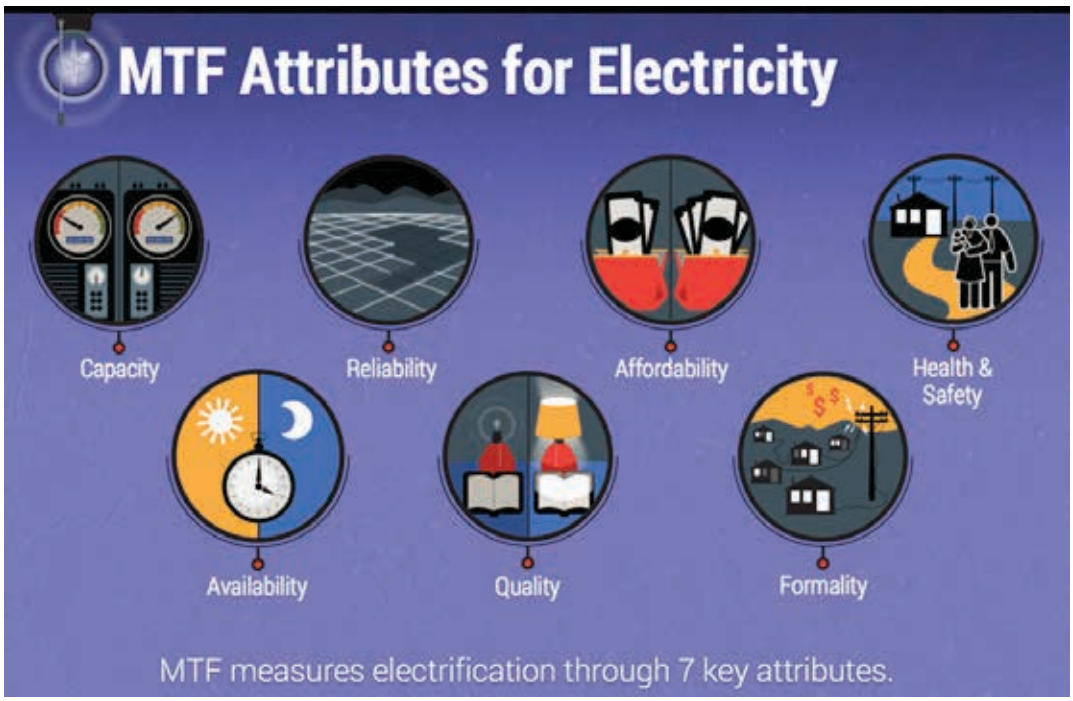
# KEY FINDINGS AND POLICY IMPLICATIONS

Technologies, attributes, tiers, and use—those are the key concepts that the Multi-Tier Framework (MTF) uses to assess the access of households in Rwanda to various sources of electricity and modern energy cooking solutions. It thus goes well beyond traditional binary assessment of energy access—of having or not having a connection to electricity, or using or not using a modern energy cooking solution. The MTF achieves this by capturing the many dimensions of energy access and the wide range of technologies that households use for power and for cooking.

## ACCESS TO ELECTRICITY

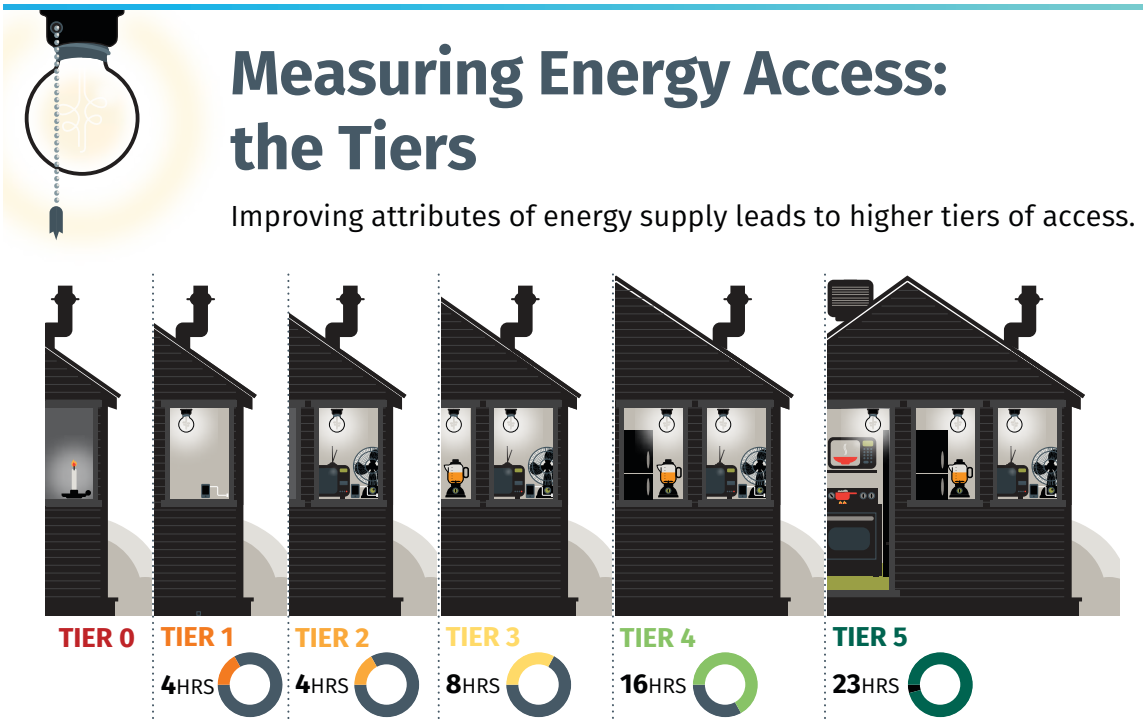
The MTF approach measures energy access provided by any technology or fuel based on seven attributes that capture key characteristics of the energy supply that affect the user experience (figure 1): Capacity, Availability,[7] Reliability, Quality, Affordability,[8] Formality, and Health and Safety. Based on those attributes, it then defines six tiers of access, ranging from Tier 0 (no access) to Tier 5 (full access) along a continuum of improvement (figure 2). Higher tiers are defined by higher Capacity and longer Availability of supply—enabling the use of medium- and high-load appliances (such as a refrigerator, washing machine, a air conditioner)—as well as by Reliability, Quality, Affordability, Formality, and Health and Safety.

FIGURE 1 • **Multi-Tier Framework attributes for access to electricity**




[7] Previously referred to as "Duration" in the 2015 Beyond Connections report, this MTF attribute is now referred to as "Availability," examining access to electricity through levels of "Duration" (day and evening). For more information, please refer to table A1.1 in this report.
[8] Affordability could not be calculated for Rwanda because the survey was not able to collect expenditure information.

FIGURE 2 • **Multi-Tier Framework tiers for access to electricity**



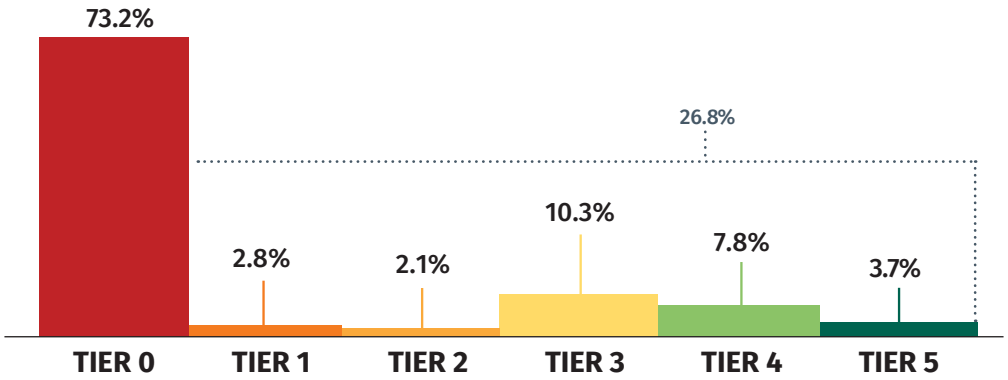

A grid is the most likely source for achieving a higher tier, though a diesel generator or a mini-grid, may also do so. Technological advances in photovoltaic solar home systems (SHSs) and direct current–powered energy-efficient appliances also make higher access possible—to Tier 3 and even Tier 4—but such systems are rare in Rwanda today.

***Technologies.*** Nationwide, 28.6% of households have access to at least one source of electricity: 23.5% of households have access through the grid, and 5.1% have access through off-grid solutions, mostly solar. The share of electrified households that use an off-grid solar solution, while low, is the result of fast progress in off-grid electrification in recent years. The majority of households that use an off-grid solar solution acquired it within the last three years. Both urban and rural households use off-grid solutions, but they are more common in rural households, where the gap in access to electricity remains wide. One-third of electrified rural households—or 5.5% of all rural households—use an off-grid solution as their primary source of electricity. Since the MTF data were collected, the government of Rwanda has electrified rapidly. According to the Ministry of Infrastructure, as of January 2018, the electrification rate has reached 43%, 31% through on-grid connections and 12% through off-grid solutions.

***MTF tiers.*** In Rwanda 26.8% of households are in Tier 1 or above, and most electrified households (those in Tier 1 or above) are in Tier 3 (figure 3). Households with access to electricity are concentrated in higher tiers: 81.3% of electrified households are in Tier 3 or above. So most electrified households have at least 8 hours of supply a day, including at least 3 hours in the evening, with enough capacity to power medium-load appliances, such

as a refrigerator, a food processor, or water pump (see table 1 for the load levels associated with various appliances).

FIGURE 3 • **The majority of households do not have access to any source of electricity; most electrified households are in Tier 3**




Almost all households in Tier 3 or above are connected to the grid. Most households in Tier 0 have no access to electricity. Only 1.9% of households in Tier 0 have grid or off-grid access, but it does not satisfy Tier 1 requirements. Access to electricity is mostly a rural challenge: 77.4% of urban households are connected to the grid, compared with 15.6% of rural households.

Access to electricity varies widely between the capital and the rest of the country: 79.4% of households in Kigali are in Tier 1 or above (most are in Tier 3 or 4), while 75.7%–85.6% of households in the country's four other provinces are in Tier 0.

***MTF attributes.*** A key question that the MTF survey seeks to answer is what prevents a household from moving to a higher tier for access to electricity. This is the value added of the MTF survey: by capturing full-spectrum data, it empowers policymakers to pursue data-informed energy access policies and to design interventions that remove barriers to households moving to a higher tier. The value of access to electricity for households is defined by analyzing MTF attributes (as answered by questions embedded in the MTF survey):

- **Capacity:** *What appliances can I power?*
- **Availability:** *Is power available when I need it?*
- **Reliability:** *Is my service frequently interrupted?*
- **Quality:** *Will voltage fluctuations damage my appliances?*
- **Affordability**: *Can I afford to purchase the minimum amount of electricity?*
- **Formality:** *Is the service provided formally or by informal connections?*
- **Health and Safety:** *Is it safe to use my electricity service or do I risk injuries from using this service?*

Because grid-connected households are considered to receive high-capacity electricity (over 2,000 W), the proportion of households that receive high-capacity electricity is the same as the proportion of households that are connected to the grid (23.5%). While 75.8% of urban households receive high-capacity electricity, only 12% of rural households do, because penetration of off-grid solutions that provide limited capacity is higher in rural areas.

Availability of electricity supply is limited for about half of households. Although 49.6% of electrified households receive electricity 23 hours a day, 7 days a week, 23% receive 16 hours or less a day. In rural areas Availability is even lower: 33.4% of electrified households receive 16 hours or less a day. Evening Availability is adequate for 71.9% of households, with little difference between urban and rural households.

Most grid-connected households, 91.7%, experience more than four electricity disruptions a week. Reliability is slightly more of an issue in urban areas than in rural households, possibly because of the higher density of grid-connected households in cities. Power outages may occur if the utility tries to cope with generation constraints or network breakdown impacting specific geographic areas.

Nationwide, 20.9% of grid-connected households face voltage issues—such as low or fluctuating voltage. Electric appliances generally require a certain voltage supply to operate properly, and low voltage supply tends to result from an overloaded electricity system or from long-distance low-tension cables connecting spread-out households to a singular grid. Voltage fluctuations and voltage surges can damage electrical appliances and sometimes result in electrical fires.

Health and safety issues—including permanent limb damage or death caused by electrocution—affect 4.7% of grid-connected households and urban households more than rural ones. It is important to ensure that all households are aware of basic safety measures and that wiring is installed according to national standards to prevent accidents when operating electricity under both normal and fault conditions. It would be worth exploring the reasons behind the serious accidents that have occurred in grid-connected households in Rwanda.

***Use.*** Average monthly household consumption of electricity is relatively low, particularly in rural areas: 20.8 kWh nationwide, 29.2 kWh in urban areas, and 9.9 kWh in rural areas. Households pay an average of 3,513.8 Rwandan francs ($4.21) a month for grid electricity, and urban households spend twice as much as rural households (4,656.4 Rwandan francs, compared with 2,009.9 Rwandan francs). Grid-connected households have been electrified for 5 years on average. Electricity consumption of unconnected households is generally low because most use small solar lanterns or solar lighting systems (SLS) that provide Tier 0 or 1 access to electricity. On average, households acquired their off-grid solar product within the last two years.

Only a few appliances have a large penetration in Rwanda, even in grid-connected households. Nationwide, 73.6% of grid-connected households own a phone charger, 59.6% own a radio,

and 45.5% own a television. Only 10.6% of grid-connected households own a refrigerator, and only 9.8% own a computer. Fans are very uncommon.

Grid-connected households do not take full advantage of the performance of the electricity supply received. Despite reaching high tiers for access to electricity, most grid-connected households own only low-load appliances that can be satisfied with Tier 1 or 2 Capacity. This is the case particularly in rural areas, where 66.8% of grid-connected households (irrespective of tier for access to electricity) use only very low–load appliances (mostly for lighting and phone charging), and 20.6% own low-load appliances, such as a television. Medium-, high-, and very high–load appliances, such as refrigerators, are extremely rare in rural areas. This could be due to the price of electricity or appliances being inaccessible to many households.

***Increasing access to higher tiers.*** There may be a tradeoff between moving households with no access to any source of electricity to Tier 1 or above and moving electrified households in Tier 1 or above to a higher tier. While the ultimate goal may be for all households to be in Tier 5, most households, particularly those in rural areas, have their current needs satisfied even if they are in a lower tier. Most households own only very low– or low-load appliances that low-cost off-grid solar solutions can power. Such solutions are likely to be a good and quickly delivered alternative, at least in the short to medium term, for households that are located away from the grid or that cannot afford a grid connection (even with a payment plan). The MTF survey results show that households that use a solar lantern would like to increase the capability of their off-grid solar solution to power additional appliances. Having a solar lantern can be a significant step to move these households from Tier 0 to a higher tier.

Several interventions are likely to increase and improve access to electricity in Rwanda:

- Densify grid connections in urban areas (24.2% of urban households are not connected to the grid).
- Promote the penetration of off-grid solar solutions among rural households, 82.5% of which do not have access to any source of electricity. Off-grid solar solutions can provide Tier 1 or 2 access to those households.
- Improve the Availability, Reliability, and Quality of the electricity supply from the grid to help households in Tiers 0–3 move to a higher tier (over half of grid-connected households are in Tiers 0–3 for access to electricity).
- Ensure that off-grid solar solutions on the market maximize the level of service their users receive and increase user satisfaction.
- Establish a renewable energy fund or financial facility to address challenges related to consumer ability to pay for or access to finance to purchase off-grid solar products and provide technical support for existing financial institutions to improve their understanding of off-grid solar products.

The main barriers that prevent households from connecting to the grid are the high connection fee (54.7% of households) and distance from the grid infrastructure (36.5% of households).

Willingness to pay (WTP) for a grid connection can be enhanced by spreading payment over time. Only 14.4% of unconnected households are willing to pay full price (56,000 Rwandan francs, or about $66) upfront for a connection to the grid.[9] But 34.8% of households are willing to pay 15,000 Rwandan francs upfront and the remainder in 24 monthly installments. Halving the upfront connection fee is less effective than spreading the payment over time: only 2.4% of households are willing to pay 28,000 Rwandan francs upfront. And 48.3% of unconnected households are not willing to pay a connection fee under any of the given terms. Other financing mechanisms may be required to connect them to the grid, and lower cost off-grid solutions may be more suitable for some of them.

WTP for an off-grid solar device that allows the households to reach Tier 1 for access to electricity also increases when a payment plan is offered: 23.9% of unconnected households are willing to buy such a device at full price (50,000 Rwandan francs, or about $60) upfront, and 30.3% are willing to buy one with a 6- or 12-month payment plan. Fewer households were willing to purchase a device at half price upfront—perhaps suggesting a mistrust in lower priced products, which are often associated with lower performance. Addressing challenges related to consumer ability to pay and access finance would be critical in increasing the off-grid solar penetration rate, which will help the government achieve an electrification rate of 70% by 2018 with 31%–35% of households connected to the grid, 13%–17% of households using Tier 2 off-grid energy solutions, and 22% of households using Tier 1 off-grid energy solutions.[10]

Among grid-connected households, 92.4% are in Tier 3 or higher for access to electricity, but only 15.8% are in Tier 5, suggesting that significant room remains for improving access among grid-connected households.

To improve access to electricity among grid-connected households, Rwanda needs to improve Reliability, Quality, and Availability. Increasing evening Availability from 3–4 hours to over 4 hours and solving voltage problems would move most households in Tier 3 to a higher tier, and reducing power disruptions to less than four per week and increasing daily Availability from 16–23 hours to over 23 hours would move households in Tier 4 to Tier 5. The average tier of grid-connected households would increase from 3.5 toward 4.5. However, the extent to which Affordability would affect grid-connected households is unknown because it is not included in the analysis due to lack of data. If many households could not afford electricity, a larger share may be in Tier 2.

[9] WTP for a grid connection was assessed by asking unconnected households whether they were willing to pay the full connection fee (56,000 Rwandan francs). If they answered no, they were asked whether they would pay 15,000 Rwanda francs upfront and the rest in 24 monthly installments. If they answered no, they were asked whether they would pay a reduced connection fee (28,000 Rwandan francs) upfront.

[10] Energy Sector Strategic Plan, 2015.

Availability and Capacity are the main factors that keep households with an off-grid solar solution in lower tiers for access to electricity. Among households with an off-grid solar solution, 26.5% receive less than 4 hours of electricity a day and are thus classified as not having access based on the MTF. Nonetheless, solar solutions can provide households with over 23 hours of electricity a day, allowing them to reach Tier 5 for daily Availability. Evening Availability is an issue for fewer households: 48.5% receive over 4 hours of electricity between 6 pm and 10 pm. Among households with an off-grid solar solution, 90.8% are in Tier 1 or higher for Capacity, but only 13.5% are in Tier 2, and none is in Tier 3 or higher.

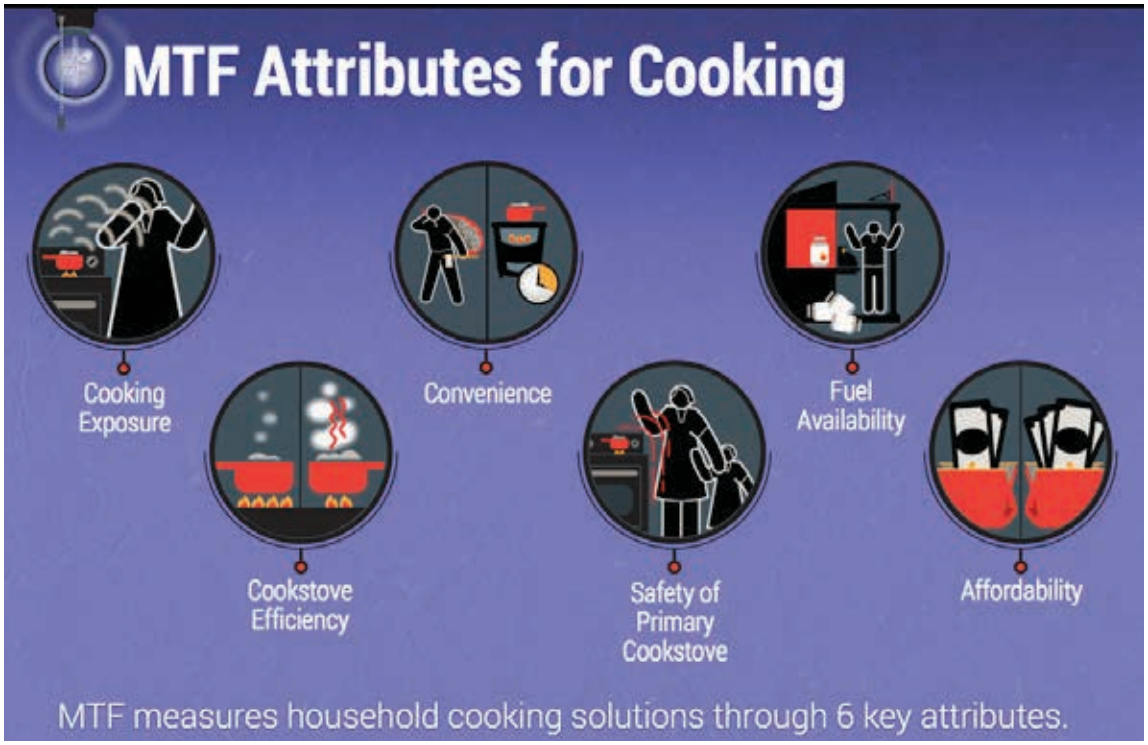
To reach a higher tier for access to electricity, households with an off-grid solar solution will need to upgrade to a larger system (or eventually connect to a mini-grid or the grid). Access through off-grid solar solutions can be further improved by adopting larger and higher performance systems that provide more hours of supply and capability to power additional appliances. Rwandan households tend to upgrade systems and add appliances over time. In particular, 49.7% of households with an off-grid solar solution reported that they want to improve the quality of light (34.6%) and size of their off-grid solar device (15.1%). By addressing ability to pay and access to finance, households that already use an off-grid solar solution will be more likely to upgrade the size of their off-grid solar system and its battery storage technologies.

While off-grid solar solutions that allow households to reach Tier 3 or above are rare, advances in solar technologies make it likely that such systems will be available in the future. The key to upgrading off-grid solar solutions (and thus moving households with an off-grid solar solution to a higher tier) will be to ensure that households can pay for them and that the devices perform well. In addition, the performance of solutions on the market differ. Ensuring that households acquire a better solution is likely to improve system performance even if the size of the solution does not change (for example, brighter and longer lasting lights, ability to power more appliances for a longer period of time, and longer life of the product), which can also lead to improved satisfaction.

## ACCESS TO MODERN ENERGY COOKING SOLUTIONS

The MTF approach measures access to modern energy cooking solutions based on six attributes (figure 4). Attributes directly related to the cooking solution (cookstove and fuel), such as Cooking Exposure, Cookstove Efficiency, and Safety of Primary Cookstove, are the main concern in the lower tiers. This report uses a simplified interim framework based on four stove categories: three-stone stove, traditional biomass stove, improved biomass stove, and clean fuel stove.

FIGURE 4 • **Multi-Tier Framework attributes for access to modern energy cooking solutions**




***MTF attributes.*** Most households use a three-stone (53.3%) or traditional stove (16.3%), both of which emit a high rate of pollutants, such as particulate matter below 2.5 microns in diameter and carbon monoxide. Households that use a three-stone or traditional stove and that do not have a good ventilation structure are in Tier 0 for Cooking Exposure, while households that use an improved cookstove (ICS), which usually emits a lower rate of pollutants, are generally in Tiers 1–3, depending on their ventilation system, contact time, and stove stacking practice. And households that use a clean fuel stove, which burns biogas or liquified petroleum gas (LPG) and has a lower emissions rate, as their primary stove are generally in Tier 4 or 5. However, stove stacking that involves a higher polluting stove such as a three-stone or traditional stove as the additional cooking solution will inevitably negatively affect indoor air quality and keep households in a lower tier for Cooking Exposure.

A household can move to a higher tier for Cooking Exposure if it has adequate ventilation, which depends on the cooking location and the presence of an exhaust system (such as a

hood). But only a quarter of households cook outdoors, and only 15.2% of households that cook indoors use an exhaust system, such as a chimney or hood. In addition to ventilation structure, contact time—how long the main cook spends in the cooking space—is also considered in the calculation of tier status for Cooking Exposure. For households that use multiple stoves, the tier for Cooking Exposure is the average tier for each stove weighted by the frequency and duration of use. Volume of the kitchen is also used to calculate the tier status for Cooking Exposure, but it is not included in the analysis for Rwanda because the MTF survey did not collect information on height of the cooking space.

Cookstove Efficiency is low for most households, particularly in rural areas. Because lab testing results on emissions levels are not available, this report uses a proxy indicator to calculate the tier for Cookstove Efficiency. Households that use a three-stone or traditional stove are in Tier 0 for Cookstove Efficiency, households that use an ICS are in Tiers 1–3, and households that use a clean fuel stove are in Tier 5.

Nationwide, 76.5% of households spend over 7 hours a week to acquire (through collection or purchase) and prepare cooking fuel. Acquiring and preparing fuel are time-consuming tasks for most households. About 84% of households use firewood as their primary cooking fuel, and most of them likely collect it for free, hence spending over 1 hour a day acquiring and preparing fuel collection and preparation. Only 3% of households spend less than 0.5 hour a week acquiring and preparing fuel, and 38.4% of households spend up to 5 minutes per meal preparing the stove.

A key question about cookstoves and their use is what constrains a household from moving up to a higher tier for access to modern energy cooking solutions. Equipped with the answers, policymakers can target energy and design interventions to remove barriers. Answering the question starts with the analysis of attributes that define the value of access to modern energy cooking solutions and fuels for the customer (as answered by the questions in MTF surveys). Each tier specifies the performance criteria for each attribute (see table A1.2). For stoves, the issues are:

- ***Cooking Exposure.*** *How is the user's respiratory health affected?* This is based on personal exposure to pollutants from cooking activities, which depends on stove emissions, ventilation structure (which includes cooking location and kitchen volume[11]), and contact time (time spent in the cooking environment).
- ***Cookstove Efficiency.*** *How much fuel will a person need to use?*
- ***Convenience.*** *How long does it take to gather and prepare the fuel and stove before a person can cook?*
- ***Safety of Primary Cookstove.*** *Is it safe to use the stove, or does a person expose himself or herself to possible accidents?* This can be based on laboratory testing and the absence of serious accidents in the household.

[11] In this report ventilation is defined as using a chimney, hood, or other exhaust system while using a stove or having doors or windows in the cooking area.

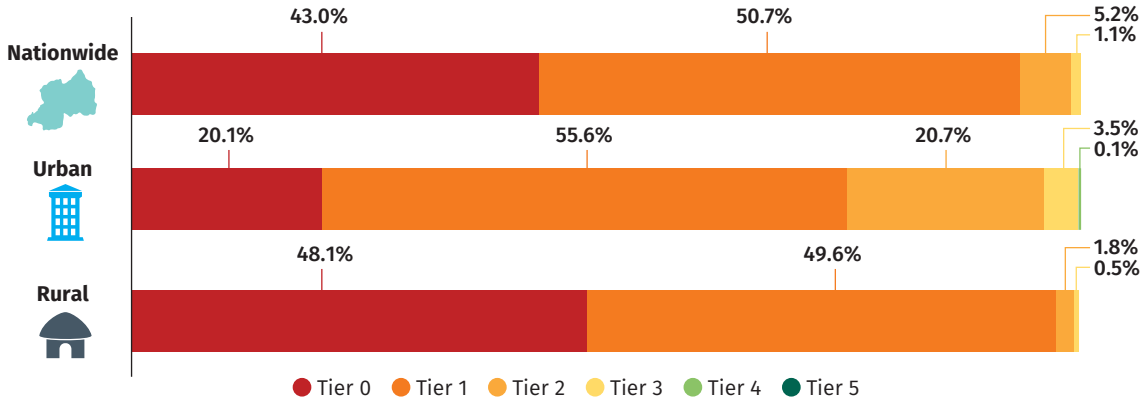
- ***Affordability.*** *Can a person afford to pay for both the stove and the fuel?*[12]
- ***Fuel Availability.*** *Is the fuel available when a person needs it?*

***Technologies.*** In Rwanda 99.6% of households cook with biomass, and a third of those household use an ICS as their primary stove, while 53.3% of households use a three-stone stove, mainly burning firewood, and 16.3% use a traditional biomass stove, also mostly using firewood. Nonetheless, 30% of households use an improved biomass stove, and 39% of those households use charcoal. Cooking with clean technologies and fuels, such as biogas, and LPG/cooking gas is rare: only 0.4% of households use them as their primary cooking fuel.

Urban and rural households have different cooking patterns. Urban households cook predominantly with charcoal (63.4%), followed by firewood (34.1%). In urban areas 63.9% of households use an improved stove, and 2% use a clean fuel stove (mainly LPG/cooking gas). Rural households cook predominantly with firewood (94.7%), and 22.4% of rural households use an improved stove, while use of clean fuel stoves is negligible.

***MTF tiers.*** In Rwanda 57% of households are in Tier 1 or above for access to modern energy cooking solutions (figure 5), despite the fact that 99.6% of households cook with biomass fuels. And 30% of households use an ICS, which has slightly lower emissions than a three-stone or traditional stove, as their primary stove. All households that use a three-stone stove or a traditional stove are considered to be in Tier 0 for stove emissions; however, if their ventilation structure is good, they are in Tier 1 for Cooking Exposure. Although lab testing results on stove emissions are unavailable or very limited, a tier for stove emissions was assigned for each stove after consultation with experts and consideration of the characteristics of each stove (see annex 2). Only 0.1% of households are in Tier 4 or 5, meaning that they use biogas or LPG as their primary cooking solution. Stove stacking with a three-stone or traditional stove inevitably negatively affects indoor air quality and could prevent households from reaching a higher tier.

FIGURE 5 • **Multi-Tier Framework tier distribution for access to modern energy cooking solutions**




[12] Affordability could not be calculated for Rwanda because the survey was not able to collect expenditure information.

***Increasing access to modern energy cooking solutions.*** Rwanda faces a double challenge in improving access to modern energy cooking solutions: a high percentage of households that still use highly polluting three-stone and traditional stoves and a very low percentage of households that use clean fuels. The ultimate objective should be to provide all households access to cooking solutions that are clean, efficient, convenient, affordable, safe, and available (Tier 4 and 5). More-efficient and clean cooking solutions can help prevent environmental degradation. In the interim, ICSs could be used to move households in Tier 0 to Tiers 1–3 (preferably the higher tiers of this range). Improving ventilation of the cooking space could also help move households to a higher tier for Cooking Exposure.

A variety of ICSs are already available on the Rwandan market, and household awareness of them is high, resulting in high WTP. In urban areas 63.9% of households use an ICS (most of them with charcoal) as their primary stove. Penetration of ICSs (most of them wood-fired stoves) is much lower among rural households (22.4%) but still a good base for expansion. The WTP results are particularly promising, considering that 77% of households in Tier 0 are willing to pay full price for an ICS, provided that a payment plan up to 24 months is offered.

Households that switch from a three-stone or traditional stove to an ICS would move from Tier 0 to Tier 1 or higher at low cost and with minimal disruption in cooking practices. And households that switch from a three-stone stove to an ICS would be expected to spend 24.2% less time acquiring and preparing fuel, assuming that all other factors are similar.

Clean fuels have yet to make a significant contribution to cooking practices in Rwanda. Only 0.5% of households use a clean fuel stove (LPG or biogas) as their primary stove. And most households that use a clean fuel stove also use a biomass cookstove, likely due to the lower cost of fuels and to cooking practices (certain meals being preferred on biomass stoves). Nonetheless, clean fuel stoves can significantly improve indoor air quality, and thus their wider adoption should be pursued.

A critical first step to scale up access to modern energy cooking solutions is to develop a comprehensive national program. While such a program would need to involve stakeholders from a wide variety of positions, roles, and levels, there is no substitute for high-level political, technical, and financial support from national leaders and agencies. This high-level support is a key success factor that requires time to build and continuous engagement to maintain.

Disseminating ICSs to the large percentage of households that expressed WTP for these solutions would likely include a combination of supply measures (such as support for stove manufacturers and distributors by, for example, establishing working capital facilities) and demand measures (such as consumer awareness campaigns and consumer financing options). Given the low penetration of ICSs in rural areas, rural households should be targeted. The program could include market development for ICSs to promote their use among all households that use biomass with a three-stone or traditional stove.

The use of clean fuels needs to be expanded, particularly in urban areas. Only 0.4% of households use clean fuels, and the reasons for the limited acceptance of clean fuels—be they financial, cultural, or situational (for example, lack of information)—should be explored. Health-related consumer awareness campaigns should be launched, in particular for higher income urban households that can afford clean fuels, and potential supply constraints should be analyzed and removed accordingly.

Given the important health benefits that clean fuels deliver, ways to expand their small share, particularly in more affluent urban areas, should be explored. A strategy to do so should be accompanied by a strategy to minimize the parallel use of biomass stoves (in particular, three-stone and traditional stoves). Potential supply constraints should be analyzed and removed accordingly, particularly for higher income urban households that can afford clean fuels.

Allowing payment for a stove in installments appears to be an effective way to increase households' ability to pay for an ICS without resorting to upfront cost subsidies, which are often unsustainable. Offering a six-month payment plan was especially effective in increasing WTP among rural households.

## GENDER ANALYSIS

***Access to electricity.*** Female-headed households have lower access to electricity for all technologies, except solar lanterns and SLSs in urban areas, where the access rate for female-headed households is higher—perhaps as a coping mechanism for unaffordable grid connection.

Being able to pay for a connection to the grid is a bigger constraint for female-headed households than for male-headed households: 61% of female-headed households and 52% of male-headed households cite the high cost of a grid connection as the main reason for not being connected to the grid. Female-headed households also opt for smaller solar solutions than male-headed households do.

The WTP analysis reveals that the combination of a reduced connection fee and longer repayment time is needed to connect a significant share of female-headed households to the grid and that female-headed households will not pay for an off-grid solar system that allows them to reach Tier 1 unless a payment plan of at least 12 months is offered.

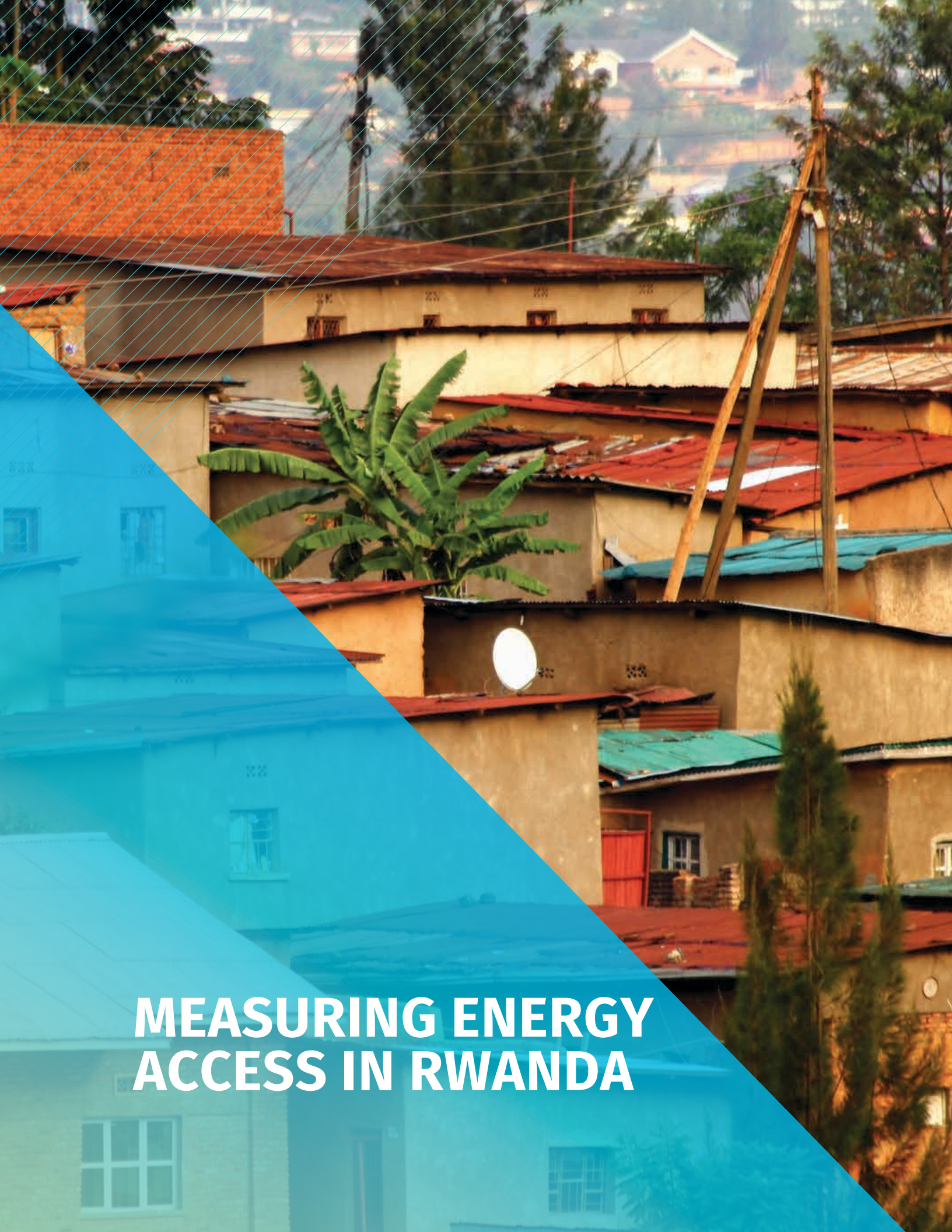
***Access to modern energy cooking solutions.*** The gender gap in access to ICSs and clean fuel stoves is small: 28.8% of female-headed households use an ICS or clean-fuel stove, compared with 30.4% of male-headed households. This suggests that female-headed households prioritize investment in modern energy cooking solutions. But the WTP module shows that ability to pay is a bigger constraint for female-headed households, who are less willing to pay full price for a stove and more often require a longer repayment plan (up to 24 months).

Programs that promote the use of ICSs and clean fuel stoves should therefore pay particular attention to constraints on female-headed households' ability to pay.

In general, women have a larger decision-making role in cookstove purchase decisions than in solar product and electric appliance purchase decisions. For 59.7% of traditional stove purchases, 54.5% of ICS purchases, and 92.3% of clean fuel stove purchases, the decision was made by women alone or jointly with a man. Women's influence in decision-making is strong in rural areas and for the purchase of stoves that use firewood and clean fuels, while the decision to purchase a stove using charcoal is generally made by men, especially in urban areas. Energy- and cooking-related awareness and marketing campaigns should thus strive to reach both male and female household members.

Women are the main cooks in 78% of households and are most affected by changes in traditional cooking practices. Women suffer more from indoor air–related health impacts, as well as from drudgery related to fuel collection. The switch to ICSs has reduced time spent acquiring firewood, with most benefits accruing to women.

Energy access programs should pay attention to gender issues and be designed and implemented to minimize gender gaps. This includes attending to the special needs and circumstances of female-headed households, especially their lower ability to pay, and increasing access to ICSs and clean fuel stoves to reduce the health and drudgery impact of traditional cooking practices that disproportionately affect women.



# MEASURING ENERGY ACCESS IN RWANDA

Without energy, promoting economic growth, overcoming poverty, and supporting human development are challenging, if not impossible. Energy access is thus a precondition to many development goals. Indeed, sustainable energy is the 7th of the 17 UN Sustainable Development Goals—to ensure access to affordable, reliable, sustainable, and modern energy for all by 2030. The Rwandan government, steadfastly committed to maximizing energy access benefits for its people, has thus collaborated with the World Bank to put the Multi-Tier Framework (MTF) survey into practice and to obtain guidance on setting access targets, policies, and investment strategies for energy access.

Rwanda is a small but densely populated country in Sub-Saharan Africa with a fast-growing economy. Its 26,338 square kilometers hold 11.6 million people, resulting in a high population density of 415 inhabitants per square kilometer. Roughly 86% of Rwanda's population lives in rural areas. Rwanda ranked 56th out of 190 countries in the 2017 World Bank *Doing Business* report.[13] And its 2015 Human Development Index value was 0.500, slightly above the average for Sub-Saharan African countries.[14]

The Rwandan government has set a target to achieve 100% electrification by 2024, according to the National Strategy for Transformation, which was approved in 2017. With the support of multiple development partners, Rwanda has been putting into place an extensive grid electrification program, with positive results. According to the Rwanda Energy Group, the number of electricity customers rose from about 110,000 in January 2009 to 720,924 in October 2017. But the pace of grid extension is insufficient to achieve the access targets. Thus, the government has set a parallel track for off-grid electrification, aiming to achieve the 2024 target through both grid extension (52% of households) and off-grid solutions (48% of households), including off-grid solar solutions and mini-grids.

[13] World Bank Doing Business website (http://www.doingbusiness.org/data/exploreeconomies/rwanda).
[14] United Nations Development Programme, Human Development Report Office website (http://hdr.undp.org/en/countries/profiles/RWA).

## THE MULTI-TIER FRAMEWORK GLOBAL SURVEY

The World Bank, with support from the Energy Sector Management Assistance Program (ESMAP), has launched the Global Survey on Energy Access, using the MTF approach. The first phase is being carried out in 17 countries across Africa, Asia, and Latin America, including Rwanda. The survey's objective is to provide more nuanced data on energy access, including access to electricity and cooking solutions. The MTF approach goes beyond the traditional binary measurement of energy access—for example, having or not having a connection to electricity, using or not using clean fuels in cooking—to capture the multidimensional nature of energy access and the vast range of technologies and sources that can provide energy access, while accounting for the wide differences in user experience.[15]

The MTF approach measures energy access provided by any technology or fuel based on a set of attributes that capture key characteristics of the energy supply that affect the user experience. Based on those attributes, it then defines six tiers of access, ranging from Tier 0 (no access) to Tier 5 (full access) along a continuum of improvement. Each attribute is assessed separately, and the overall tier for a household's access to electricity is the lowest applicable tier attained among the attributes.[16]

### ACCESS TO ELECTRICITY

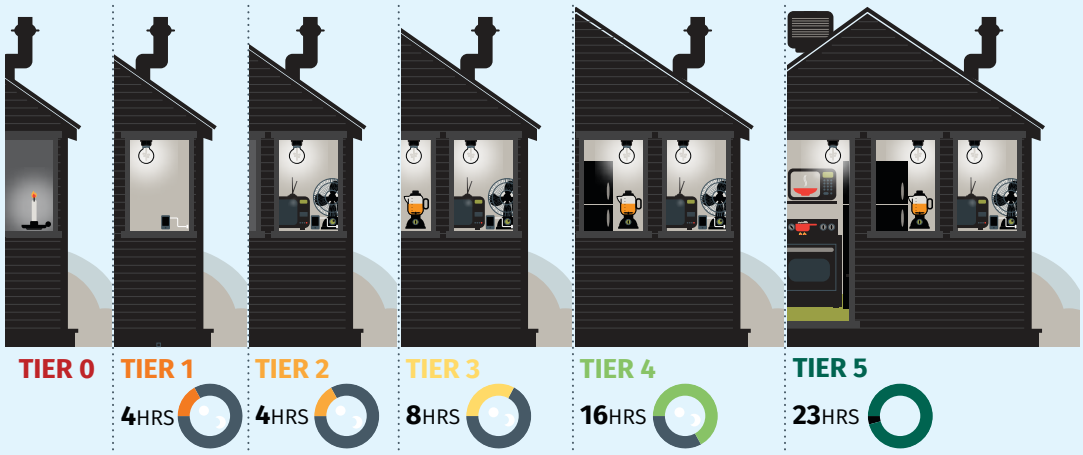
Access to electricity is measured based on seven attributes: Capacity, Availability, Reliability, Quality, Affordability, Formality, and Health and Safety (see table A1.1). Tier 0 refers to households that receive electricity for less than 4 hours per day (or less than 1 hour per evening) or that have a primary energy source with capacity of less than 3 W (see box 1 for minimum requirements by tier of electricity access). Tier 1 refers to households with limited access to small quantities of electricity provided by any technology, even a small solar lighting system (SLS; see box 2 for a typology of off-grid solar devices), for a few hours a day, enabling electric lighting and phone charging.

Higher tiers are defined by higher Capacity and longer Availability of supply—enabling the use of medium- and high-load appliances (such as a refrigerator, washing machine, or air conditioner)—as well as by Affordability (applicable for Tiers 3–5) and Reliability, Quality, Formality, and Health and Safety (applicable for Tiers 4 and 5) (see table 1 for load levels, indicative electric appliances, and associated Capacity tiers). A grid is the most likely source for achieving a higher tier, though a diesel generator or a large mini-grid may also do so. Technological advances in photovoltaic solar home systems (SHS) and direct current–powered energy-efficient appliances also make higher access possible—to Tier 3 and even Tier 4—but such systems are rare in Rwanda today.

The Rwandan government requested that the MTF survey not collect data on the Affordability attribute because the National Institute of Statistics of Rwanda is carrying out other surveys that are capturing this information. So this report does not assess the Affordability attribute, though it provides some

[15] The MTF access rate includes access provided by off-grid technologies, which is often excluded by the binary rate, but excludes connections that do not meet its criteria for minimum level of service.
[16] Bhatia and Angelous 2015.

## BOX 1 • MINIMUM REQUIREMENTS BY TIER OF ELECTRICITY ACCESS




| Tier 0 | Tier 1 | Tier 2 |
|---|---|---|
| Electricity is not available or is available for less than 4 hours per day (or less than 1 hour per evening). Households cope with the situation by using candles, kerosene lamps, or dry-cell-battery-powered devices (flashlight or radio). | At least 4 hours of electricity per day is available (including at least 1 hour per evening), and capacity is sufficient to power task lighting and phone charging or a radio (see table 1). Sources that can be used to meet these requirements include an SLS, an SHS, a mini-grid (a small-scale and isolated distribution network that provides electricity to local communities or a group of households), and the national grid. | At least 4 hours of electricity per day is available (including at least 2 hours per evening), and capacity is sufficient to power low-load appliances—such as multiple lights, a television, or a fan (see table 1)—as needed during that time. Sources that can be used to meet these requirements include rechargeable batteries, an SHS, a mini-grid, and the national grid. |

| Tier 3 | Tier 4 | Tier 5 |
|---|---|---|
| At least 8 hours of electricity per day is available (including at least 3 hours per evening), and capacity is sufficient to power medium-load appliances—such as a refrigerator, freezer, food processor, water pump, rice cooker, or air cooler (see table 1)—as needed during that time. In addition, the household can afford a basic consumption package of 365 kWh per year. Sources that can be used to meet these requirements include an SHS, a generator, a mini-grid, and the national grid. | At least 16 hours of electricity per day is available (including 4 hours per evening), and capacity is sufficient to power high-load appliances—such as a washing machine, iron, hair dryer, toaster, "and microwave (see table 1)—as needed during that time. There are no frequent or long unscheduled interruptions, and the supply is safe. The grid connection is legal, and there are no voltage issues. Sources that can be used to meet these requirements include mini-grids and the national grid. | At least 23 hours of electricity per day is available (including 4 hours per evening), and capacity is sufficient to power very high–load appliances—such as an air conditioner, space heater, vacuum cleaner, or electric cooker (see table 1)—as needed during that time. The most likely source |

*Source:* Bhatia and Angelou 2015.

information on ability to pay for grid connection fees, purchase of off-grid systems, and cooking solutions based on MTF survey data collected on household current energy-related expenditures of households and from the willingness to pay (WTP) module.

### BOX 2 • TYPOLOGY OF OFF-GRID SOLAR DEVICES AND TIER CALCULATION FOR CAPACITY

Three types of solar devices are classified by the number of light bulbs and the type of appliance or service that a household can use.

**Solar lantern.** Powers a single light bulb and allows only part of the household to be classified in Tier 1. Under the MTF methodology the number of household members in Tier 1 is based on the light output (lumen-hours) and phone charging capability of the solar lantern. Because the survey could not gather precise information on these service outputs, this report uses a simplified methodology. For a household that owns one solar lantern without phone charging capability, it is assumed that 20% of the household members are in Tier 1; for a household that owns one solar lantern with phone charging capability, it is assumed that 60% of the household members are in Tier 1.

**Solar lighting system (SLS).** Powers two or more light bulbs and allows part or all of the household to be classified in Tier 1. For a household that uses an SLS without phone charging capability, it is assumed that 70% of the household members are in Tier 1; for a household that uses an SLS with phone charging capability, it is assumed that all the household members are in Tier 1.

**Solar home system (SHS).** Powers two or more light bulbs and appliances such as a television, iron, microwave, or refrigerator. See table 1 for the load level associated with each tier.

This is a simplified methodology used to approximate off-grid access based on survey results (since survey data lack details on system sizes and performance). For a household that uses an SHS, it is assumed that all the household members are at least in Tier 2 for Capacity. To review a more detailed methodology where system size and their performance are explained, please consult the World Bank's Beyond Connections report. A more thorough analysis of survey data will be carried out in the MTF Global report.

*Source:* Bhatia and Angelou 2015.

### TABLE 1 • Load levels, indicative electric appliances, and associated Capacity tiers

| Load level | Indicative electric appliances | Capacity tier typically needed to power the load |
|---|---|---|
| Very low load (3–49 W) | Task lighting, phone charging, radio | TIER 1 |
| Low load (50–199 W) | Multipoint general lighting, television, computer, printer, fan | TIER 2 |
| Medium load (200–799 W) | Air cooler, refrigerator, freezer, food processor, water pump, rice cooker | TIER 3 |
| High load (800–1,999 W) | Washing machine, iron, hair dryer, toaster, microwave | TIER 4 |
| Very high load (2,000 W or more) | Air conditioner, space heater, vacuum cleaner, water heater, electric cookstove | TIER 5 |

*Source:* Bhatia and Angelou 2015.

## ACCESS TO MODERN ENERGY COOKING SOLUTIONS

Access to modern energy cooking solutions is measured based on six attributes: Cooking Exposure, Cookstove Efficiency, Convenience, Safety of Primary Cookstove, Affordability, and Fuel Availability (see table A1.2). Cooking Exposure assesses personal exposure to pollutants from cooking activities, which depends on stove emissions, ventilation structure (which includes cooking location and kitchen volume[17]), and contact time (time spent in the cooking environment). Cookstove Efficiency assesses the performance of the stove in regard to its thermal efficiency. To calculate Cookstove Efficiency, it is important to have lab testing results. Convenience measures the time spent acquiring (through collection or purchase) fuel and preparing fuel and the stove for cooking. Safety of Primary Cookstove assesses the safety in using the most used cookstove within the household. Affordability assesses a household's ability to pay for both the cookstove and fuel. Fuel Availability assesses the availability of fuel when needed for cooking purposes.

Attributes directly related to the cooking solution (cookstove and fuel; see box 3 for a typology of cookstoves), such as Cooking Exposure, Cookstove Efficiency, and Safety of Primary Cookstove, are the main concern in the lower tiers. Households with a three-stone stove or traditional biomass stove are mostly in Tier 0 (no access), households with an improved biomass stove are in Tiers 1–3, and households with a cookstove fueled with electricity, biogas, liquified petroleum gas (LPG), or natural gas are in Tier 4 or 5.[18] Convenience, measured as time spent acquiring (through collection or purchase) and preparing fuel, is applicable in Tiers 2–5. Additional attributes—such as Affordability and Fuel Availability—are applicable in higher tiers. This report uses a simplified interim framework based on four stove categories: three-stone stove, traditional biomass stove, improved biomass stove, and clean fuel stove.

The MTF for access to modern energy cooking solutions has been simplified for four of the six attributes (Cooking Exposure, Cookstove Efficiency, Fuel Availability, and Safety of Primary Cookstove) because threshold values for each tier have not been approved by a competent agency and there is currently no system of certification and labelling for cooking solutions in place that could enable easy identification of cooking solutions during household surveys.[19]

[17] In this report ventilation is defined as using a chimney, hood, or other exhaust system while using a stove or having doors or windows in the cooking area.
[18] These categories are approximate. The actual tier allocation needs to be done through appropriate stove tests, reflecting local cooking practices and conditions.
[19] Bhatia and Angelou 2015.

### BOX 3 • TYPOLOGY OF COOKSTOVES IN RWANDA

Cookstoves in Rwanda were classified into four categories (see annex 2 for detailed information):

**Three-stone stove.** A pot balanced on three stones over an open fire. Fuel use and emissions are high, and thermal efficiency and safety are low. Three-stone stoves usually use firewood, but other solid fuels may also be used.

**Traditional biomass stove.** Locally produced using mud, metal, or other low-cost materials and following cultural practices. Traditional biomass stoves use biomass fuels. In Rwanda six types of stoves were identified as traditional: round mud stove, rocket stove, gisafuriya, double and triple movable metal charcoal stove, all metal stove, and Muyaga.

**Improved biomass stove.** Uses newer stove technology to improve efficiency, cleanliness, and safety. Improved biomass stoves use less energy to deliver a given amount of usable heat than three-stone and traditional stoves do, and they may also produce less indoor and overall air pollution. Thus, improved biomass stoves may enable cleaner and more efficient delivery of traditional fuels, though they may not meet emissions or efficiency standards. Their performance cannot be visually identified, and thus they must be tested. In Rwanda nine types of improved stoves were identified: Darfour 1, Darfour 2, canarumwe, canamake ivuguruye, canamake itavuguruye, fixed canamake itavuguruye, double and triple movable (canamake itavuguruye), sawdust/rice husks stove, and Save80.

**Clean fuel stove.** Uses fuels with very low levels of polluting emissions, such as biogas, LPG/cooking gas, electricity, ethanol, natural gas, and solar. Such fuels often provide high technical performance in emissions and efficiency that is largely "stove independent." In Rwanda only biogas and LPG/cooking gas are used by households.

A key question about cookstoves and their use is what constrains a household from moving to a higher tier. Equipped with the answers, policymakers can target a specific population and design interventions to remove barriers. Answering the question starts with the analysis of attributes that define the value of access to modern energy cooking solutions and fuels for the customer (as answered by the questions in MTF surveys). Each tier specifies the performance criteria for each attribute (see table A1.2). For stoves, the issues are:

- **Cooking Exposure:** *How is the user's respiratory health affected?* This is based on personal exposure to pollutants from cooking activities, which depends on stove emissions, ventilation structure (which includes cooking location and kitchen volume[20]), and contact time (time spent in the cooking environment).
- **Cookstove Efficiency:** *How much fuel will a person need to use?*
- **Convenience:** *How long does it take to gather and prepare the fuel and stove before a person can cook?*
- **Safety of Primary Cookstove:** *Is it safe to use the stove, or does a person expose himself or herself to possible accidents?* This can be based on laboratory testing and the absence of serious accidents in the household.
- **Affordability:** *Can a person afford to pay for both the stove and the fuel?*[21]
- **Fuel Availability:** *Is the fuel available when a person needs it?*

[20] In this report ventilation is defined as using a chimney, hood, or other exhaust system while using a stove or having doors or windows in the cooking area.
[21] Affordability could not be calculated for Rwanda because the survey was not able to collect expenditure information.

Health impacts from household air pollution caused by traditional cooking activities have been a key driver in promoting clean and efficient cooking. According to the World Health Organization guidelines for indoor air quality,[22] average annual PM2.5 concentration should be less than 10 μg/m$^3$, and 24-hour exposure to carbon dioxide concentration should be less than 7 μg/m$^3$. The World Health Organization guidelines and interim targets have been a reference for the MTF.

Direct exposure measurement on the body of the cook would be the most accurate methodology. However, this process is very costly and not practical to implement through a large-scale household survey. One alternative is to calculate exposure based on simulation through mathematical models that consider key factors contributing to indoor air quality, such as indoor fuel combustion, ambient air pollution in the area, and kitchen volume and air exchange. Indoor emissions depend on the characteristics of each cooking solution (to account for stacking), along with its use, duration, and pattern. Emissions also depend on fuel quality, device maintenance, and user adherence to specifications. This approach is under development; its validity has not been verified by comparing the wide range of simulated data and direct measured exposure data.

Another alternative is to use proxy indicators that do not provide measured or estimated exposure data but classify different real-life situations in the sense of contributing more or less to exposure. By including a broad variety of factors, the overall assessment still presents a comprehensive picture of exposure. The validity of this approach has not been verified by comparing the proxy indicators with direct measured exposure data and how they aligned with the World Health Organization guidelines.

The analysis for Rwanda uses a simplified approach with proxy indicators because granularity in cookstove classification and lab testing results for most stoves were lacking. This interim approach considers the household's or user's perspective of accessing energy services and the exposure of family members, particularly the primary cook, to indoor air pollution.

To estimate Cooking Exposure, the first step is to determine the tier for emissions for a household based on its primary and secondary stoves. Each stove that the household uses is classified based on a combination of the stove design and the primary fuel used with that stove. This classification is adapted from EnDev's Cooking Energy System (table 2). For households that use only one stove, the tier for emissions for that stove is used. For households that use more than one stove (or stack their stoves), the emissions of each stove are weighted by the proportion of time spent cooking with it. For the analysis of access to modern energy cooking solutions in Rwanda, households with a three-stone or traditional stove as their primary stove are in Tier 0, households with an improved cookstove (ICS) are Tiers 1–3, and households with a clean fuel stove are in Tier 4 or 5. Households that use a clean fuel stove exclusively are in Tier 5; the tier for households that use a clean fuel stove as their primary stove and engage in stove stacking was based on the proportion of time spent cooking with each stove.

The second step is to determine the ventilation for the cooking area, categorized by the location of the cooking activity. A household that prepares its meals indoors in an area with fewer than two openings (windows and doors) to the outside is classified as having poor ventilation. A household that prepares

[22] World Health Organization, 2014, *WHO Guidelines for Indoor Air Quality: Household Fuel Combustion*, Geneva (http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1).

its meals indoors in an area with two or more openings is classified as having average ventilation. And a household that cooks its meals outdoors is classified as having good ventilation. Ventilation mitigates the indoor air pollution that a household is exposed to by diluting the concentration of emissions from polluting fuels and expelling the pollutants from the cooking area.

Households in Tier 0 for emissions remain in Tier 0 for Cooking Exposure if they have poor or average ventilation but move to Tier 1 if they have good ventilation. Households in Tiers 1–3 for emissions (using a traditional cookstove or ICS) move down one tier for Cooking Exposure if they have bad ventilation, remain in the same tier if they have average ventilation, and move up one tier if they have good ventilation. Households in Tier 4 for emissions remain in Tier 4 for Cooking Exposure if they have poor or average ventilation and move to Tier 5 if they have good ventilation. Households in Tier 5 for emissions remain in Tier 5 regardless of ventilation.

TABLE 2 • **Stove emissions tier**

| Type of fuel | Description of level | Tier |
|---|---|---|
| **Firewood, dung, twigs, and leaves** | Three-stone, tripod, flat mud ring | 0 |
| | Conventional ICS | 1 |
| | ICS with chimney, rocket stove with conventional material for insulation | 2 |
| | Rocket stove with high insulation, rocket stove with chimney (not well sealed) | 3 |
| | Rocket stove with chimney (well sealed), rocket stove gasifier, batch feed gasifier | 4 |
| **Charcoal** | Traditional charcoal stoves | 0 |
| | Old generation ICS | 1 |
| | Conventional ICS | 2 |
| | Advanced insulation charcoal stoves | 3 |
| | Advanced secondary air charcoal stoves | 4 |
| **Rice husks, pellets, and briquettes** | Natural draft gasifier (only pellets and briquettes) | 3 |
| | Forced air | 4 |
| **LPG and biogas; electricity** | | 5 |

Efficiency is calculated by using draft International Organization for Standardization thermal efficiency standards. Stoves with less than 10% thermal efficiency are in Tier 1, those with 10%–20% thermal efficiency are in Tier 1, those with 20%–30% thermal efficiency are in Tier 2, those with 30%–40% thermal efficiency are in Tier 3, those with 40%–50% thermal efficiency are in Tier 4, and those with 50% or higher thermal efficiency are in Tier 5. Since a high percentage of households use multiple cooking solutions, it is also critical to incorporate the frequency of use for each stove to assess efficiency. However, in Rwanda the lab testing results for cookstoves are limited, so the tier for each stove type was assigned as follows: a three-stone stove is Tier 0, a traditional stove is Tier 0, an ICS is Tiers 1–3, and a clean fuel stove is Tier 4 or 5.

## USING THE MULTI-TIER FRAMEWORK TO DRIVE POLICY AND INVESTMENT

The MTF survey provides detailed energy data at the household level for governments, development partners, the private sector, nongovernmental organizations, investors, and service providers. On the supply side, it captures data on all energy sources that households use, with details on each MTF attribute. On the demand side, it provides data on energy-related spending; energy use; user preferences; WTP for grid, off-grid, and cooking solutions; and customers' satisfaction with their primary energy source.

MTF data enable governments to set country-appropriate access targets for maximizing energy access. The data can be used in setting targets for universal access based on the country's conditions, budget, and target date for achieving universal access. They can also help governments to balance improving energy access to existing users (raising electrified households to higher tiers) and providing new connections—and to determine what minimum tier the new connections should target.

MTF data also inform the design of access interventions, in addition to prioritizing them so that they may have the maximum impact on tier access for a given budget. The data can be disaggregated by attribute and technology, providing insight into the deficiencies that restrict households in lower tiers and the key barriers—such as lack of generation capacity, high energy cost, or a poor transmission and distribution network. Access interventions can thus be targeted to maximize household access in a timely and cost-efficient way. MTF data provide guidance about what technologies are most suited to satisfy demand of non-electrified households (for example, grid or off-grid). And MTF data on demand—such as energy spending, WTP, energy use, and appliances—inform the design and targeting of their programs, projects, and investments for energy access.

The MTF surveys provide three types of disaggregation: by urban-rural, by quintile, and by gender of household head. For gender-disaggregated data, non-energy information such as household total monthly expenditure, education level, and other socio-economic data is also collected. Such data add value to energy access planning, implementation and financing. The MTF survey provides additional gender-related information, including on gender roles in determining energy-related spending and gender-differentiated impacts on health and time use.

## MULTI-TIER FRAMEWORK SURVEY IMPLEMENTATION IN RWANDA

MTF survey data were collected from November 14 to December 1, 2016, by the Center for Economic and Social Studies under the guidance and supervision of the Ministry of Infrastructure and the National Institute of Statistics of Rwanda.[23] The survey was funded by the Scaling Up Renewable Energy Program in Low Income Countries (SREP) and the Energy Sector Management Assistance Program (ESMAP). Following staff training and a pilot survey, 11 teams were dispatched to collect data from 3,300 households in 275 villages in 5 provinces covering electrified and non-electrified populations in urban and rural areas

[23] The electrification rate has been improved since the MTF data were collected.

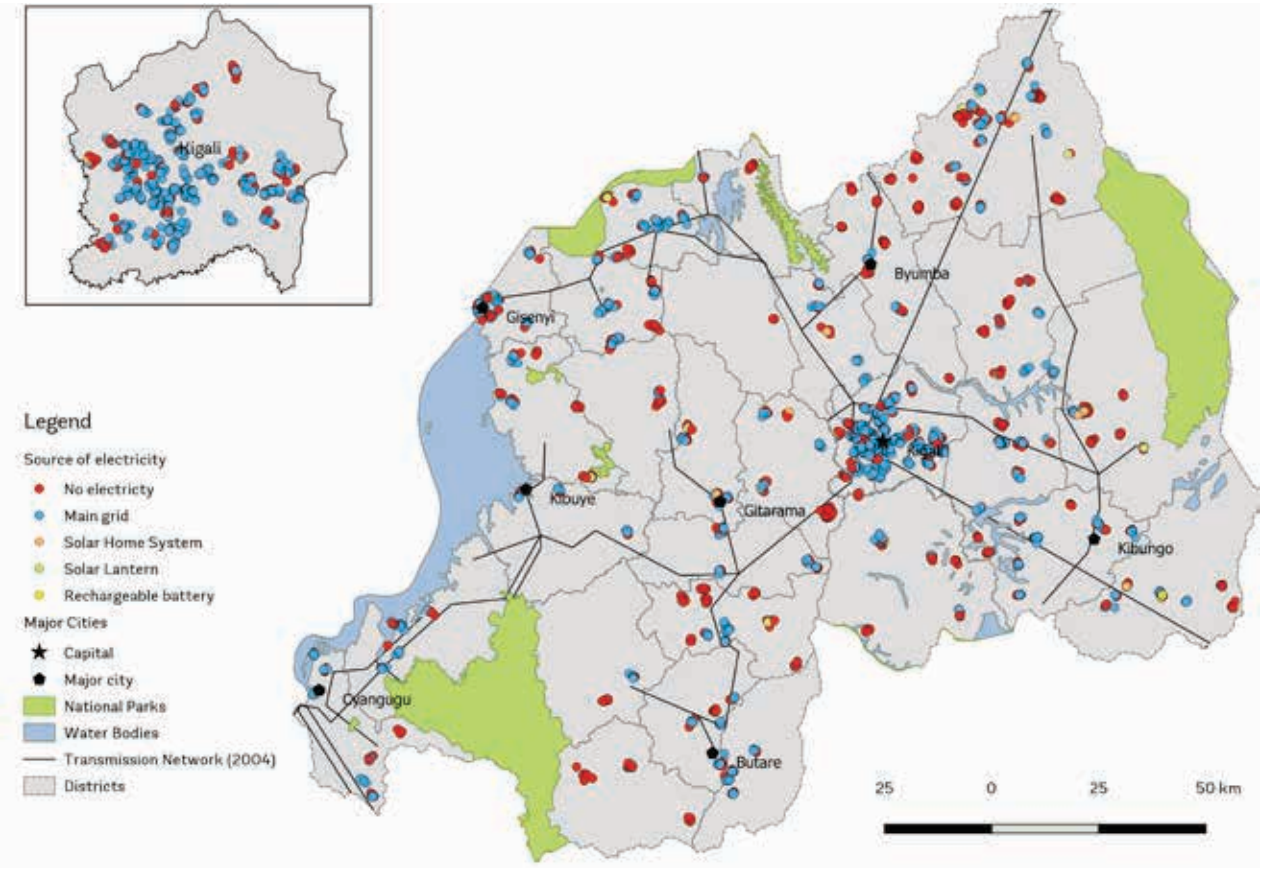
(table 3, figure 6). The MTF survey in Rwanda is nationally representative, capturing data at the urban and rural levels, and at the province level. The sampling strategy is provided in annex 3.

TABLE 3 • **Distribution of villages and households in Rwanda sampled for the Multi-Tier Framework survey**

| | Urban | | | | Rural | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Electrified | | Non-electrified | | Electrified | | Non-electrified | | | |
| Provinces | Villages | HHs | Villages | HHs | Villages | HHs | Villages | HHs | Villages | HHs |
| **Kigali** | 57 | 684 | 11 | 132 | 9 | 108 | 2 | 24 | 79 | 948 |
| **Southern** | 8 | 96 | 10 | 120 | 12 | 144 | 17 | 204 | 47 | 564 |
| **Western** | 11 | 132 | 7 | 84 | 17 | 204 | 13 | 156 | 48 | 576 |
| **Northern** | 5 | 60 | 2 | 24 | 9 | 108 | 12 | 144 | 28 | 336 |
| **Eastern** | 6 | 72 | 18 | 216 | 37 | 444 | 12 | 144 | 73 | 876 |
| **Total** | **87** | **1,044** | **48** | **576** | **84** | **1,008** | **56** | **672** | **275** | **3,300** |

*Note:* The MTF survey used the sampling frame of the 2012 Rwanda Population and Housing Census.

FIGURE 6 • **Spatial distribution of the households in Rwanda sampled for the Multi-Tier Framework survey**



# ACCESS TO ELECTRICITY

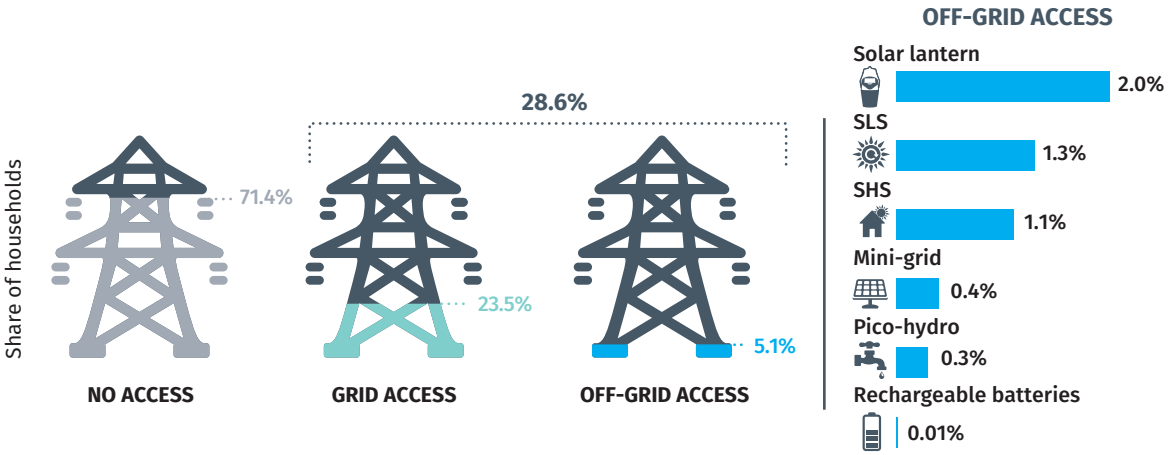
Photo: Simone D. McCourtie / World Bank

## ASSESSING ACCESS TO ELECTRICITY

### TECHNOLOGIES

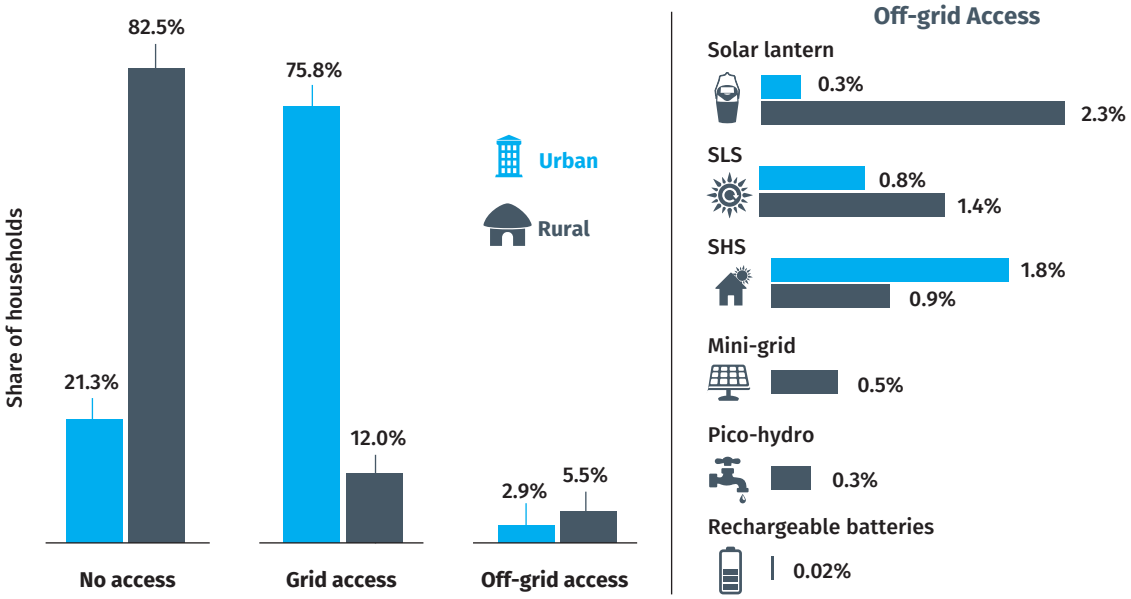
In Rwanda 28.6% of households have access to at least one source of electricity: 23.5% of households have access through the grid, and 5.1% have access through off-grid solutions, mostly solar (figure 7). The share of electrified households that use an off-grid solar solution, while low, is a result of fast progress in off-grid electrification in recent years. The majority of households that use an off-grid solar solution acquired it within the last two years. Other off-grid technologies, such as a mini-grid or pico-hydro, are rarely used as a primary electricity source in Rwandan households, so this report does not include a detailed analysis of these solutions. But these technologies could play a more significant role in access to electricity in Rwanda in the future.

FIGURE 7 • **Less than 30% of Rwandan households have access to at least one source of electricity**




Both urban and rural households use off-grid solutions, but they are more common in rural households, where the gap in access to electricity remains wide. One-third of electrified rural households—or 5.5% of all rural households—use an off-grid solution as their primary source of electricity (figure 8). See box 3 for the typology of off-grid solar solutions (solar lantern, solar lighting systems [SLSs], and solar home systems [SHSs]).

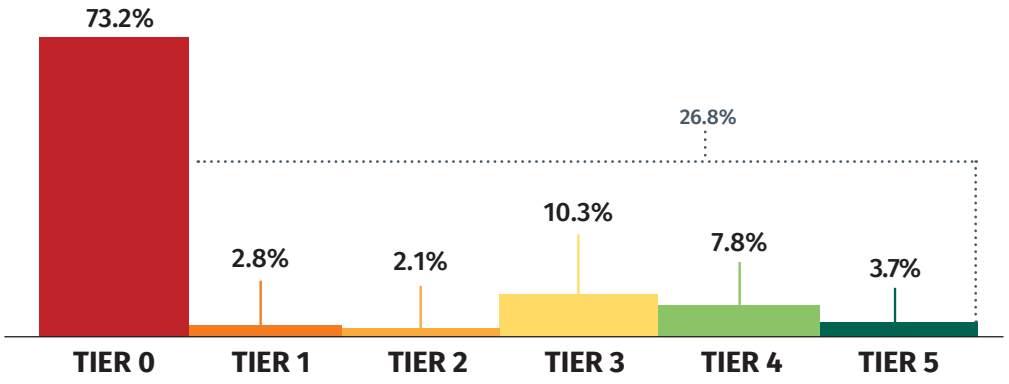
FIGURE 8 • **Off-grid solar devices are particularly important in closing the gap in access to electricity in rural areas**




## MTF TIERS

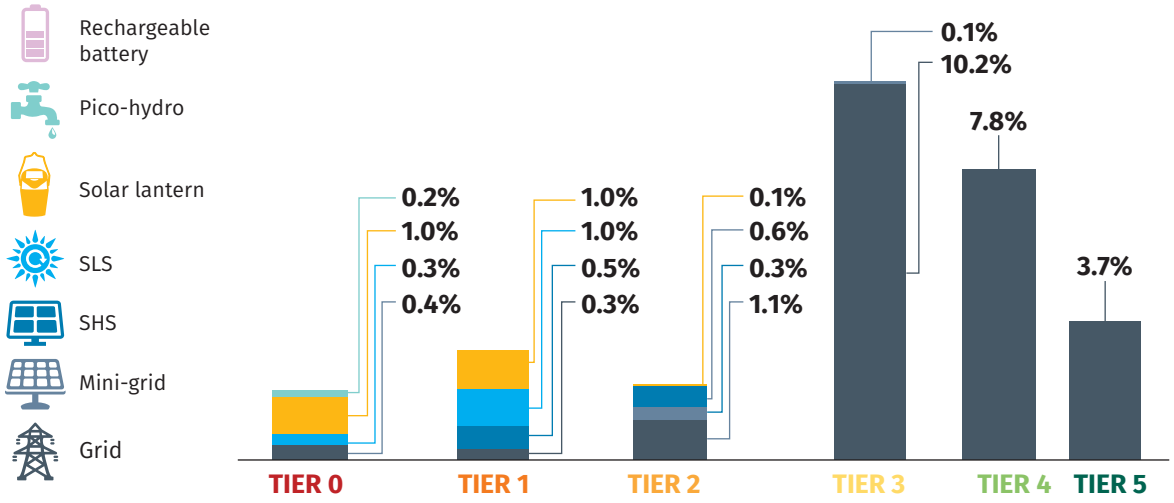
In Rwanda 26.8% of households are in Tier 1 or above, and most electrified households (those in Tier 1 or above) are in Tier 3 (figure 9). Although 28.6% of households are electrified through a connection to the grid or through off-grid solutions, only 26.8% of households are in Tier 1 or above. Households with access to electricity are concentrated in higher tiers: 81.3% of electrified households are in Tier 3 or above. So most electrified households have at least 8 hours of supply a day, including at least 3 hours in the evening, with enough capacity to power medium-load appliances, such as a refrigerator, food processor, or water pump (see table 1 for the load levels associated with various appliances).

FIGURE 9 • **The majority of households do not have access to any source of electricity; most electrified households are in Tier 3**



The average tier for all households is 0.9, compared with 3.3 for only households with access to electricity (those in Tiers 1–5).[24] Almost all households in Tier 3 or above for access to electricity are connected to the grid (figure 10). Among households that are not, off-grid solar solutions are critical in providing electricity. Among households in Tier 1, 71.4% use a solar lantern or SLS. Over half the households in Tier 2 are connected to the grid; the rest use an SHS.

FIGURE 10 • **Grid-connected households are typically in Tier 3 or above for access to electricity, while households that use off-grid solutions are typically in Tiers 0–2**



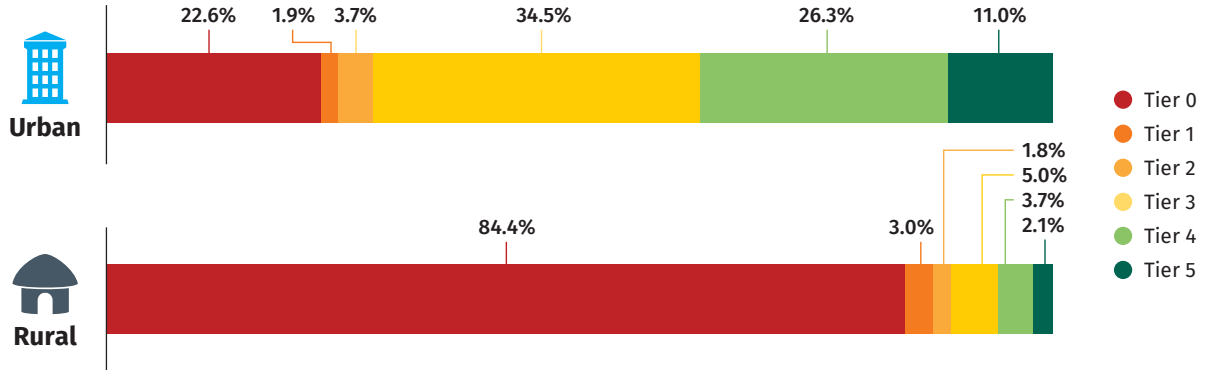

Most households in Tier 0 have no access to electricity. Only 1.9% of households in Tier 0 have grid or off-grid access, but it does not satisfy Tier 1 requirements (figure 11). This is due mainly to the limited Capacity or Availability of off-grid solutions (1.5% of households) or to the limited Availability of grid supply (0.4% of households).

FIGURE 11 • **Most households in Tier 0 do not have access to any source of electricity**

[24] The average tier is calculated by aggregating the proportion of households in each tier with the tier value. The average tier obtained takes into account the extent of access (how many households have access) and the intensity of access (level of access that households have).

Access to electricity is mostly a rural challenge: 77.4% of urban households are in Tier 1 or above, compared with 15.6% of rural households (figure 12). The average tier for urban households is 2.7, compared with 0.5 for rural households.

FIGURE 12 • **Urban households are more likely than rural households to be in Tier 3 or above access to electricity**




Access to electricity varies widely between the capital and the rest of the country: 79.4% of households in Kigali are in Tier 1 or above (most are in Tier 3 or 4), while 75.7%–85.6% of households in the country's four other provinces are in Tier 0 (table 4).

TABLE 4 • **High share of households in Kigali are in Tier 1 or above**

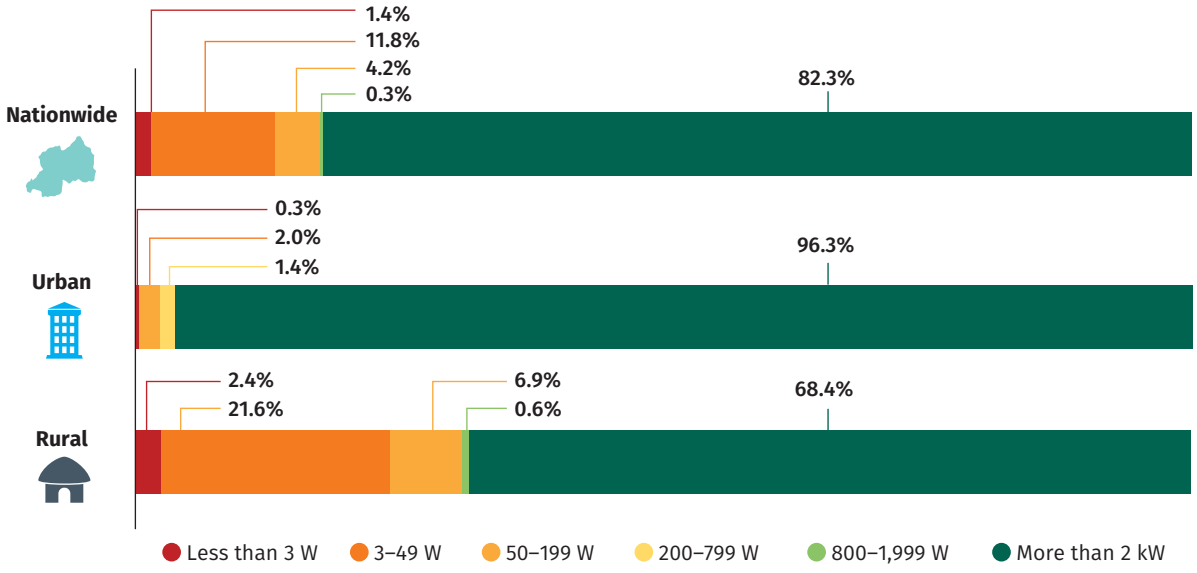
| Province | hare of households with Tier 1+ access |
|---|---|
| City of Kigali | 79.4 |
| Eastern | 24.3 |
| Western | 22.2 |
| Northern | 19.3 |
| Southern | 14.4 |

## MTF ATTRIBUTES

### *Capacity*

Because grid-connected households are considered to receive high-capacity electricity (over 2,000 W), the proportion of households that receive high-capacity electricity is the same as the proportion of households that are connected to the grid (23.5%). While 75.8% of urban households receive high-capacity electricity, only 12% of rural households do, because penetration of off-grid solutions that provide limited capacity is higher in rural areas (figure 13).

FIGURE 13 • **Capacity is more of an issue in rural areas**




## *Availability*

The availability of electricity supply is limited for about half of households. Although 49.6% of households with any source of electricity receive electricity 23 hours a day, 7 days a week, 23% receive 16 hours or less a day (figure 14). In rural areas Availability is even lower: 33.4% of households receive 16 hours or less a day. Evening Availability is adequate for 71.9% of households (figure 15), with little difference between urban and rural households. Limitations in Availability are usually caused by electricity generation shortages.

FIGURE 14 • **Half of households do not receive 24/7 electricity supply**

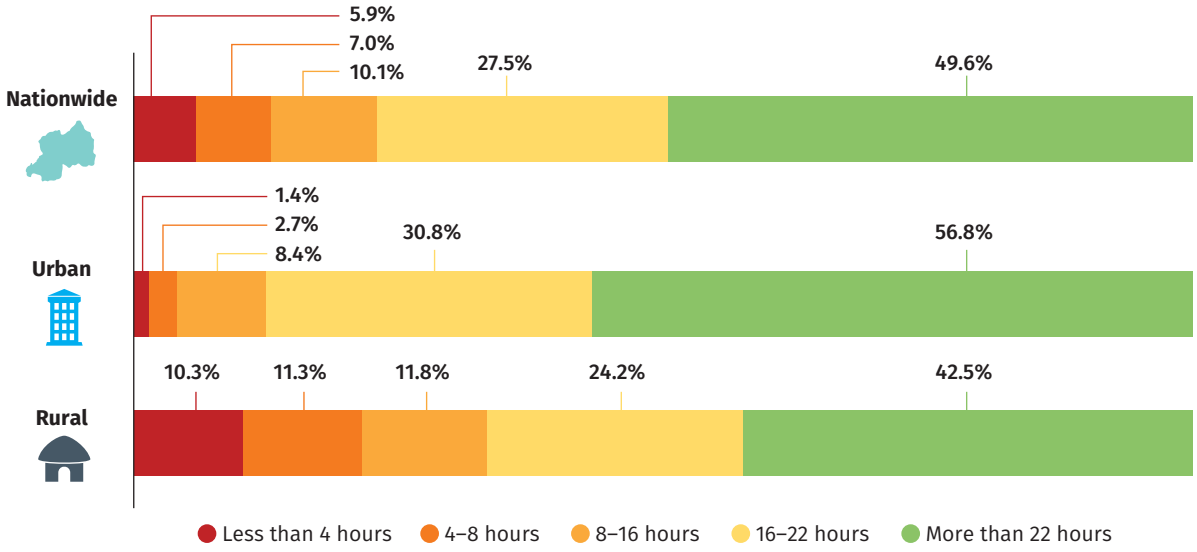
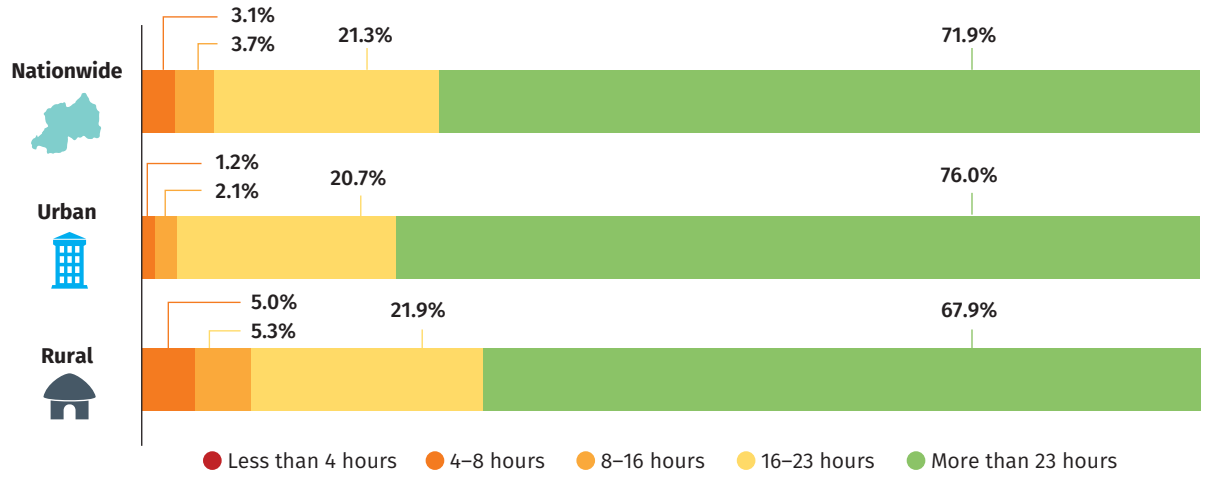


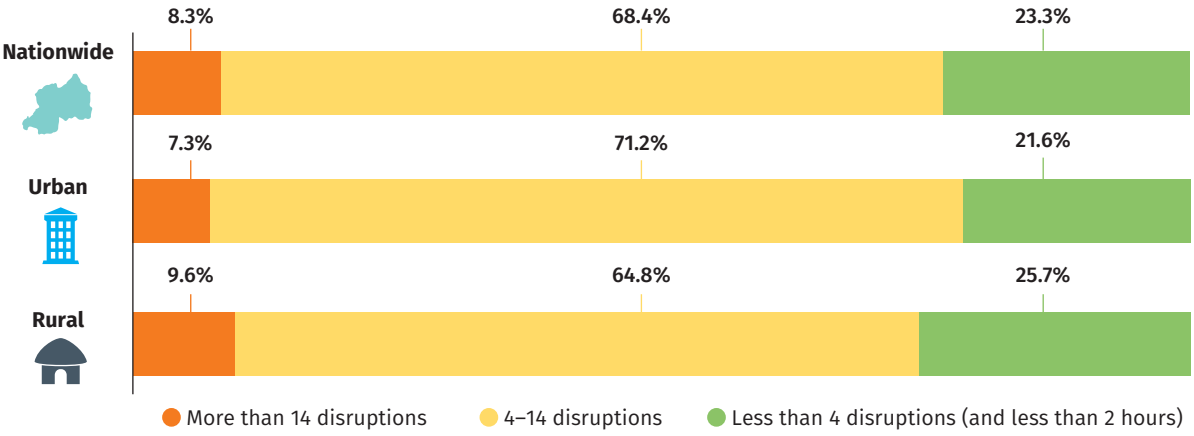
FIGURE 15 • **Nearly 72% of households receive 4 hours of electricity in the evening**




## *Reliability*

In Rwanda 91.7% of grid-connected households experience more than four electricity disruptions a week (figure 16). Reliability is slightly more of an issue in urban areas than in rural areas, possibly because of the higher density of grid-connected households in cities. Power outages, a cause of low Reliability, may occur if the utility tries to cope with generation constraints or network breakdown impacting specific geographic areas.

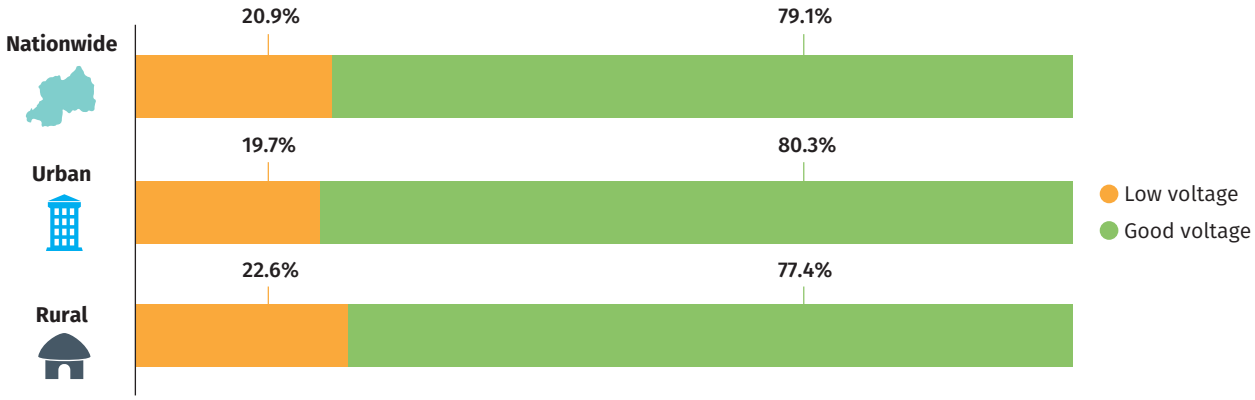
FIGURE 16 • **Urban households suffer slightly more from power supply disruptions than rural households do**




## *Quality*

Nationwide, 20.9% of grid-connected households face voltage issues—such as low or fluctuating voltage (figure 17). Electric appliances generally require a certain voltage supply to operate properly, and low voltage supply tends to result from an overloaded electricity system or from long-distance low-tension cables connecting spread-out households to a singular grid. Voltage fluctuations and voltage surges can damage electrical appliances and sometimes result in electrical fires.

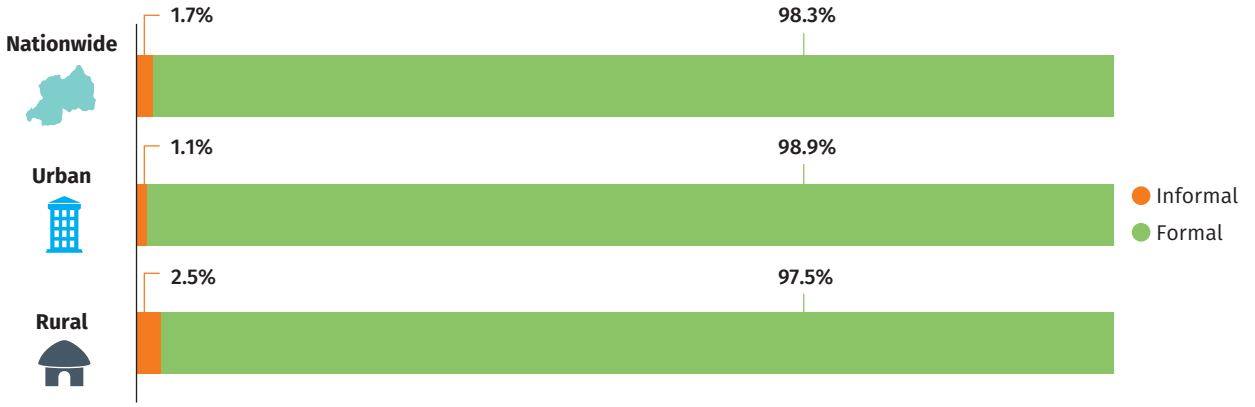
FIGURE 17 • **Voltage issues affect one in five grid-connected households**




## *Formality*

Only 1.7% of grid-connected households have an informal grid connection, which may pose a safety risk (because informal electricity supply is unlikely to be regulated) and has a risk of disconnection (figure 18). Reporting on Formality is challenging because households may be sensitive about disclosing such information in a survey. The Multi-Tier Framework (MTF) survey infers information on Formality from indirect questions that respondents may be more willing to answer (such as what method a household uses to pay the electricity bill), so the actual percentage of households with an informal connection may differ from the data reported here.

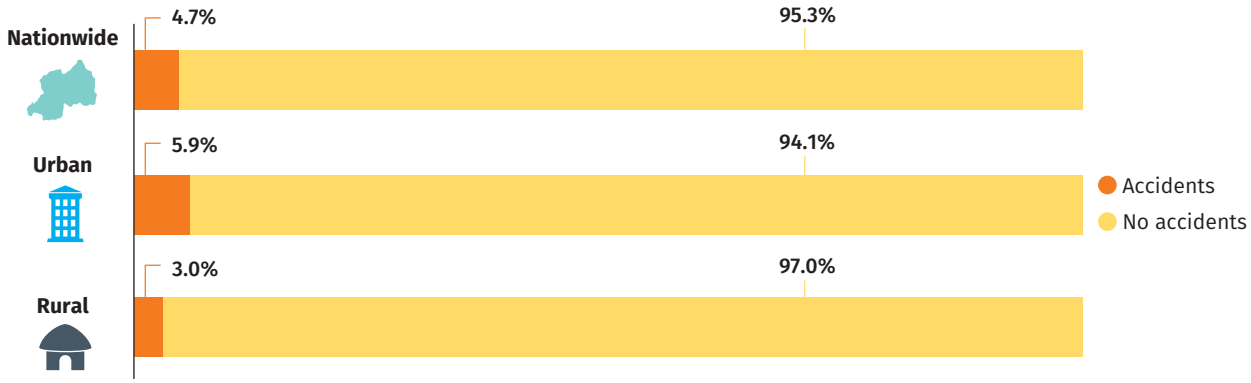
FIGURE 18 • **Less than 2% of households have an informal connection to the grid**




## *Health and Safety*

Health and Safety issues—including permanent limb damage or death caused by electrocution—affect 4.7% of grid-connected households and urban households more than rural ones (figure 19). It is important to ensure that all households are aware of basic safety measures and that wiring is installed according to national standards to prevent accidents when operating electricity under both normal and fault conditions. It would be worth exploring the reasons behind the serious accidents that have occurred in grid-connected households in Rwanda.

FIGURE 19 • **Less than 5% of grid-connected households reported a serious accident caused by electrocution**

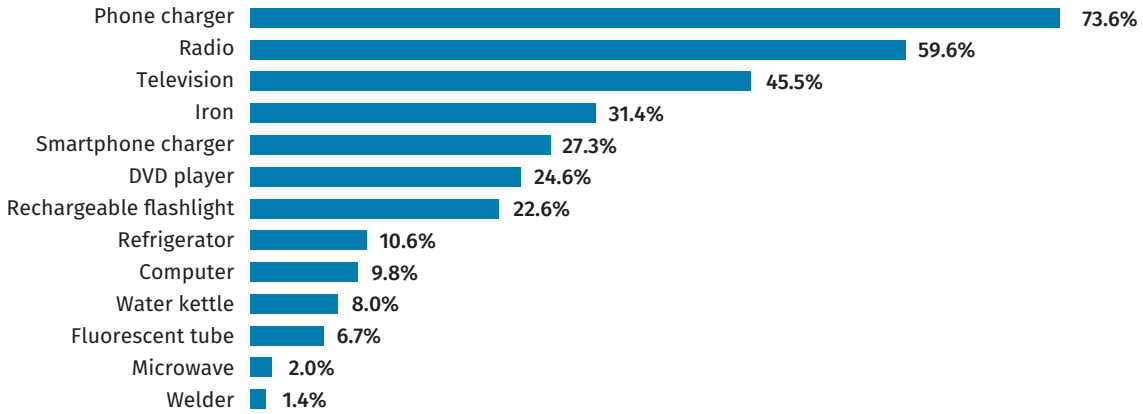



## USE

Average monthly household consumption of electricity is relatively low, particularly in rural areas: 20.8 kWh nationwide, 29.2 kWh in urban areas, and 9.9 kWh in rural areas. Households pay an average of 3,513.8 Rwandan francs a month for grid electricity, and urban households spend twice as much as rural households (4,656.4 Rwandan francs, compared with 2,009.9 Rwandan francs). Grid-connected households have been electrified for 5 years on average. Electricity consumption of unconnected households is generally low because most use small solar lanterns or SLSs that provide Tier 0 or 1 access to electricity. Comparing electricity consumption of grid-connected and unconnected households is less useful because off-grid solar products are designed to maximize energy efficiency by bundling solar power with direct current–powered LEDs and other energy-efficient appliances. On average, households acquired their off-grid solar product within the last year.

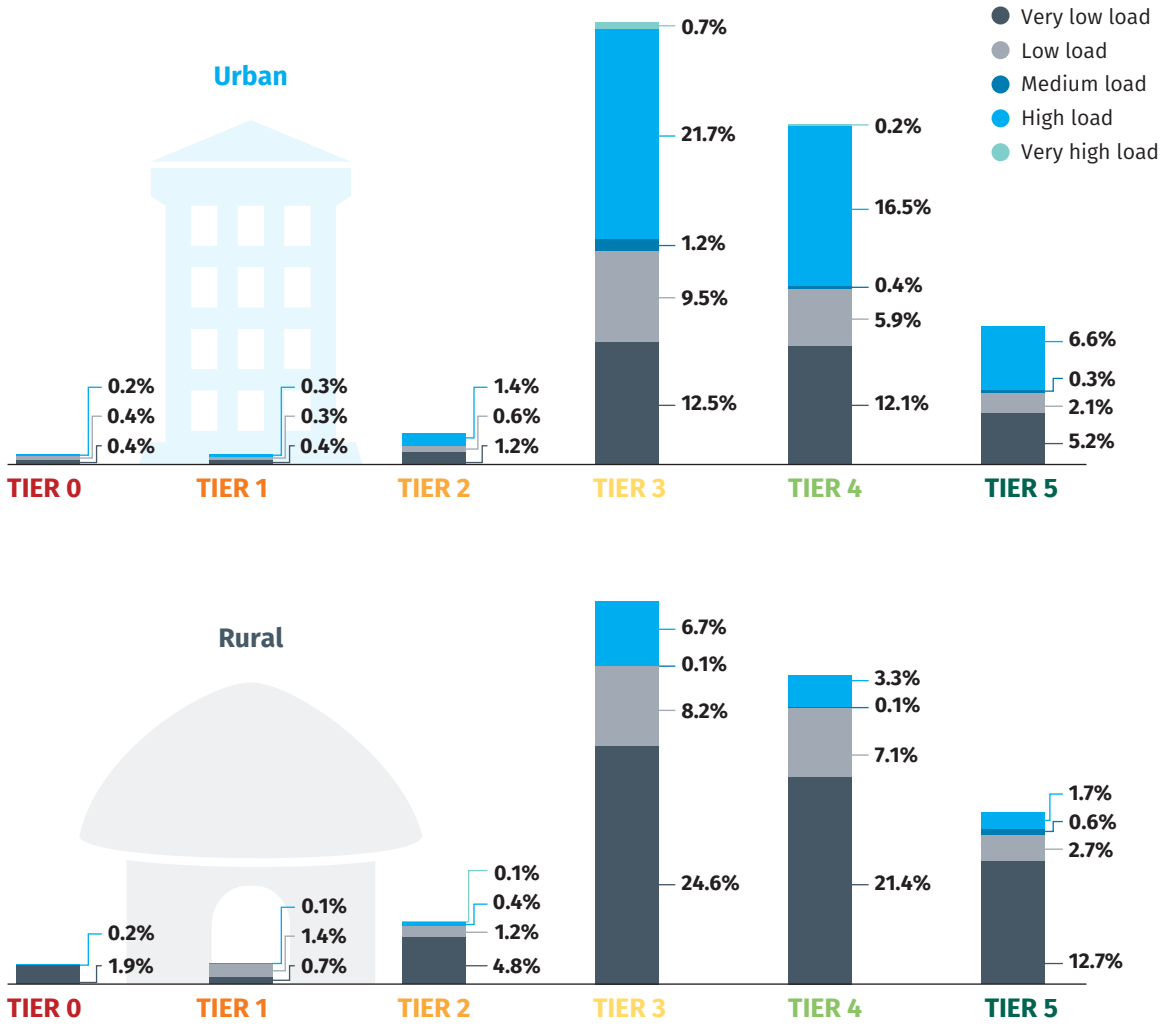
Only a few appliances have a large penetration in Rwanda, even in grid-connected households. Among grid-connected households, 73.6% own a phone charger, 59.6% own a radio, and 45.5% own a television (figure 20). Only 10.6% of grid-connected households own a refrigerator, and only 9.8% own a computer. Fans are very uncommon.

FIGURE 20 • **The three most common appliances in grid-connected households are phone chargers, radios, and televisions**



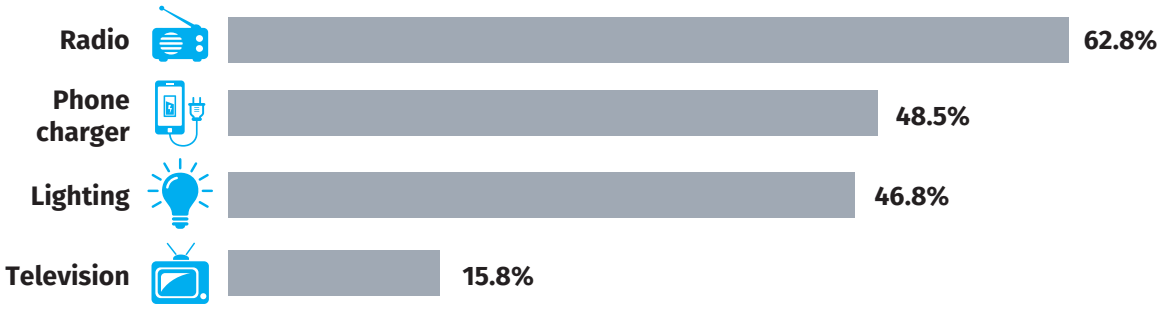
Grid-connected households do not take full advantage of the performance of the electricity supply received. Despite reaching high tiers for access to electricity, most grid-connected households own only low-load appliances that can be satisfied with Tier 1 or 2 Capacity. This is the case particularly in rural areas, where 66.8% of grid-connected households (irrespective of tier for access to electricity) use only very low–load appliances (mostly for lighting and phone charging), and 20.6% own low-load appliances, such as a television (figure 21). Medium-, high-, and very high–load appliances, such as refrigerators, are extremely rare in rural areas. This could be due to the price of electricity or appliances being inaccessible to many households. However, due to the lack of information on spending, it is not possible to investigate whether the price of electricity constrains households from consuming more electricity.

FIGURE 21 • **Irrespective of tier for access to electricity, two-thirds of rural grid-connected households use only very low–load appliances**



Households with an off-grid solar solution also use electricity mostly for lighting, phone charging, and listening to the radio. Among households that use an off-grid solar device, 62.8% own a radio, 48.5% own a mobile charger, and 15.8% own a television (figure 22). No other appliances have penetrated households that use an off-grid solar solution.

FIGURE 22 • **Households that use an off-grid solar solution own only very low– and low-load appliances**




The type of appliances that households with an off-grid solar solution use is in line with the capacity of their system. For off-grid solar solutions the capacity of the system is generally defined by the type of appliances it can power, so the appliances broadly correspond to tier for access to electricity.

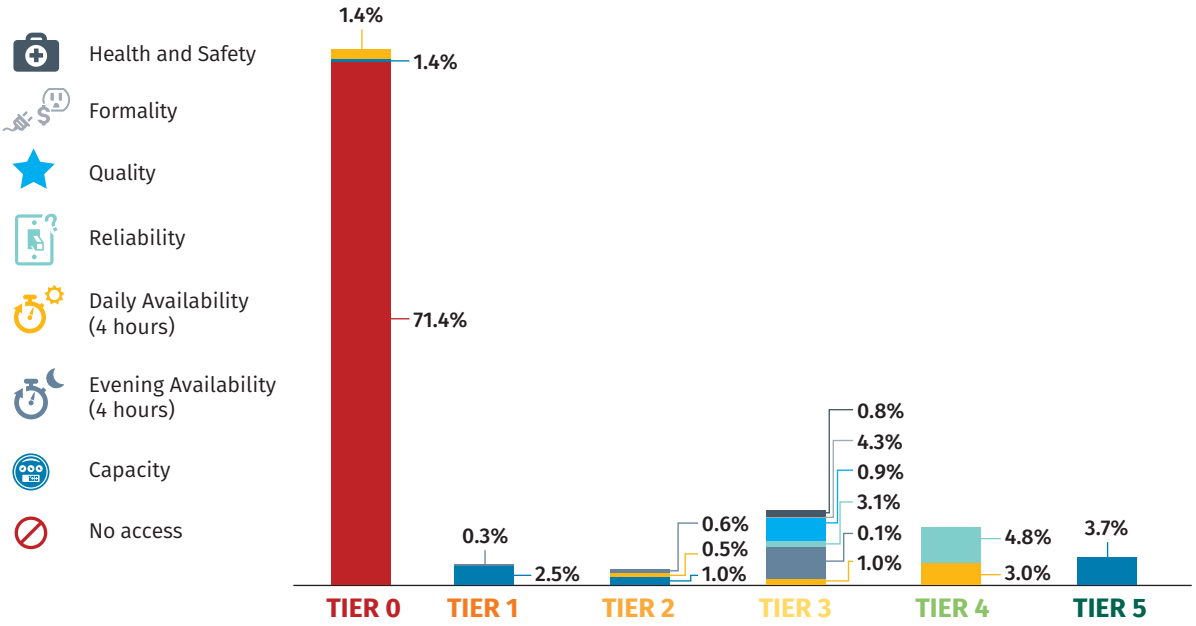
## IMPROVING ACCESS TO ELECTRICITY

Rwanda's greatest challenge is to move households without access to electricity to Tier 1. Almost all households in Tier 0 have no access to any source of electricity (grid or off-grid), and only a small share are in Tier 0 because of low Capacity or limited Availability (figure 23). It is thus fundamental to provide households in Tier 0 with access to electricity through the national grid, mini-grids, or standalone off-grid solutions.

Access among electrified households can be further improved by increasing Availability, Quality, and Reliability of electricity supply, mainly through the grid. Most electrified households are in Tier 3 or 4 for access to electricity. Limited evening Availability (less than 4 hours) and Quality issues (such as inadequate voltage) keep most households in Tier 3 from moving to a higher tier, while Reliability issues (at least four outages a week) and limited daily Availability (16–23 hours a day) keep most households in Tier 4 from moving to a higher tier. Addressing these challenges would move most electrified households to Tier 5. Larger off-grid solar solutions, in turn, could move households in Tiers 1 and 2 to a higher tier.

Affordability could be another factor impeding households from reaching a higher tier for access to electricity. Affordability was not explored in the Rwandan survey, so conclusions regarding its role cannot be drawn in this analysis. If Affordability is an issue for electrified households (that is, if the cost of 365 kWh a year accounted for more than 5% of household spending), many households in Tier 3 or above may be in Tier 2.

FIGURE 23 • **More than 70% of households are not in Tier 1 because they lack access to any source of electricity**




MTF gap analysis helps policymakers prioritize their strategy and policy between moving households with no access to any source of electricity to Tier 1 or above and moving electrified households in Tier 1 or above to a higher tier. While the ultimate goal may be for all households to be in Tier 5, most households, particularly in rural areas, have their current needs satisfied even if they are in a lower tier. Most households own only very low– or low-load appliances that low-cost off-grid solar solutions can power. Such solutions are likely to be a good and quickly delivered alternative, at least in the short to medium term, for households that are located away from the grid or that cannot afford a grid connection (even with a payment plan).

Several interventions are likely to increase and improve access to electricity in Rwanda:

- Densify grid connections in urban areas (24.2% of urban households are not connected to the grid).
- Promote the penetration of off-grid solar solutions among rural households, 82.5% which do not have access to any source of electricity. Off-grid solar solutions can provide Tier 1 or 2 access to those households.
- Improve the Availability, Reliability, and Quality of the electricity supply from the grid to help households in Tiers 0–3 move to a higher tier (over half of grid-connected households are in Tiers 0–3 for access to electricity). One possible intervention is to design energy-efficiency measures that can reduce the overall and peak load that has to be met, which would eventually improve the Reliability of electricity supply.
- Ensure that off-grid solar solutions on the market maximize the level of service their users receive and increase user satisfaction.
- Establish a renewable energy fund or financial facility to address challenges related to consumer ability to pay for or access to finance to purchase off-grid solar products and provide technical support for existing financial institutions to improve their understanding of off-grid solar products.

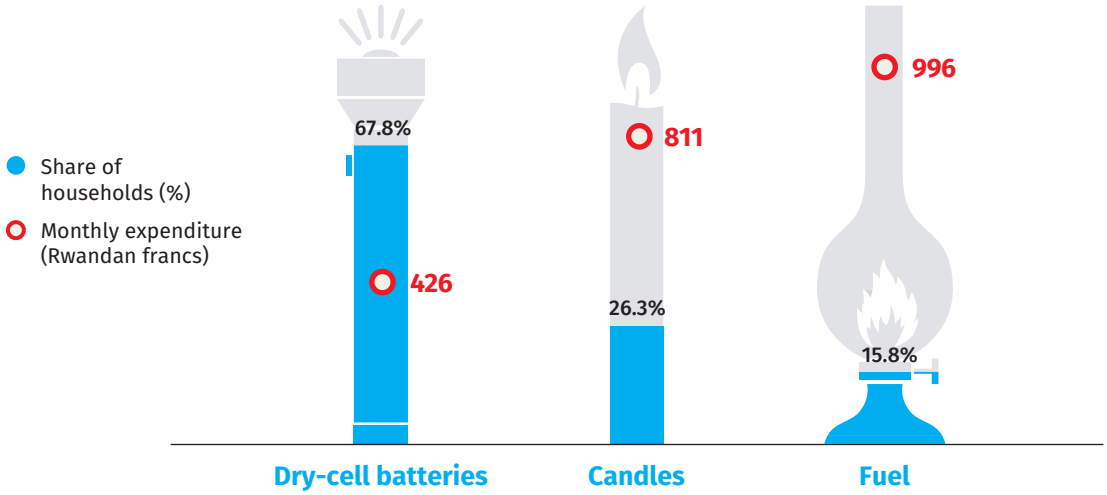
Causes of low electricity consumption and ownership of appliances (such as ability to pay the tariff, lack of productive uses, unavailability of or inability to pay for appliances, and being unaccustomed to electricity use) should be analyzed, and adequate measures should be implemented to boost the use of grid electricity.

It is critical to ensure that electricity connections and off-grid systems are affordable. The MTF willingness to pay (WTP) module shows that a 6- to 24-month payment period increases WTP for both a grid connection and an off-grid SHS and should thus be the primary measure for improving household ability to pay. Additional, targeted support may eventually be needed for poorer households (those spending less than $1 a month on lighting and phone charging) to reach Tier 1 for access to electricity.

## PROVIDING ELECTRICITY ACCESS TO HOUSEHOLDS WITHOUT AN ELECTRICITY SOURCE

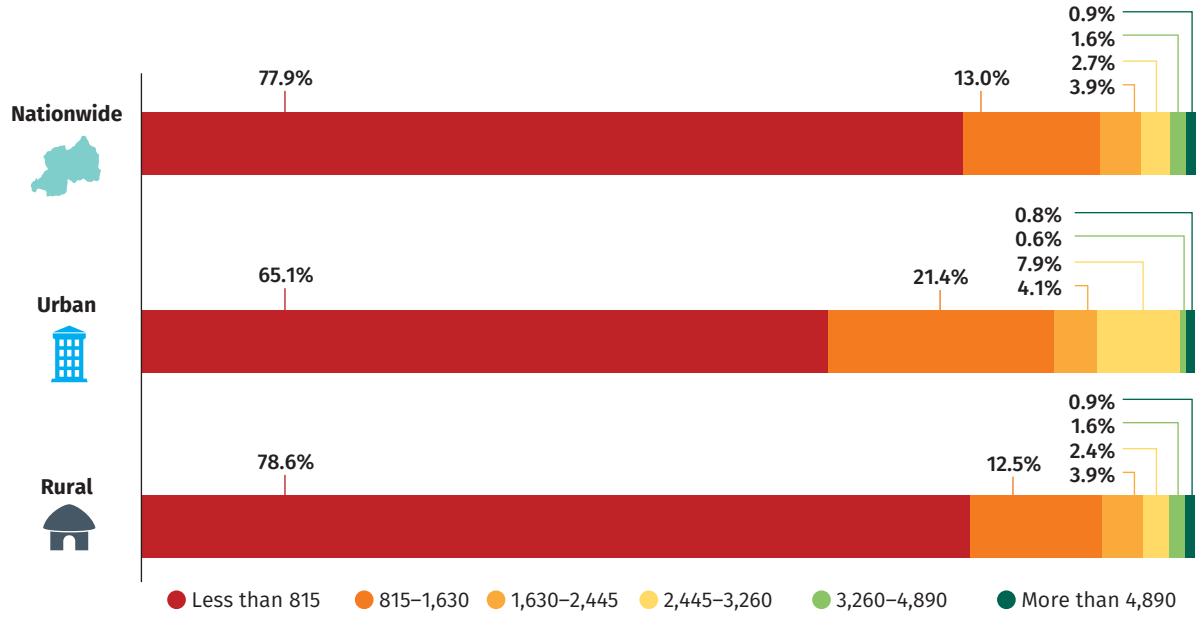
In Rwanda 71.4% of households have no access to any source of electricity and use lighting alternatives such as candles, fuels, and dry-cell batteries. These alternatives typically provide lower lighting performance and adversely affect human health and the environment. Dry-cell batteries are the most common lighting alternative for households without access to electricity, particularly in rural areas, followed by candles (popular in urban areas) and fuel (kerosene) (figure 24). Dry-cell batteries are also the least expensive lighting alternative. Despite lack of access to electricity, 14% of unconnected households own a phone charger, which they must use outside the house.

FIGURE 24 • **Most households without access to electricity use dry-cell batteries for lighting, most likely because it is the least expensive alternative**



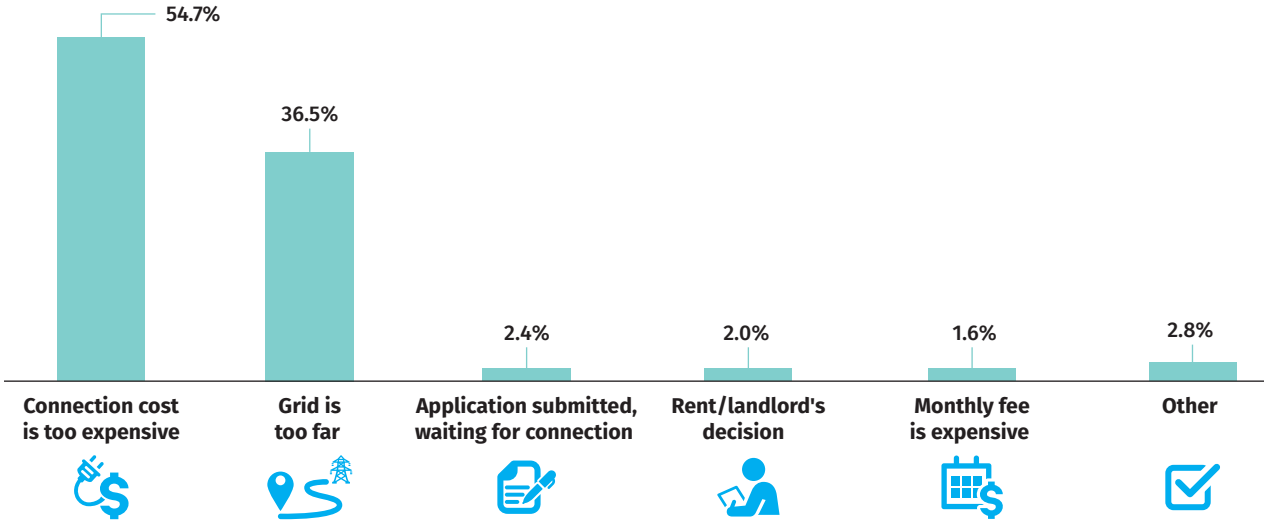

Among unconnected households, 77.9% spend less than 815 Rwandan francs (roughly $1) a month on coping solutions for lighting (including dry-cell batteries, candles, and fuel) and phone charging outside the home (figure 25). Only 5.2% of households spend over 2,445 Rwandan francs (roughly $3) a month. Low spending may reflect low capacity to pay, in which case initiatives to increase access to electricity need to include targeted financing mechanisms for poorer households

FIGURE 25 • **Nearly 80% of unconnected households spend less than 815 Rwandan francs (roughly $1) a month on coping solutions for lighting and phone charging outside the home, suggesting low capacity to pay**



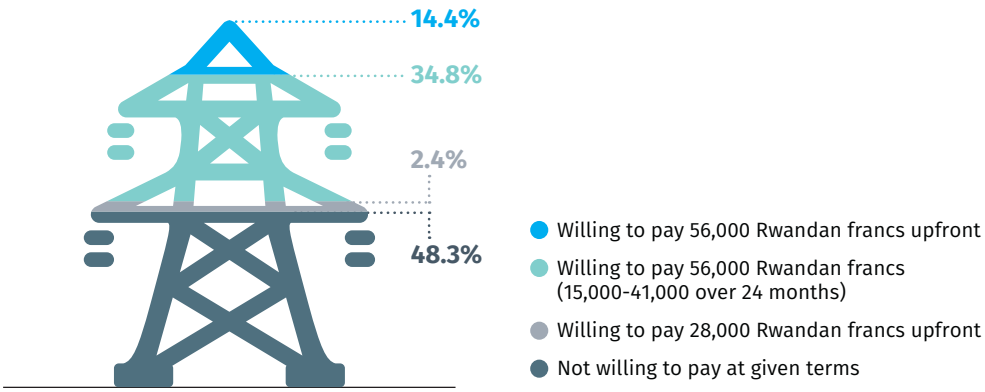

The main barriers that prevent households from gaining connectivity to the grid are the high connection fee (54.7% of households) and distance from the grid infrastructure (36.5% of households) (figure 26). To reduce the burden of paying a grid connection fee, the government of Rwanda introduced a new connection policy in May 2017.

FIGURE 26 • **Over half of unconnected households are not connected to the grid because of high connection cost**



WTP for a grid connection can be enhanced by spreading payment over time. Only 14.4% of unconnected households are willing to pay full price (56,000 Rwandan francs) upfront for a connection to the grid (figure 27).[25] But 34.8% of households are willing to pay 15,000 Rwandan francs upfront and the remainder in 24 monthly installments. Halving the upfront connection fee is less effective than spreading the payment over time: only 2.4% of households are willing to pay 28,000 Rwandan francs upfront. Among unconnected households, 48.3% are not willing to pay a connection fee under any of the given terms. Other financing mechanisms may be required to connect them to the grid, and lower cost off-grid solutions may be more suitable for some of them.

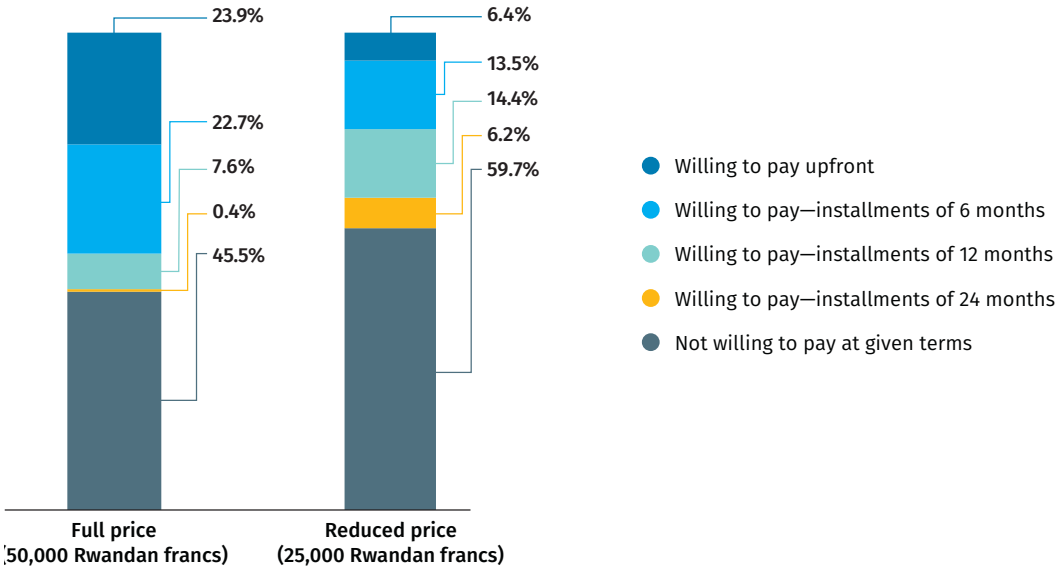
FIGURE 27 • **Willingness to pay for a grid connection increases when payment is spread over time**




WTP for an off-grid solar device that allows households to reach Tier 1 for access to electricity also increases when a payment plan is offered. Among unconnected households, 23.9% are willing to buy such a device at full price (50,000 Rwandan francs, or about $60) upfront, and 30.3% are willing to buy one with a 6- or 12-month payment plan (figure 28). Fewer households were willing to purchase a device at half price upfront—perhaps suggesting a mistrust in lower priced products, which are often associated with lower performance.

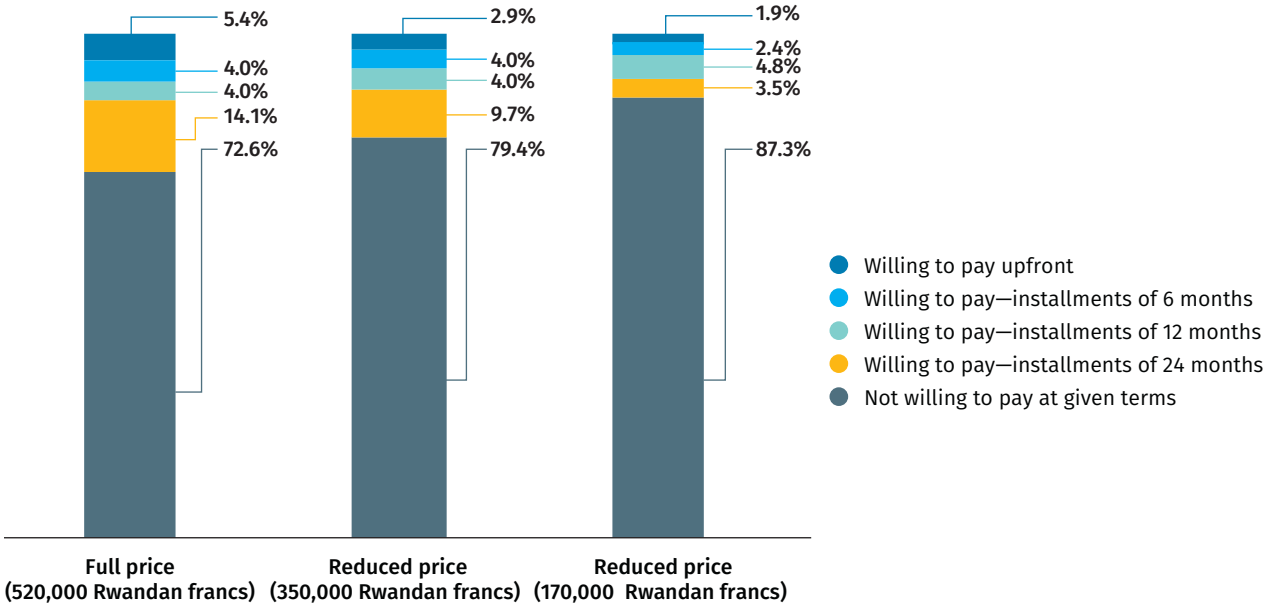
[25] WTP for a grid connection was assessed by asking unconnected households whether they were willing to pay the full connection fee (56,000 Rwandan francs). If they answered no, they were asked whether they would pay 15,000 Rwanda francs upfront and the rest in 24 monthly installments. If they answered no, they were asked whether they would pay a reduced connection fee (28,000 Rwandan francs) upfront.

FIGURE 28 • **Nearly 25% of unconnected households are willing to pay full price upfront for an off-grid solar device that allows them to reach Tier 1 for access to electricity, and more than 30% are willing to pay with a 6- or 12-month payment plan**




WTP for a more expensive off-grid solar device that allows households to reach Tier 2 for access to electricity is low, even with an installment plan and price reductions: 87.3% of households are not willing to pay 520,000 Rwandan francs for such a device under any given terms (figure 29). WTP increases as the price drops, but 72.6% of households would not pay for a device even at a reduced price of 170,000 Rwandan francs under any given terms. Thus, addressing challenges related to ability to pay and access to finance would be critical in increasing the uptake of high-capacity off-grid solar systems.

FIGURE 29 • **Willingness to pay for an off-grid solar device that allows a household to reach Tier 2 for access to electricity is low regardless of price or payment plan options**



Off-grid solar solutions are a recent phenomenon in Rwanda and expanding fast, thanks to consumer financing schemes. Nationwide, 75% of households have owned an off-grid solar solution for a year or less, and 59.4% of households with an off-grid solar solution used a payment plan to acquire it (figure 30). Nearly a third of the payment plans used "pay-as-you-go" mobile phone payments, and the rest were based on a fixed fee (mostly monthly).

FIGURE 30 • **Nearly 60% of households with an off-grid solar solution used a payment plan to acquire it**

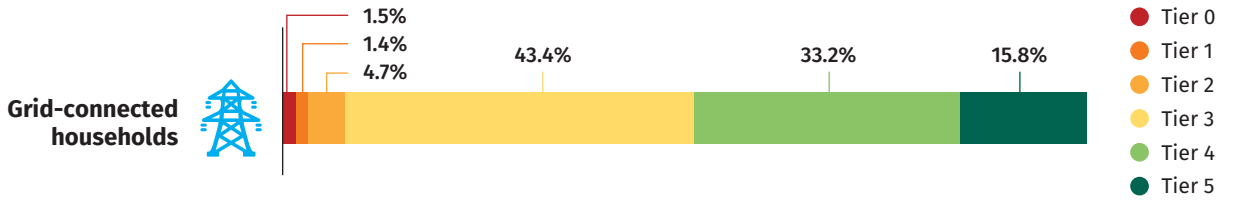
Households with no access to electricity can move to Tier 1 or above through both grid and off-grid expansion. With grid expansion, newly electrified households will most likely move from Tier 0 to Tiers 3–5, provided that grid performance (particularly Availability) remains similar to its current state. With off-grid expansion, newly electrified households will most likely move from Tier 0 to Tier 1 or 2, due to the limited Capacity and Availability that off-grid solutions provide.

The choice between grid and off-grid expansion should be driven by the least-cost electrification pathways to satisfy household demand. Grid connections are likely to be cost-effective in urban areas, where grid infrastructure already exists and where households tend to have higher consumption and to use higher load appliances (see figure 21) and thus require a higher tier for access to electricity. Off-grid solutions are likely to be cost-effective in rural areas, where households tend to be far from the grid and to consume little electricity, primarily for lighting and phone charging and less often for powering a radio or television (see figure 22), which can be easily powered by off-grid solutions that allow households to reach Tier 1 or 2.

## IMPROVING ELECTRICITY ACCESS FOR GRID-CONNECTED HOUSEHOLDS

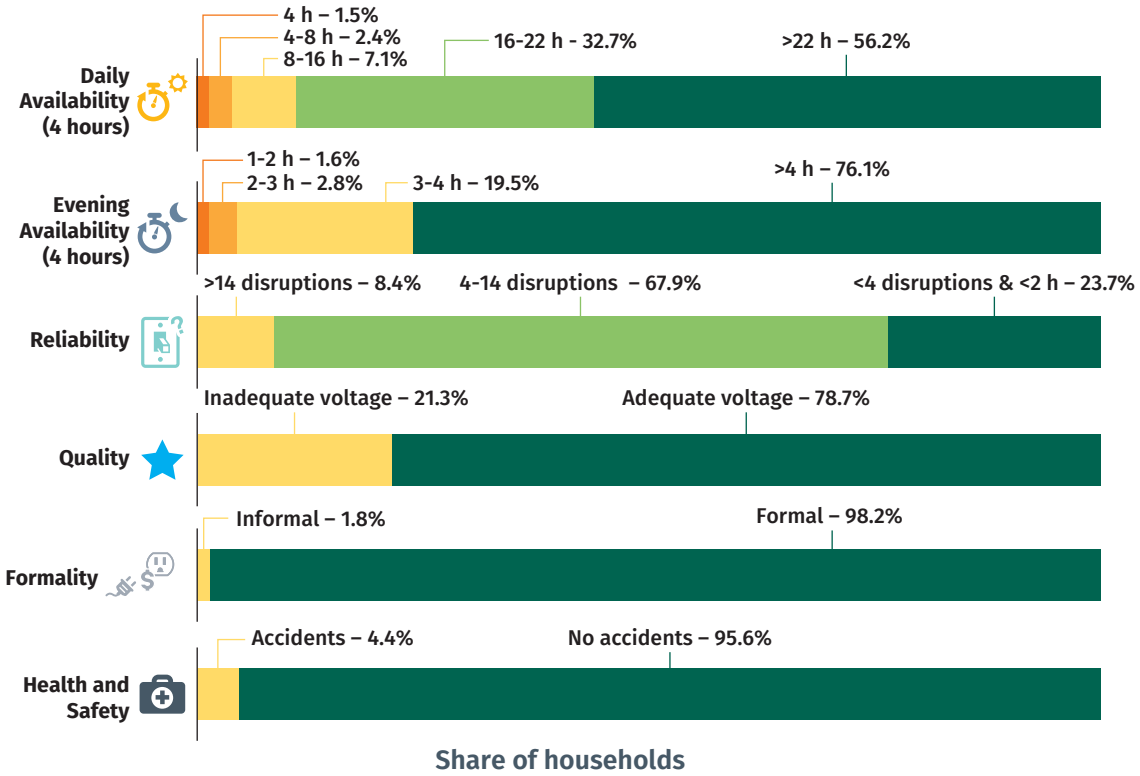
Among grid-connected households, 92.4% are in Tier 3 or higher for access to electricity, but only 15.8% are in Tier 5, suggesting that significant room remains for improving access among grid-connected households (figure 31). And 75.8% of urban households are connected to the grid, compared with 12% of rural households. But the tier distribution of grid-connected households is similar in urban and rural areas: most households are in Tier 3 or 4.

FIGURE 31 • **Most grid-connected households are in Tier 3 or higher**



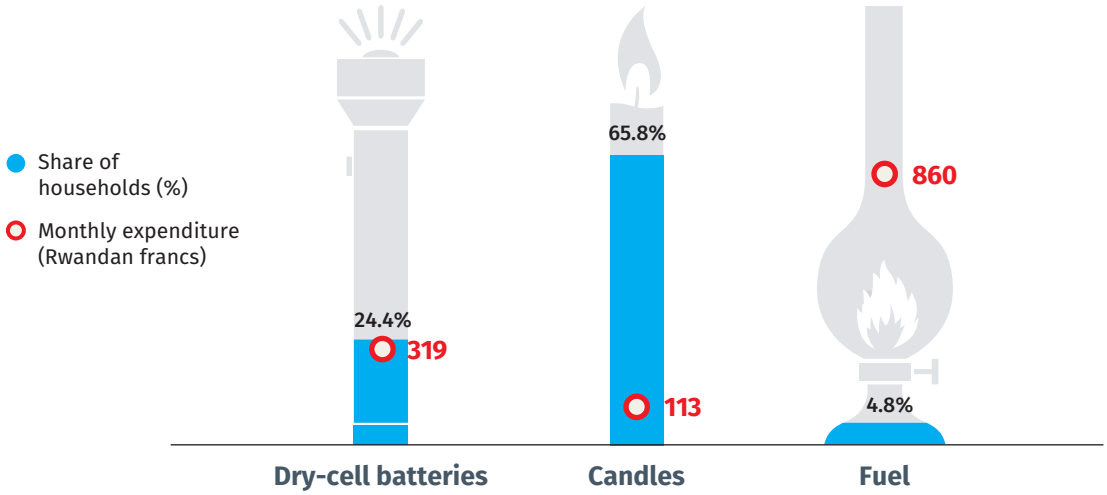

Reliability, Availability, and Quality are the main attributes that prevent households from reaching a higher tier. Reliability affects 76.3% of grid-connected households, with the majority suffering 4–14 power disruptions a week (figure 32). And 56.2% of households receive more than 23 hours of electricity a day, but 23.9% have evening Availability of less than 4 hours. Voltage issues also affect 21.3% of households. Households with a connection to the national grid are in Tier 5 for Capacity.

FIGURE 32 • **Availability and Reliability are the main issues affecting grid-connected households**



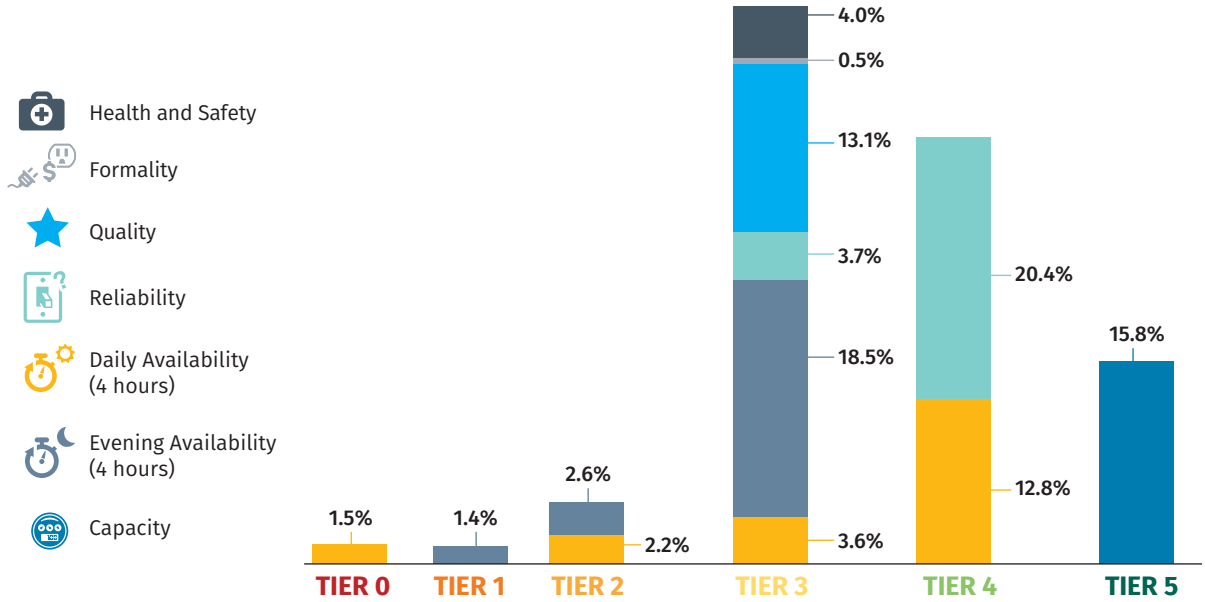

Insufficient or unreliable electricity supply has costs for grid-connected households. Grid-connected households use candles and dry-cell batteries as backup solution, to cope with insufficient Availability and poor Reliability. Among grid-connected households—particularly those in urban areas—65.8% use candles as a backup solution for lighting, and 24.4%—mostly in rural areas—use dry-cell batteries (figure 33). The monthly cost of backup solutions range from 113 Rwandan francs for candles to 860 Rwandan francs for fuel. Urban households spend three times as much on fuel as rural households do.

FIGURE 33 • **Most grid-connected households use candles—the least expensive alternative—as a backup solution for lighting**




To increase access to electricity among grid-connected households, Rwanda needs to improve Reliability, Quality, and Availability. Increasing evening Availability from 3–4 hours to over 4 hours and solving voltage problems would move most households in Tier 3 to a higher tier, and reducing power disruptions to less than four per week and increasing daily Availability from 16–23 hours to over 23 hours would move households in Tier 4 to Tier 5 (figure 45). The average tier of grid-connected households would increase from 3.5 toward 4.5. However, the extent to which Affordability would affect grid-connected households is unknown because it is not included in the analysis due to lack of data. If many households could not afford electricity, a larger share may be in Tier 2. Households that allocate more than 5% of their budget for a basic consumption package (365 kWh a year) are in Tier 2.

FIGURE 34 • **Improving Reliability, Availability, and Quality of supply would greatly enhance access to electricity among grid-connected households**



Among grid-connected households, 75.1% are satisfied with their electricity supply, and only 7.1% of grid-connected households are unsatisfied (figure 35). Although 43.2% of households do not have any problems with their supply, 26.7% of households consider unpredictable interruptions of supply a key issue, and 20.5% of households consider high cost of supply a key concern (figure 36).

FIGURE 35 • **Most grid-connected households are satisfied with their electricity supply**

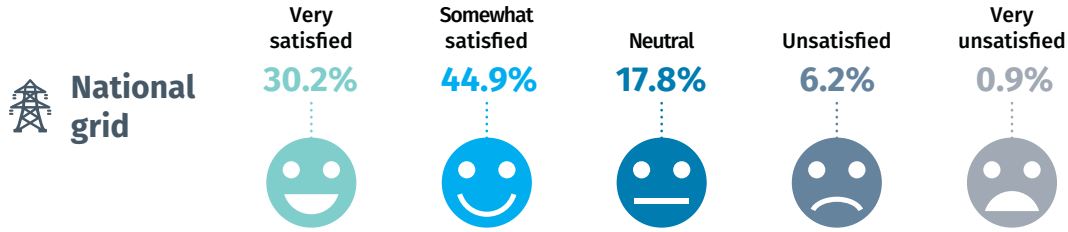
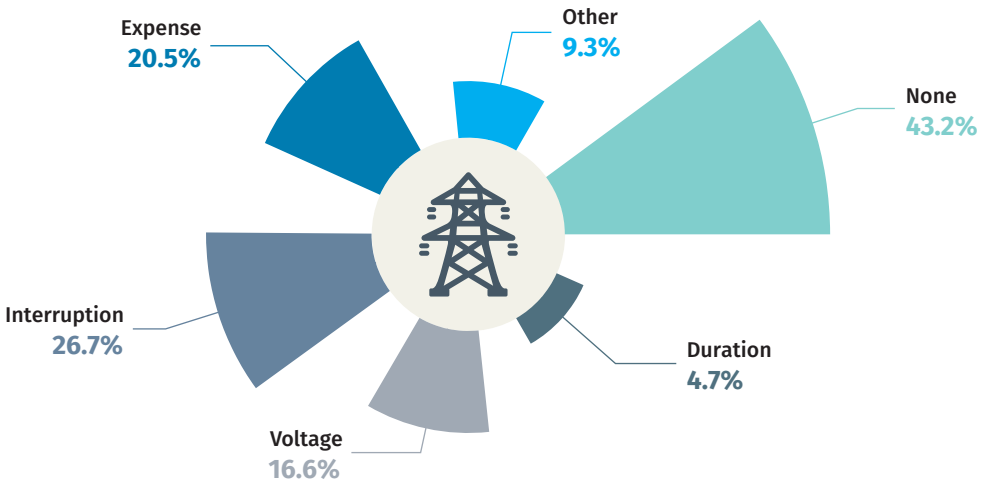



FIGURE 36 • **Unpredictable interruptions and high cost of supply are the key concerns of grid-connected households**



## IMPROVING ELECTRICITY ACCESS FOR HOUSEHOLDS WITH OFF-GRID SOLAR SOLUTIONS

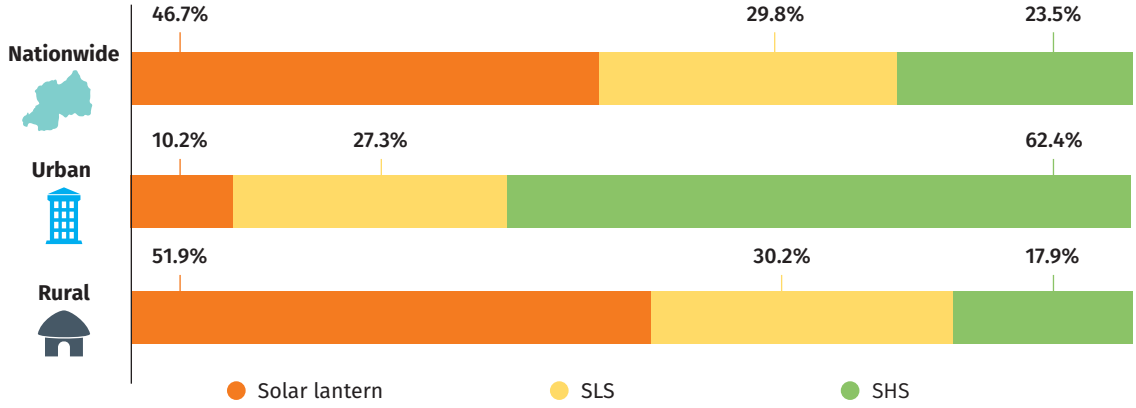
The penetration of off-grid energy solutions in Rwanda is still low, at 5.1% of households—including 5.5% of rural households and 2.9% of urban households—use an off-grid solar solution. These households are limited to Tiers 0–2 for access to electricity but could move to a higher tier over time. Nationwide, 57.3% of households with an off-grid solar solution are in Tier 1, which includes lighting and phone charging (figure 37). And 29.3% of households are in Tier 0 because of low Capacity (insufficient lighting and inability to charge phones) or low Availability (less than 4 hours a day). Only 13.5% are in Tier 2 (and can thus power a television). Urban households (40%), which have a larger off-grid system, are more likely than rural households (1%) to be in Tier 2.

FIGURE 37 • **Households that use an off-grid solar solution are limited to Tiers 0–2 for access to electricity**

*Note:* The number of households that use an off-grid solar solution as their primary source of electricity in the survey is 87.

Among off-grid solar solutions, 46.7% are solar lanterns, which are particularly common among rural households, 29.8% are SLSs, which have similar penetration among urban and rural households, and 23.5% are SHSs (figure 38). Urban households are three times as likely as rural households to have an SHS.

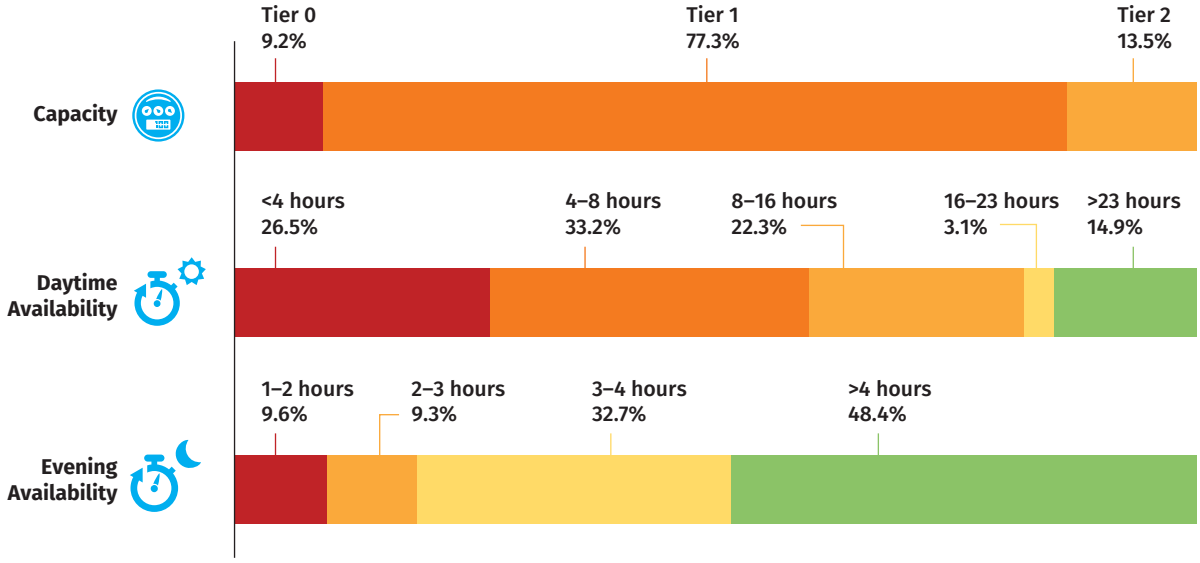
FIGURE 38 • **Solar home systems are more common in urban areas, while solar lanterns are more common in rural areas**




Availability and Capacity are the main factors that keep households with an off-grid solar solution in a lower tier for access to electricity. Among households with an off-grid solar solution, 26.5% receive less than 4 hours of electricity a day and are thus classified as not having access based on the MTF (figure 39). Evening Availability is an issue for fewer households: 48.4% receive over 4 hours of electricity

between 6 pm and 10 pm. Among households with an off-grid solar solution, 90.8% are in Tier 1 or above for Capacity, but only 13.5% are in Tier 2, and none is in Tier 3 or above.

FIGURE 39 • **More than 25% of households with an off-grid solar solution are in Tier 0 because of poor daily Availability**




To reach a higher tier for access to electricity, households with an off-grid solar solution will need to upgrade to a larger system (or eventually connect to a mini-grid or the grid). Access through off-grid solar solutions can be further improved by adopting larger and higher performance systems that provide more hours of supply and capability to power additional appliances (figure 40). In particular 49.7% of households with an off-grid solar solution reported that they want to improve the quality of light (34.6%) and system size of their off-grid solar device (15.1%). By addressing ability to pay and access to finance, households that already use an off-grid solar solution will be more likely to upgrade the system size. In addition, households with an off-grid solar solution report that they use more appliances today than they did with their first solar device (figure 41).

FIGURE 40 • **Better devices that provide electricity supply for more hours could enhance access to electricity among households with an off-grid solar solution**

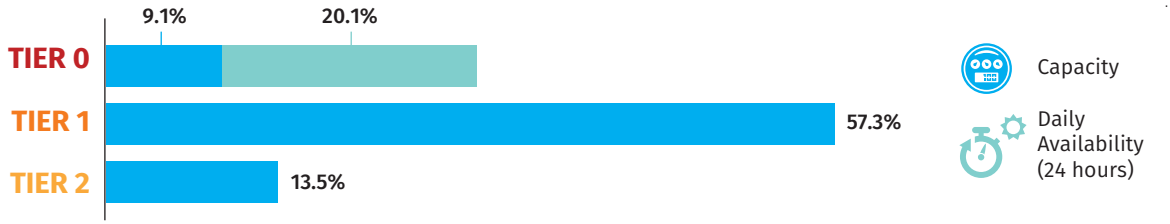
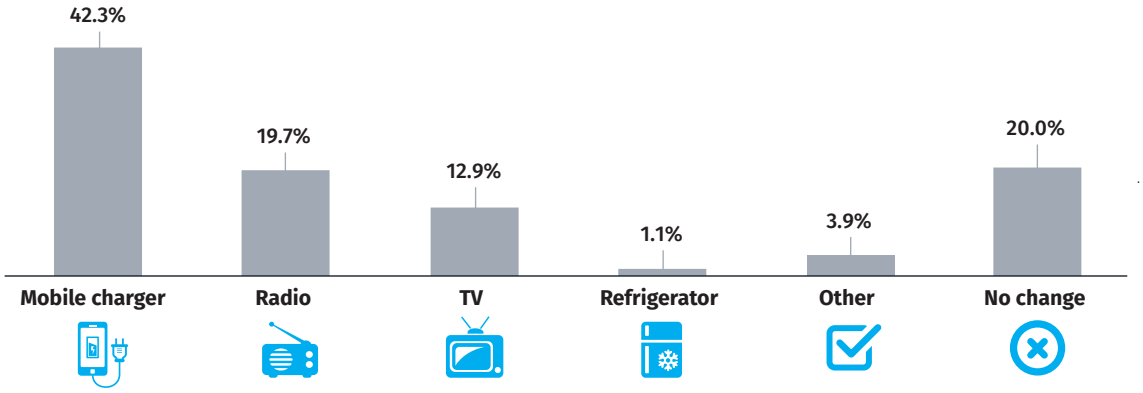


FIGURE 41 • **Phone charging is the most common additional energy service used by households that upgraded their solar solution**




While off-grid solar solutions that allow households to reach Tier 3 or above are rare, advances in solar technologies make it likely that such systems will be available in the future. The key to upgrading off-grid solar solutions (and thus moving households with an off-grid solar solution to a higher tier) will be to ensure that households can pay for them (see the findings on WTP in figure 29). In addition, the performance of solutions on the market differ. Ensuring that households acquire a better solution is likely to improve system performance even if the size of the solution does not change (for example, brighter and longer lasting lights, ability to power more appliances for a longer period of time, and longer life of the product), which can also lead to improved satisfaction.

In Rwanda 39.9% of households with an off-grid solar solution are satisfied with it (figure 42). Satisfaction is lower among households with an off-grid solar solution than among grid-connected households, although satisfaction tends to rise with the size of the solution. Households that use a solar lantern are concerned mostly by the quality of light, followed by the system's capacity, while households that use an SHS are concerned mostly by duration of electricity supply, followed by system cost (figure 43).

FIGURE 42 • **Nearly 40% of households with an off-grid solar solution are satisfied with it**

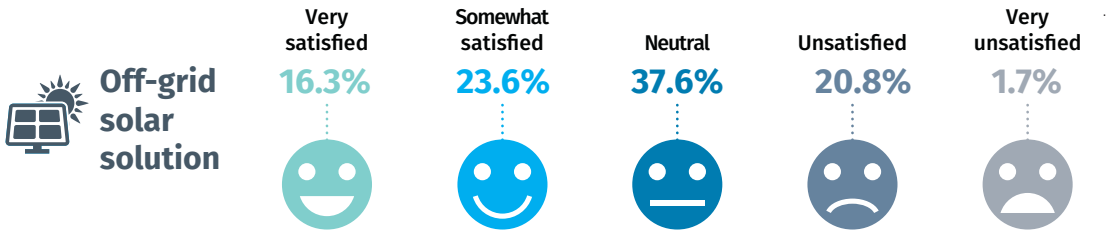
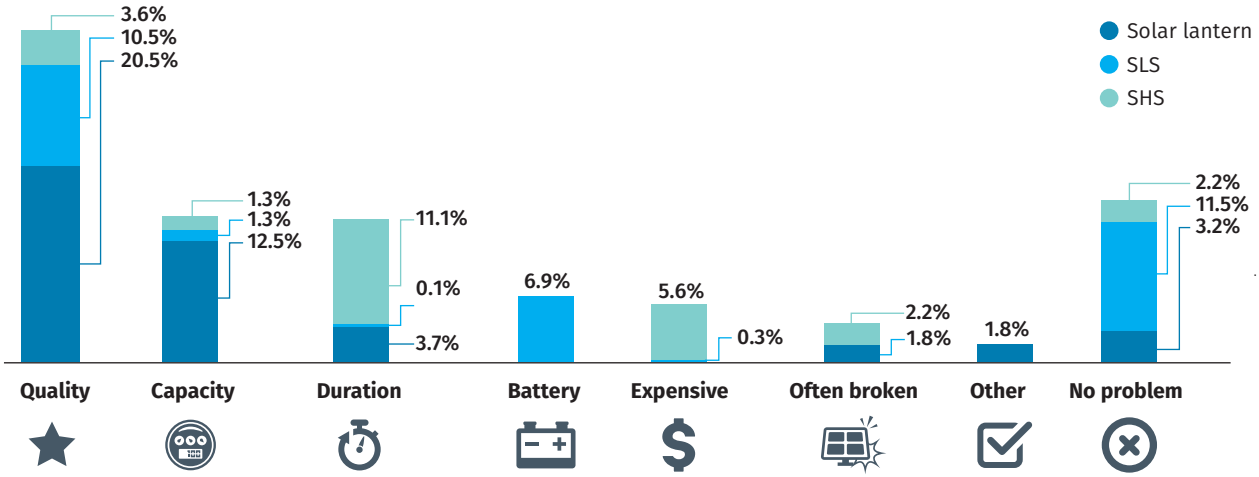
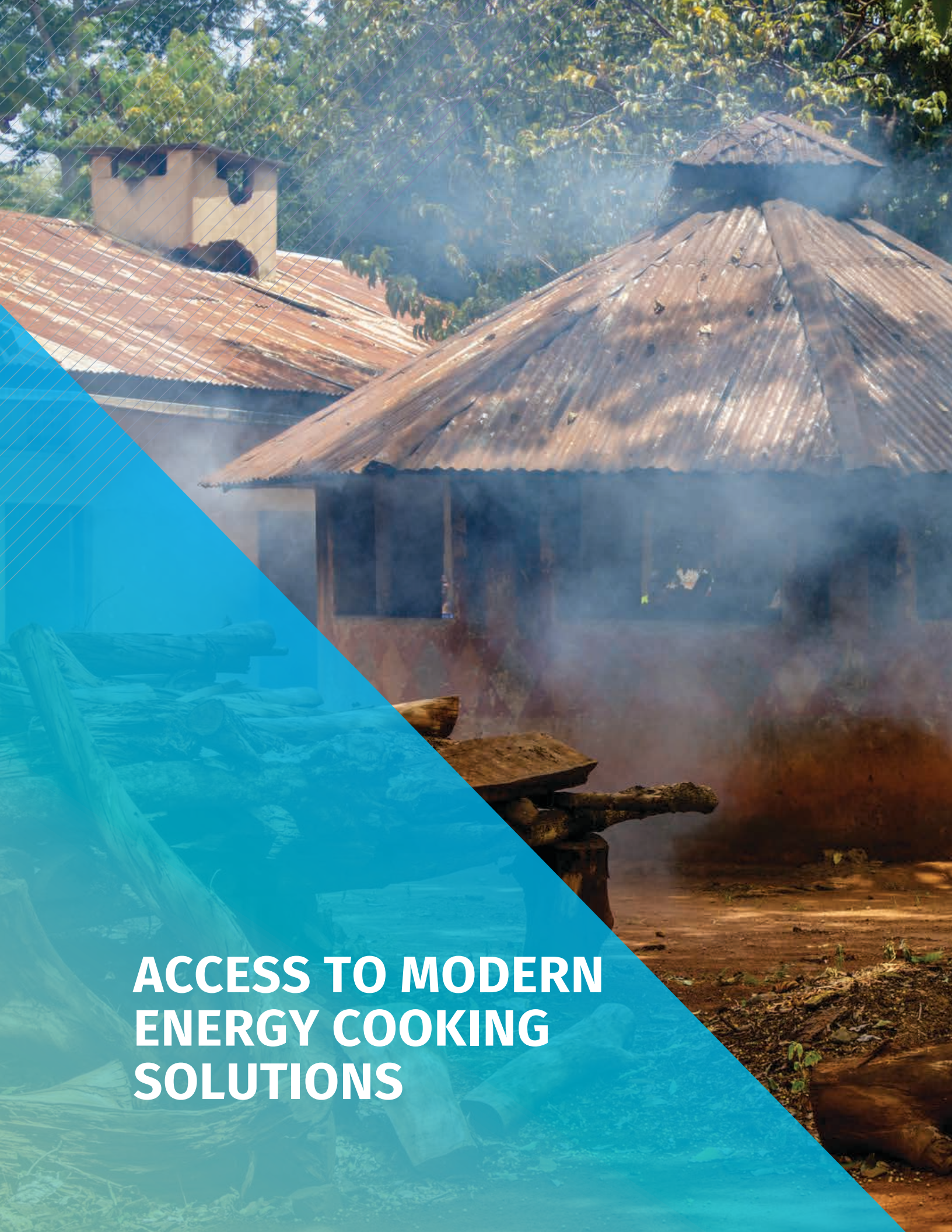


FIGURE 43 • **The most common issues with off-grid solar systems are quality of light and system capacity and duration**





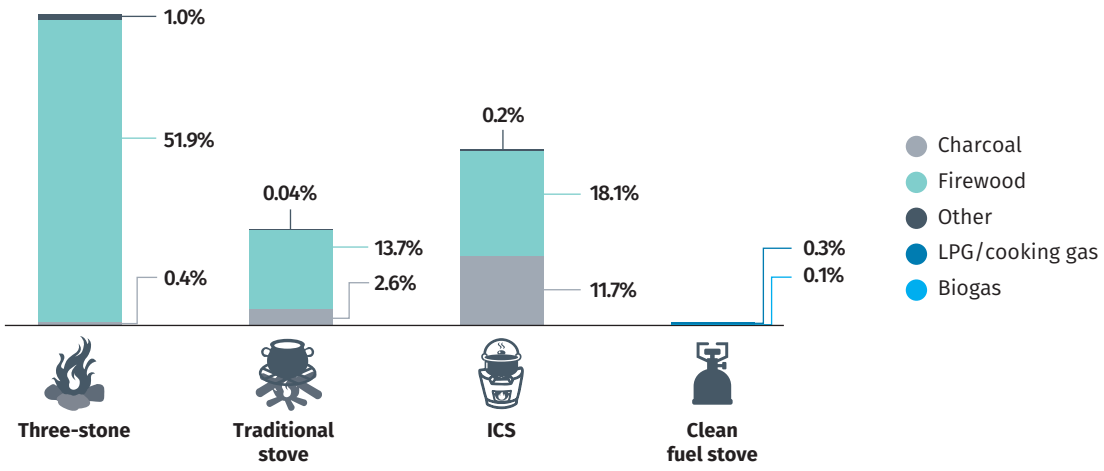
# ACCESS TO MODERN ENERGY COOKING SOLUTIONS

## ASSESSING ACCESS TO MODERN ENERGY COOKING SOLUTIONS

### TECHNOLOGIES

In Rwanda 99.6% of households cook with biomass, and a third of those households use an improved cookstove (ICS) as their primary stove: 53.3% of households use a three-stone stove, mainly burning firewood, and 16.3% use a traditional biomass stove, also mostly using firewood (figure 44). Nonetheless, 30% of households use an improved biomass stove, and 39% of those households use charcoal. Cooking with clean technologies and fuels, such as biogas, and liquefied petroleum gas (LPG)/cooking gas is rare: only 0.4% of households use them as their primary cooking fuel.

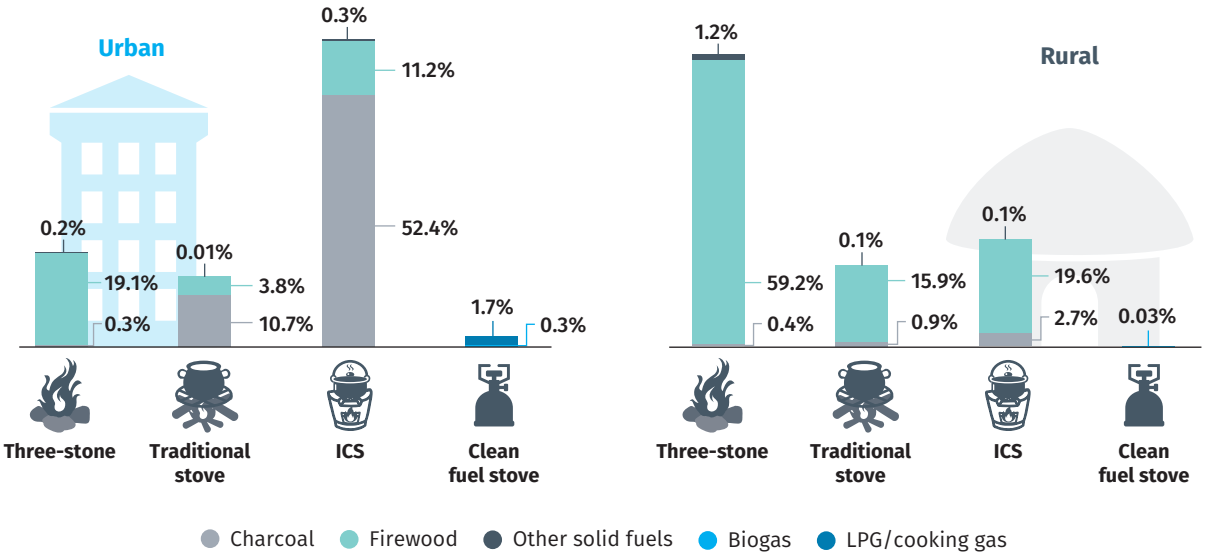
FIGURE 44 • **Virtually all households cook with biomass, mainly firewood, and nearly 70% use a three-stone or traditional stove as their primary stove**




*Note:* Other solid fuels include peat, animal waste/dung, crop residue/plant biomass, sawdust, and processed biomass (pellets/woodchips).

Urban and rural households have different cooking patterns. Urban households cook predominantly with charcoal (63.4%), followed by firewood (34.1%) (figure 45). In urban areas 63.9% of households use an ICS, and 2% use a clean fuel stove (mainly LPG/cooking gas). Rural households cook predominantly with firewood (94.7%). In rural areas 22.4% of households use an improved stove, and use of clean fuel stoves is negligible.

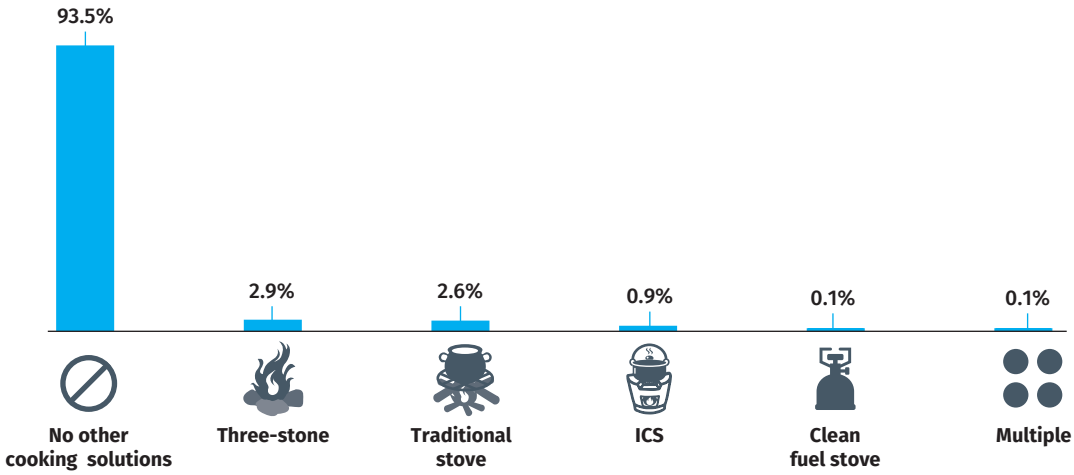
FIGURE 45 • **Over half of urban households cook with charcoal and use an improved cookstove**




## *Stove stacking*

Stove stacking (using multiple cookstoves) reflects households' aspiration to use higher performing solutions or the need for backup solutions, which are often used in addition to (rather than instead of) existing cooking solutions. Stove stacking occurs in 6.6% of households (figure 46). This may be because the energy transition toward cleaner cooking solutions has not materialized yet.[26] Stove stacking is slightly more common in urban areas (10.7%) than in in rural areas (5.6%).

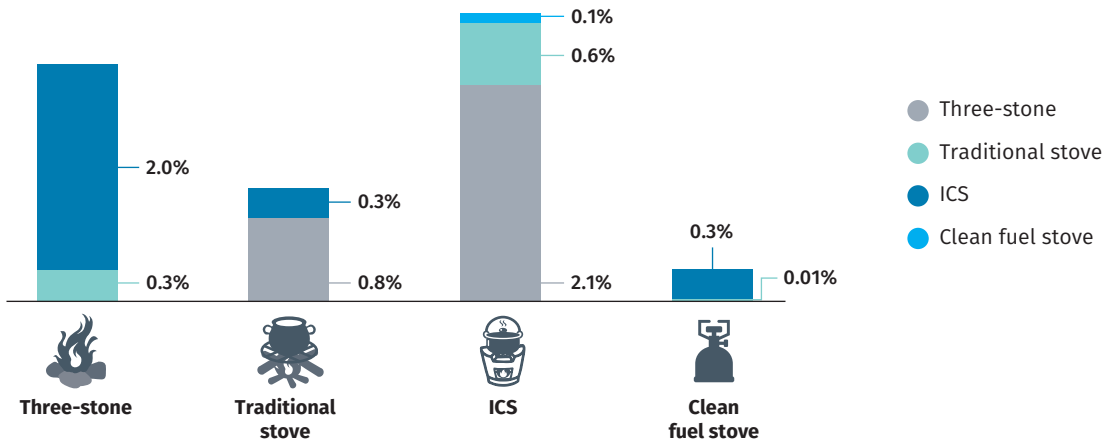
FIGURE 46 • **More than 93% of households use only one cookstove to meet their energy cooking needs**




[26] For additional explanation on the origins and reasons behind fuel stacking, see Bhatia and Angelou (2015), p. 46.

For the majority of households that use more than one cookstove, the additional stove is lower performing than the primary stove (figure 47). But most households that use a three-stone stove as their primary stove also use an ICS. Most households that use a clean fuel stove as their primary stove also use an ICS as a secondary stove.

FIGURE 47 • **For most households that use more than one cookstove, the additional stove is lower performing**

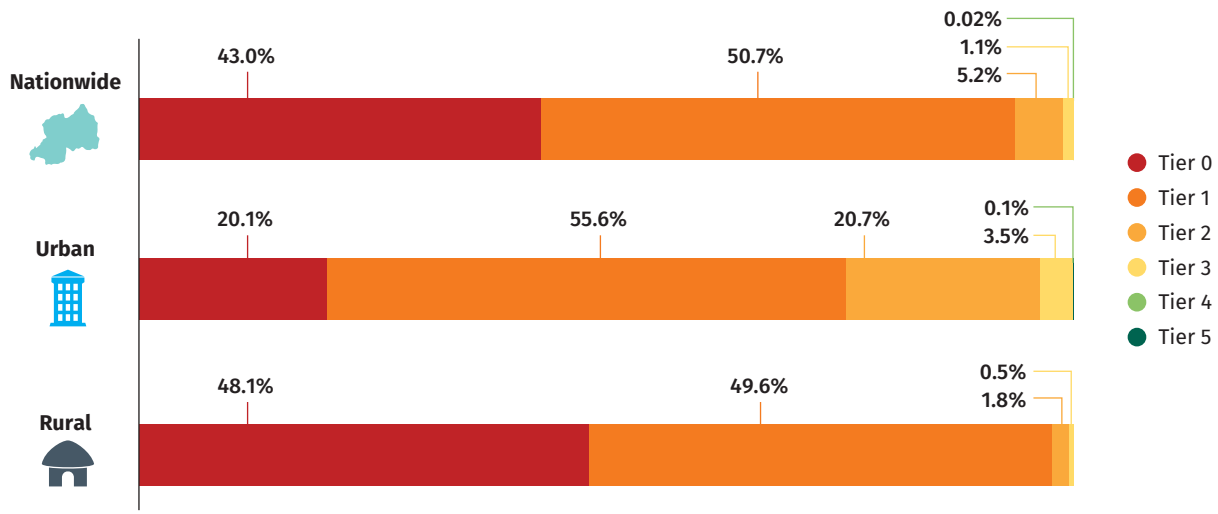



## MTF TIERS

Since the Multi-Tier Framework (MTF) for cooking is still being finalized, this report presents only a preliminary estimated tier structure based on basic stove classification and taking into account defined attributes that can be measured. For details on this simplified methodology, see the attribute analysis below. The complete analysis will be carried out once the final cooking framework is published.

In Rwanda 57% of households are in Tier 1 or above for access to modern energy cooking solutions (figure 48), despite the fact that 99.6% of households cook with biomass fuels. And 30% of households use an ICS, which has slightly lower emissions than a three-stone or traditional stove, as their primary stove. All households that use a three-stone stove or a traditional stove are considered to be in Tier 0 for stove emissions; however, if their ventilation structure is good, they are in Tier 1. Tier status for households that use an ICS cannot be determined without detailed data on stove performance in terms of emissions and efficiency, so most households that use an ICS are roughly assigned between Tier 1 and Tier 3. Their final tier for Cooking Exposure is determined after considering contact time as well as ventilation structure. Only 0.1% of households are in Tier 4 or 5, meaning that they use biogas or LPG as their primary cooking solution. Stove stacking with a three-stone or traditional stove inevitably negatively affects Cooking Exposure and could prevent households from reaching a higher tier.

FIGURE 48 • **Less than 1% of Rwandan households are in Tier 4 or 5 for access to modern energy cooking solutions**




## MTF ATTRIBUTES

### *Cooking Exposure*

Cooking Exposure is a proxy indicator to measure the health impacts of cooking activity. It is a function of cookstove emissions (which are a function of the device's characteristics, its use duration and pattern, user adherence to use specifications, maintenance, and fuel quality), kitchen volume, air exchange rate, and ambient pollution (see table A1.2).[27]

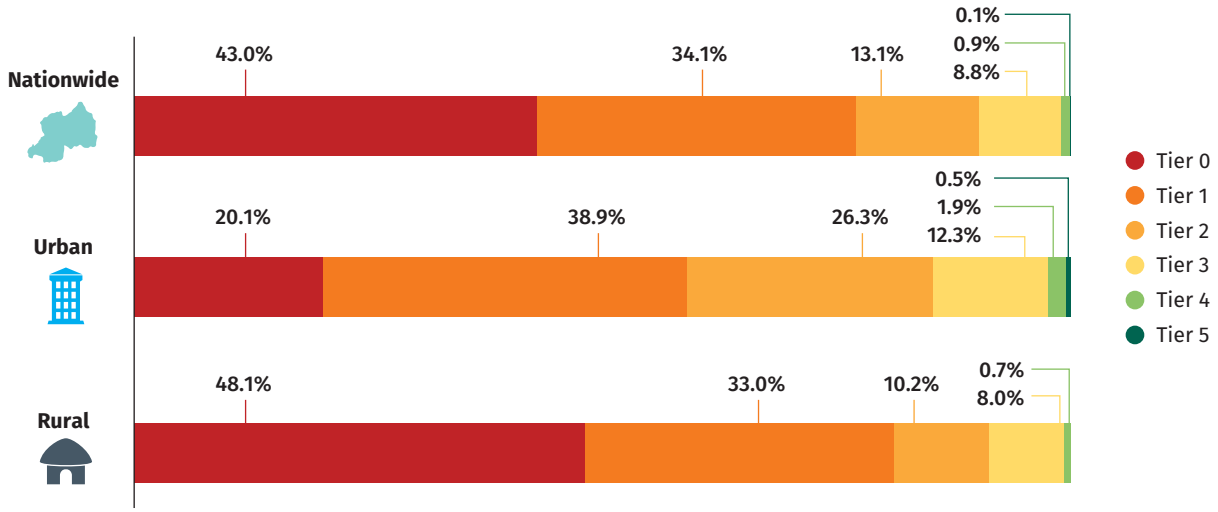
Most households use a three-stone (53.3%) or traditional stove (16.3%), both of which emit a high rate of pollutants, such as particulate matter below 2.5 microns in diameter and carbon monoxide. Households that use a three-stone or traditional stove without a good ventilation structure are in Tier 0 for Cooking Exposure, while households that use an ICS, which usually emits a lower rate of pollutants, are generally in Tiers 1–3, depending on their ventilation system, contact time, and stove stacking practice (figure 49). And households that use a clean fuel stove, which burns biogas or LPG and has a lower emissions rate, as their primary stove are generally in Tier 4. However, stove stacking that involves a higher polluting stove such as a three-stone or traditional stove as the additional cooking solution will inevitably negatively affect indoor air quality and keep households in a lower tier for Cooking Exposure.

A household can move to a higher tier for Cooking Exposure if it has good ventilation, which depends on the cooking location and the presence of an exhaust system (such as a hood). But only a quarter of households cook outdoors, and only 15.2% of households that cook indoors use an exhaust system, such as a chimney or hood. In addition to ventilation structure, contact time—how long the main cook spends in the cooking space—is also considered in the calculation of tier status for Cooking Exposure.

[27] Bhatia and Angelou 2015.

For households that use multiple stoves, the tier for Cooking Exposure is the average tier for each stove weighted by the frequency and duration of use. The volume of the kitchen is also a component used to calculate the tier status for Cooking Exposure, but it is not included in the analysis for Rwanda because the MTF survey did not collect information on height of cooking space.

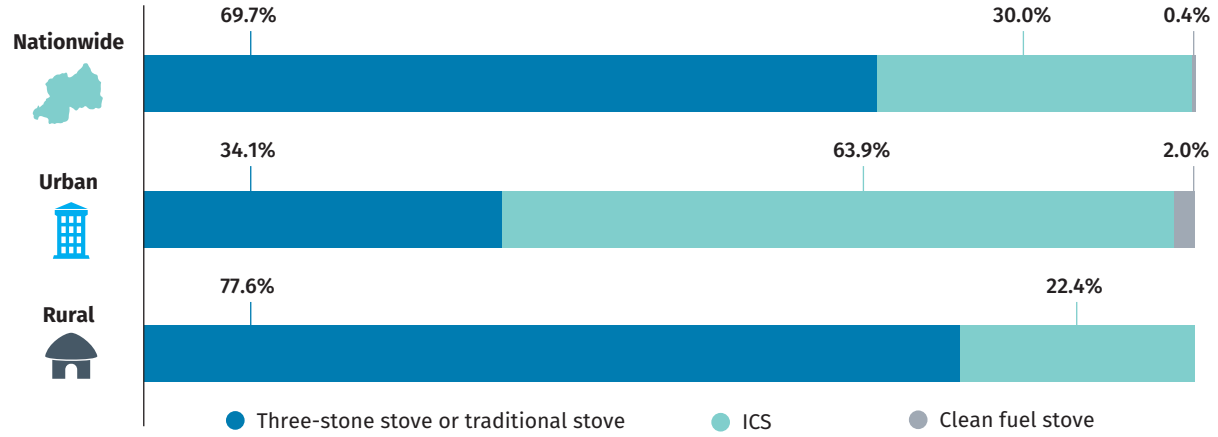
FIGURE 49 • **More than 40% of households are in Tier 0 for Cooking Exposure**




## *Cookstove Efficiency*

Cookstove Efficiency is low for most households, particularly in rural areas. Cookstove Efficiency can be assessed only based on laboratory measurement under standard conditions, field testing under actual conditions, or visual identification through a system of certification and labeling by stove brand. Without such system, a rough proxy of cookstove performance in terms of efficiency has been established, mirroring the performance in terms of emissions rates. Households that use a three-stone or traditional stove are in Tier 0, households that use an ICS are in Tiers 1–3, and households that use a clean fuel stove are in Tier 4 or 5 (figure 50).

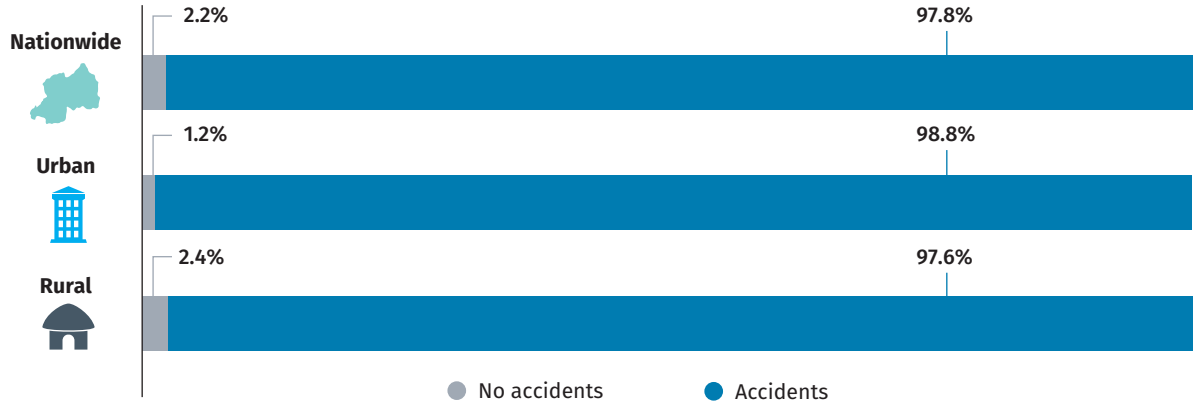
FIGURE 50 • **Nearly 70% of households use a low-efficiency cookstove**



## SAFETY OF PRIMARY COOKSTOVE

Most households did not recall a major injury over the last year that required medical attention. Only 2.2% of households reported the death or serious injury of a household member, including permanent health damage, burns/fire/poisoning, severe cough or respiratory problem, or other major injury, due to their cooking solution (figure 51). Accidents are more likely to occur in rural households that use a three-stone stove.

FIGURE 51 • **Accidents due to cooking solutions occurred in 2.2% of households**




### *Convenience*

Nationwide, 76.5% of households spend over 7 hours a week to acquire (through collection or purchase) and prepare cooking fuel (figure 52). Acquiring and preparing fuel are time-consuming tasks for most households. About 84% of households use firewood as their primary cooking fuel, and most of them likely collect it for free, hence spending over 1 hour a day acquiring and preparing fuel. Only 3% of households spend less than 0.5 hour a week acquiring and preparing fuel. And 38.4% of households spend 5 minutes or less per meal preparing the stove (figure 53).

FIGURE 52 • **More than 75% of households spend over 7 hours a week acquiring and preparing fuel**

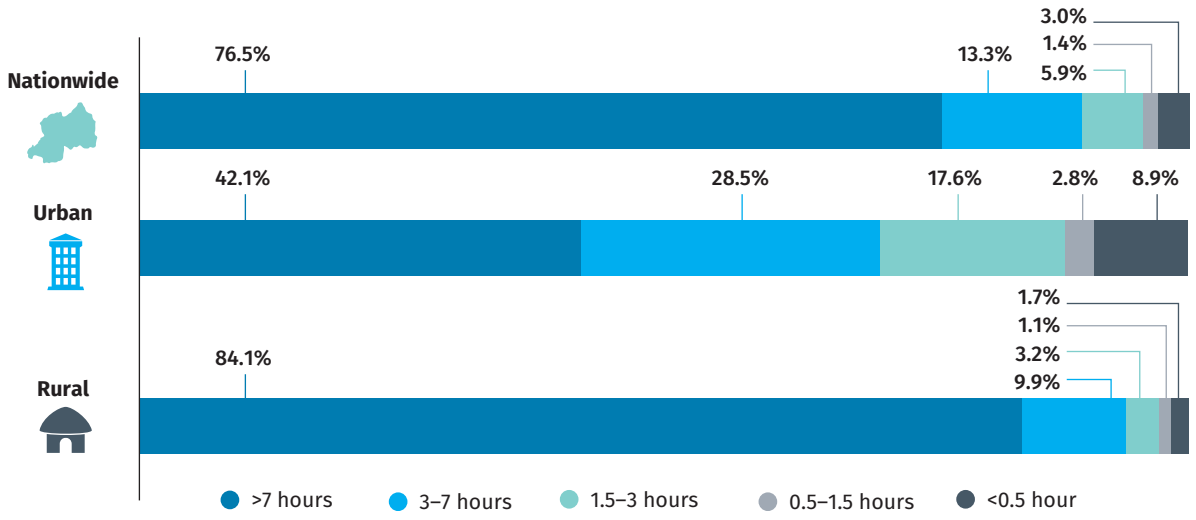
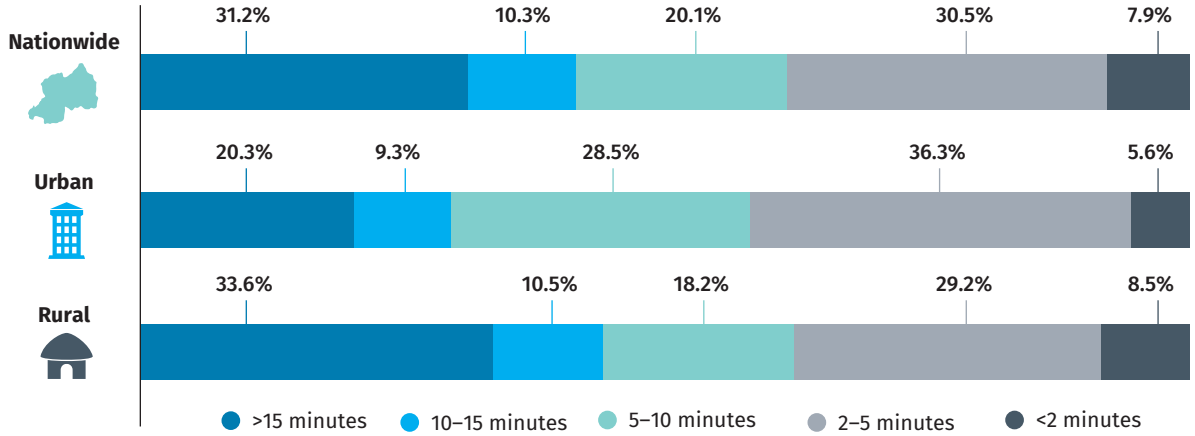


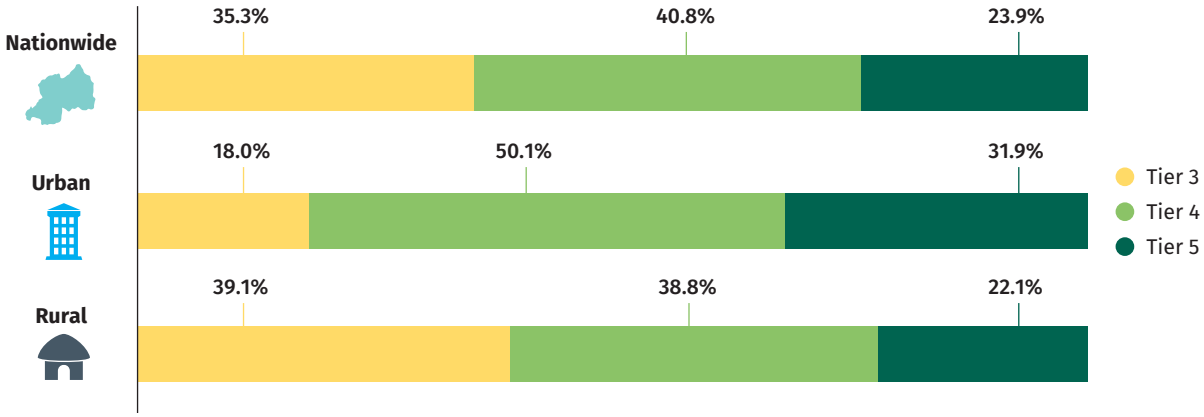
FIGURE 53 • **More than 60% of households spend over 5 minutes per meal preparing the stove**




### *Fuel Availability*

In Rwanda 35.3% of households stated that their primary cooking fuel is only sometimes or rarely available, which is equivalent to Tier 3 (figure 54). This issue was less common in urban areas (18%) than in rural areas (39.1%).

FIGURE 54 • **Fuel is only sometimes or rarely available for 35.3% of households**



## IMPROVING ACCESS TO MODERN ENERGY COOKING SOLUTIONS

Rwanda faces a double challenge in improving access to modern energy cooking solutions: a high percentage of households that still use biomass with a three-stone or traditional stove and a very low percentage of households that use clean fuels. The ultimate objective should be to provide all households access to cooking solutions that are clean, efficient, convenient, affordable, safe, and available (Tiers 4 and 5). But the very low penetration of clean fuels suggests a long journey to that goal. In the interim, ICSs could be used to move households in Tier 0 to Tiers 1–3 (preferably the higher tiers of this range). This interim strategy should be a part of a larger and long-term strategy to move households to a higher tier over time. Market development can be a part of the strategy.

The MTF data provide several indications for why expanding the use of ICSs is a desirable and achievable target. First, while doing so would not eliminate the threat of indoor air pollution entirely, it would reduce emissions that are harmful to health and the environment and save households time or money in acquiring fuel, with most of the benefit accruing to women. Average monthly consumption of charcoal was 36 kilograms for households with an ICS, compared with 50 kilograms for households with a traditional stove. And using an ICS yields 39 minutes of savings in fuel acquisition and preparation, compared with using a three-stone stove, again with most of the savings accruing to women.

A variety of ICSs are already available on the Rwandan market, and household awareness of them is high, resulting in high willingness to pay (WTP). Of urban households, 63.9% use an ICS (most of them with charcoal) as their primary stove. Penetration of ICSs (most of them wood-fired stoves) is much lower among rural households (22.4%) but still a good base for an expansion. The WTP results are particularly promising, considering that 77% of households in Tier 0 are willing to pay full price for an ICS, provided that a payment plan up to 24 months is offered.

A critical first step to scale up access to modern energy cooking solutions is to develop a comprehensive national program. While such a program would need to involve stakeholders from a wide variety of positions, roles, and levels, there is no substitute for high-level political, technical, and financial support from national leaders and agencies. This high-level support is a key success factor that requires time to build and continuous engagement to maintain.

Disseminating ICSs to the large percentage of households that expressed WTP for these solutions would likely include a combination of supply measures (such as support for stove manufacturers and distributors by, for example, establishing working capital facilities) and demand measures (such as consumer awareness campaigns and consumer financing options). Given the low penetration of ICSs in rural areas, rural households should be targeted. The program can include market development for ICSs to promote their adoption among all households that use biomass with a three-stone or traditional stove.

The use of clean fuels needs to be expanded, particularly in urban areas. Only 0.4% of households use clean fuels, and the reasons for the limited acceptance of clean fuels—be they financial, cultural, or situational (for example, lack of information)—should be explored. Health-related consumer awareness

campaigns should be launched, in particular for higher income urban households that can afford clean fuels, and potential supply constraints should be analyzed and removed accordingly.

Health-related consumer awareness campaigns would be critical for promoting clean fuel stoves and ICSs.

Given the important health benefits that clean fuels deliver, ways to expand their small share, particularly in more affluent urban areas, should be explored. A strategy to do so should be accompanied by a strategy to minimize the parallel use of biomass stoves (in particular, three-stone and traditional stoves). Potential supply constraints should be analyzed and removed accordingly, particularly for higher income urban households that can afford clean fuels.

Allowing payment for a stove in installments appears to be an effective way to increase households' ability to pay for an ICS without resorting to upfront cost subsidies, which are often unsustainable. Offering a six-month payment plan was especially effective in increasing WTP among rural households.

Considering the important health benefits that clean fuels deliver, ways to expand their small share, particularly in more affluent urban areas, should be explored. The majority of households that use clean fuels also use a biomass stove in parallel, and these households are unlikely to reach Tier 4 or 5 unless they minimize the use of the biomass stove. Only 18% of households that use a clean fuel stove that qualifies for Tier 4 or 5 for Cooking Exposure are also in Tier 4 or 5 for Convenience. The majority of households that use a clean fuel stove spend considerable time acquiring and preparing fuel, which suggests that their biomass stoves are still used extensively. A national strategy to expand the use of clean fuel stoves should thus be accompanied by a strategy to minimize the parallel use of biomass stoves (in particular three-stone and traditional stoves).

Improved biomass stoves limit households to a lower tier for access to modern energy cooking solutions than clean fuel stoves do and are more common and are used exclusively more often. Nationwide, 30% of households use an improved biomass stove, and 84% of households use it exclusively. Households with an ICS use considerably less fuel than households with a traditional stove do, and their household members spend less time collecting firewood. This freed time benefits women in particular because they carry the largest burden of firewood collection (see the next section on gender analysis).

ICSs are a promising solution for a large percentage of households in Tier 0, which use a three-stone or traditional stove. More than half of respondents are willing to pay for an ICS at the price of 3,000 Rwandan francs, and three-quarters are willing to pay for one at a discounted price of 1,000 Rwandan francs. WTP is higher for urban households and for households that spend more on fuel.

Allowing households to spread the full price payment over six months has almost the same effect as offering a discounted price: 72% of households are willing to pay full price for an ICS upfront or in six monthly installments. Allowing payment in installments appears to be an effective way to increase households' ability to pay for an ICS without resorting to upfront cost subsidies, which are often unsustainable. Offering a six-month payment plan was especially effective in increasing WTP among rural households.

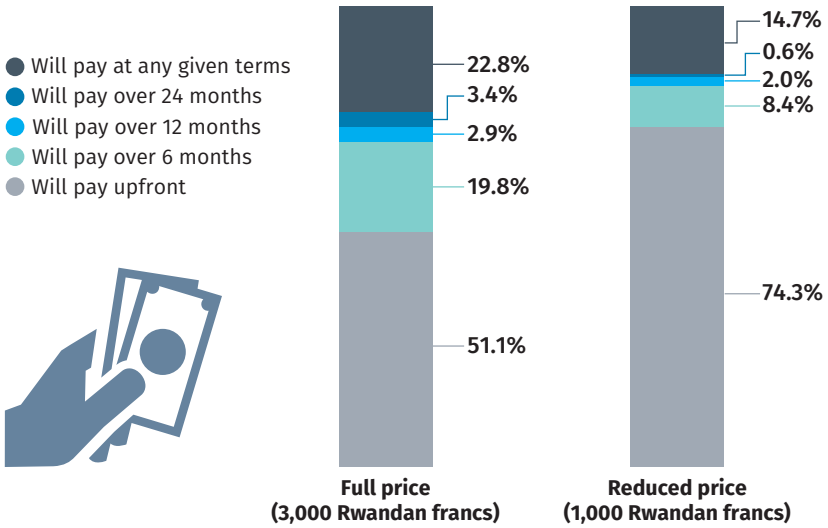
Affordability of stoves could also be impeding households from reaching a higher tier for access to modern energy cooking solutions. Affordability was not explored in the Rwandan survey; thus, conclusions regarding its role cannot be drawn for this analysis. If Affordability is an issue for households that use clean fuels (that is, if the levelized cost of the cookstove and fuel is higher than 5% of household spending[28]) many households in Tier 4 or 5 may be in Tier 3.

## INCREASING ADOPTION OF IMPROVED COOKSTOVES AS PRIMARY COOKING SOLUTIONS

ICSs are the most feasible and quickest way to move the 43% of households in Tier 0 to Tier 1 or higher, while market development for clean fuels is a long-term goal. The over two in three households that use a three-stone or traditional stove as their primary stove could be encouraged to adopt an ICS while using the same fuel (firewood or charcoal). By switching primary stoves, these households would move from Tier 0 to Tier 1 or higher at low cost and with minimal disruption in cooking practices. Those households could also save time spent acquiring and preparing fuel. Households that switch from a three-stone stove to an ICS can reduce time spent acquiring and preparing fuel by 24.2%, and compared with households that use a traditional stove exclusively, households that use an ICS exclusively can reduce time spent acquiring and preparing fuel by 18.3%.

Payment plans and reduced prices increase WTP. Households are willing to pay for an ICS, but the high upfront cost presents a barrier. About half of households are willing to purchase an ICS at full price (3,000 Rwandan francs, or about $3.60 upfront) (figure 55), including nearly 60% of urban households. An additional 26.1% of households are willing to pay if a payment plan is available, and 74.3% of households are willing to pay full price upfront if the price is reduced to 1,000 Rwandan francs.

FIGURE 55 • **Most households are willing to pay for an improved cookstove, especially if allowed to pay over time**




*Note:* 1 U.S. dollar = 815 Rwandan francs (average exchange rate between November 14, 2016, and December 1, 2016).

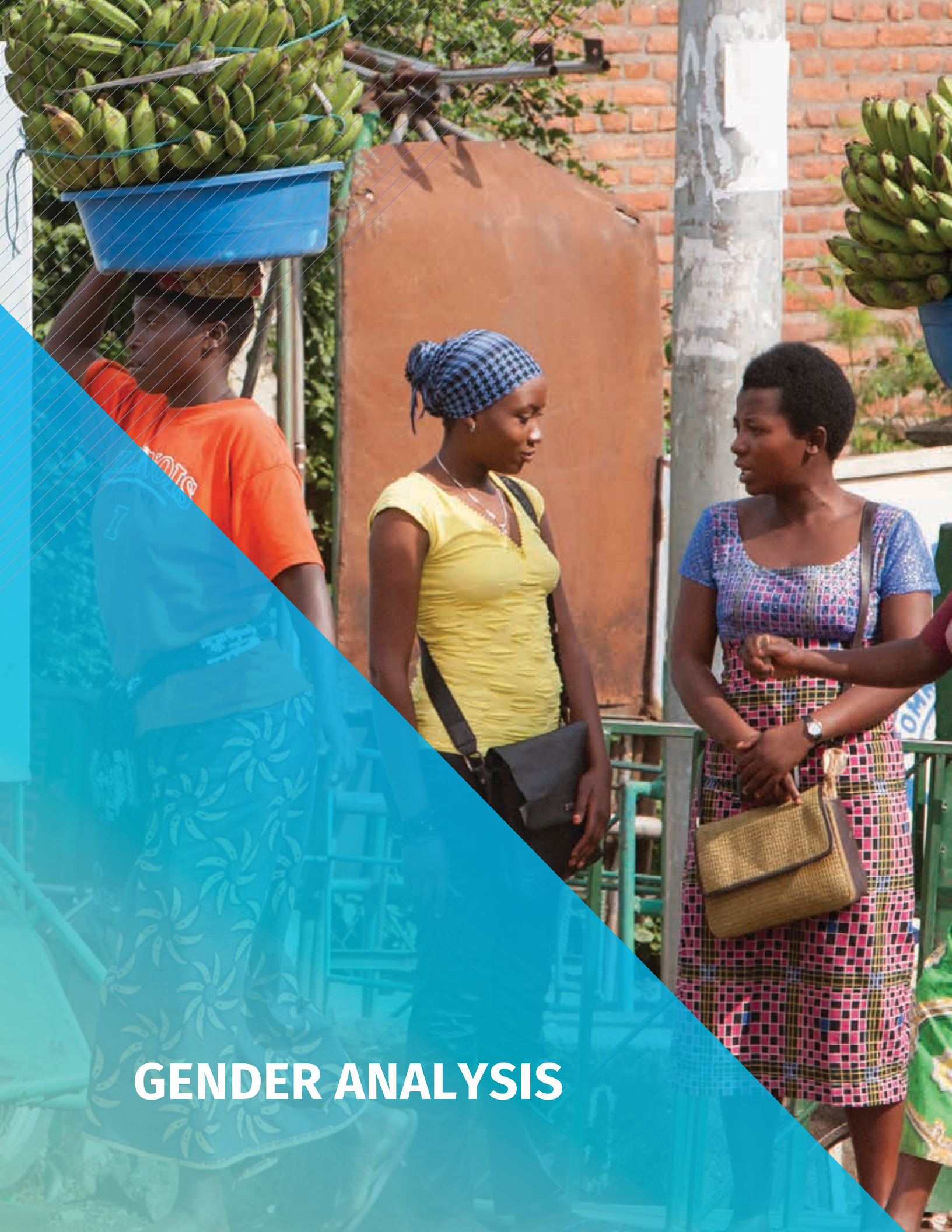
[28] The Rwandan government requested that the MTF survey not collect data on the Affordability attribute because the National Institute of Statistics in Rwanda is carrying out other surveys that are capturing this information.

Household firewood expenditure and fuel collection time are driving forces behind WTP for ICSs. Households spend an average of 2,176 Rwandan francs (or $2.60) a month on firewood. Monthly firewood expenditure is 14% higher (2,474 Rwandan francs) for households that are willing to pay upfront for an ICS and 66% lower (719 Rwandan francs) for households that are not willing to pay for an ICS. Time spent collecting firewood also determines WTP. Households spend 132 minutes a week collecting fuel, but households that are willing to pay upfront for an ICS spend 151 minutes and households that are not willing to pay for an ICS spend 24 minutes on average (about 18% less time).

## INCREASING PENETRATION OF CLEAN FUEL STOVES

Clean fuels have yet to make a significant contribution to cooking practices in Rwanda. Only 0.4% of households use a clean fuel stove (LPG or biogas) as their primary stove. And most households that use a clean fuel stove also use a biomass cookstove, likely due to the lower cost of fuels and to cooking practices (certain meals being preferred on biomass stoves). Nonetheless, clean fuel stoves can significantly improve indoor air quality, and thus their wider adoption should be pursued.

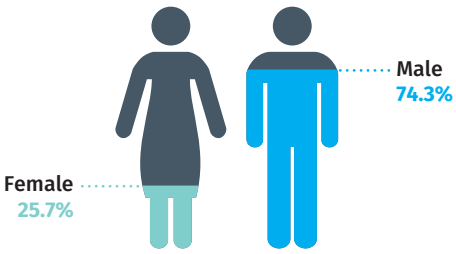
The potential to expand the use of clean fuels and clean fuel stoves should be further analyzed with regards to Fuel Availability and Affordability. Based on this understanding, a national systemic clean cooking strategy needs to be devised to move Rwandan households to a higher tier for access to modern energy cooking solutions. In addition, the reasons for the use of secondary biomass stoves should be better understood. Based on this analysis, target groups should be identified among which clean fuels and clean fuel stoves should be promoted under the aforementioned national strategy. This should include campaigns to raise awareness on the health benefits delivered by clean fuels and on the importance of reducing the use of secondary stoves.



# GENDER ANALYSIS

Nationwide, 25.7% of households are headed by women (figure 56). Female-headed households account for 26% of rural households and 23.9% of urban households. The average age of female household heads is 55, compared with 44 for male household heads. About 49% of female household heads and 80% of male household heads fall into the 25–54 age group. Over half of female households heads have never attended school, compared with a fifth of male household heads. And about 76% of female household heads are employed, compared with 90% of male heads.

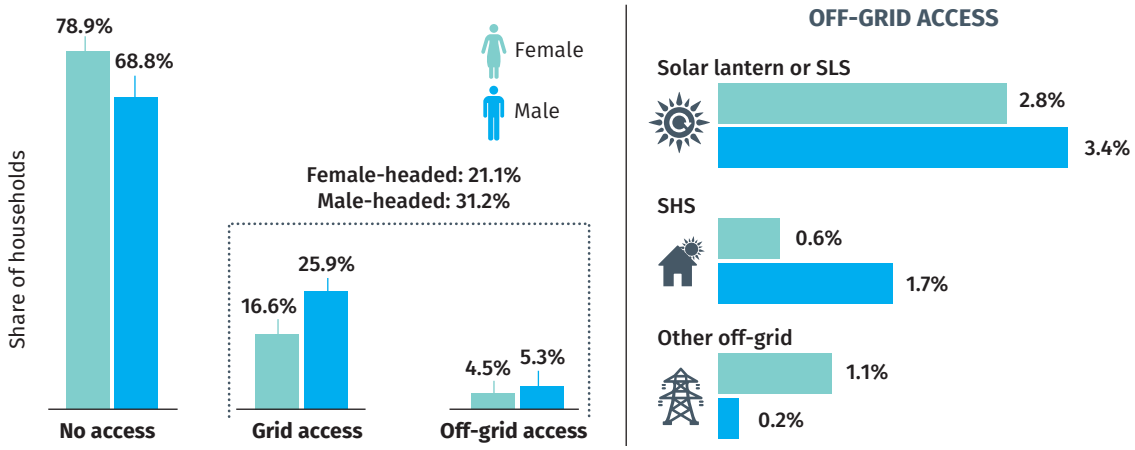
FIGURE 56 • **Men head 65.1% of households**




## ACCESS TO ELECTRICITY

Only 21.1% of female-headed households have access to any source of electricity, compared with 31.2% of male-headed households, and female-headed households have lower access rates for both grid and off-grid electricity (figure 57). In urban areas female-headed households have significantly lower access to the grid than male-headed households do but are more likely to have off-grid solutions, mainly solar lanterns or solar lighting systems (SLSs) (figure 58). This could mean that female-headed households that are unable to access the grid are more likely to resort to lower cost off-grid solar solutions. In rural areas female-headed households have lower access to both grid and off-grid electricity (figure 59).

FIGURE 57 • **Female-headed household are less likely to have access to any source of electricity than male-headed households are**




*Note:* Other off-grid solutions include mini-grid, pico-hydro, and rechargeable batteries.

FIGURE 58 • **In urban areas female-headed households have higher access to solar lanterns and solar lighting systems than male-headed households do**

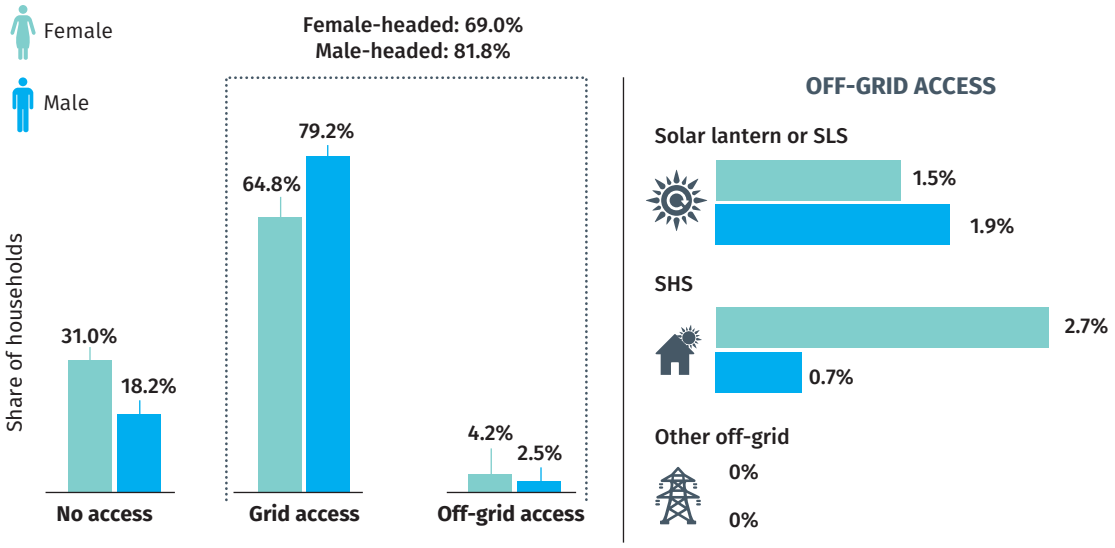
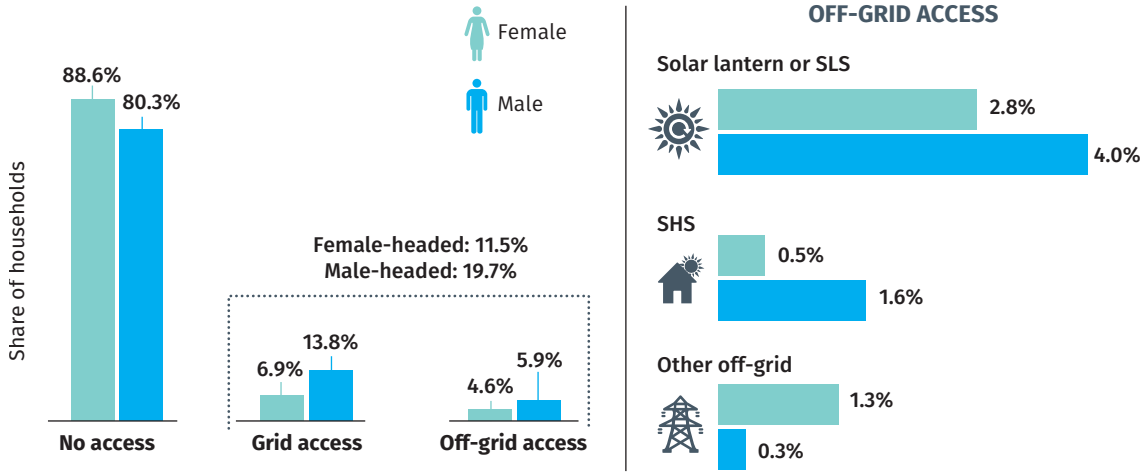



FIGURE 59 • **In rural areas female-headed households have higher access to other off-grid solutions than male-headed households do**




In Rwanda 80.3% of female-headed households are in Tier 0 for access to electricity, compared with 70.9% of male-headed households (figure 60). In Tiers 1–5 the share of male-headed households is higher than the share of female-headed households, and the gap is wider in higher tiers. The gender gap for Tier 0 is wider in urban areas, where most households are connected to the grid, than in rural areas or nationwide (figures 61 and 62). Female-headed households have a much harder time connecting to the grid than male-headed households do.

FIGURE 60 • **More than 80% of female-headed households are in Tier 0, compared with roughly 71% of male-headed households**

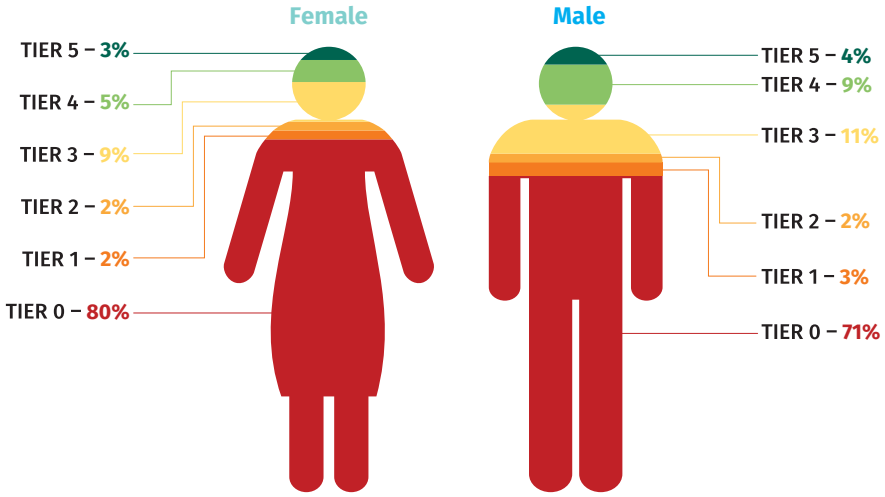



FIGURE 61 • **In urban areas the gender gap is particularly wide in Tiers 0 and 4**

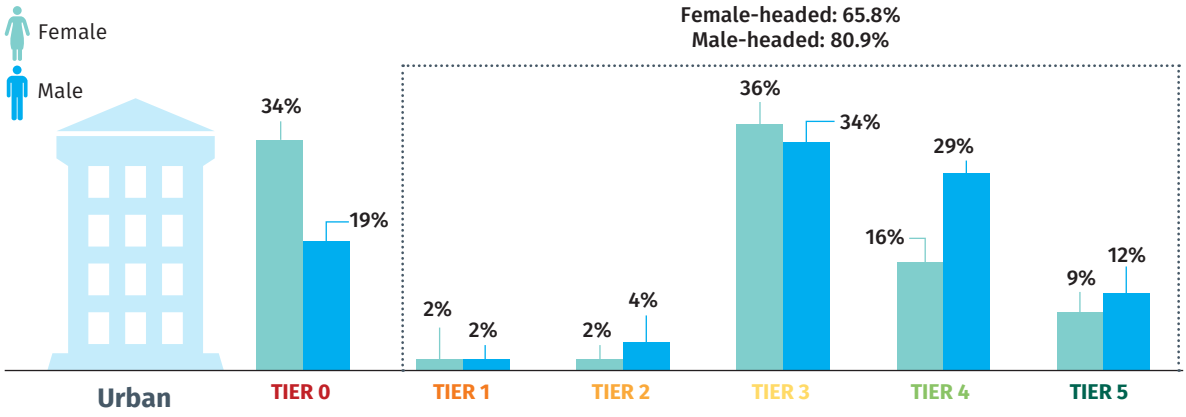
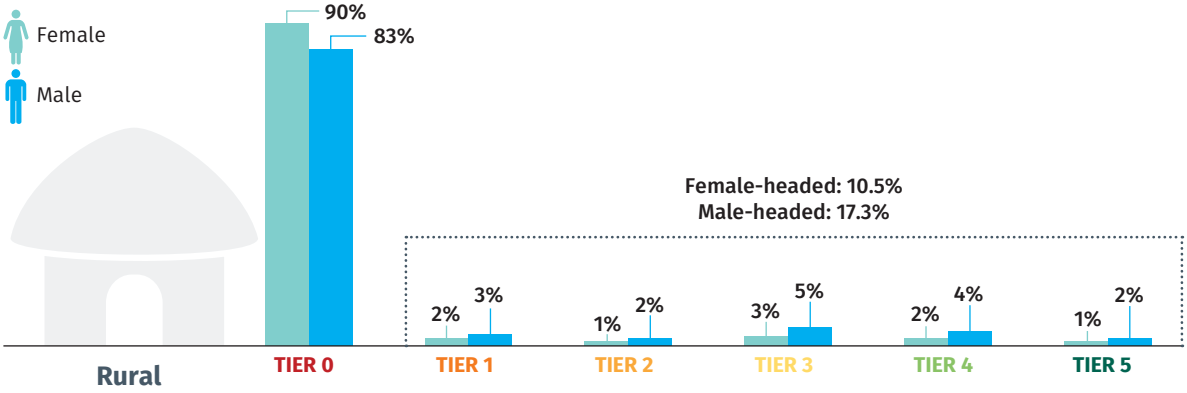
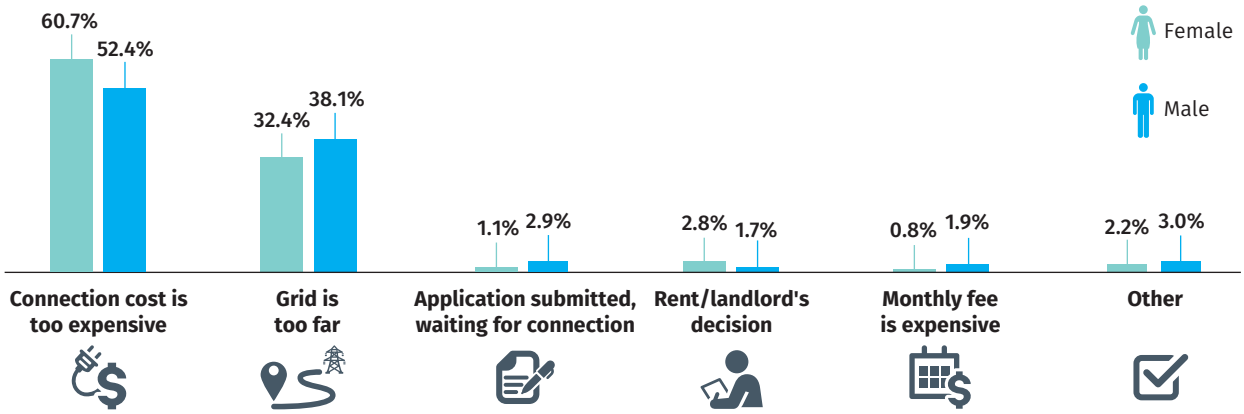



FIGURE 62 • **In rural areas the widest gender gap is in Tier 0**



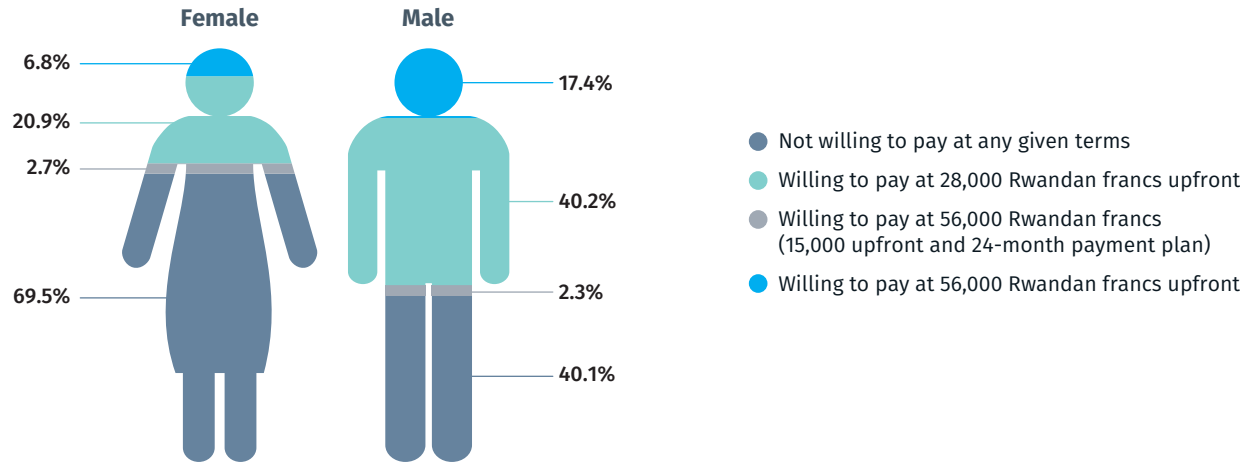
For 60.7% of female-headed households and 52.4% of male-headed households the main barrier that prevents them from connecting to the grid is the high connection cost (figure 63).

FIGURE 63 • **More than 60% of female-headed households and more than 52% of male-headed households are not connected to the grid because the connection cost is too high**




In Rwanda 69.5% of female-headed households are not willing to pay for the connection fee under any given terms, compared with 40.1% of male-headed households (figure 64). The results may be due to the fact that fewer female household heads (76%) than male household heads (90%) are employed. The gender gap in willingness to pay (WTP) indicates that gender-targeted financing mechanisms are required to increase grid connections for female-headed households.

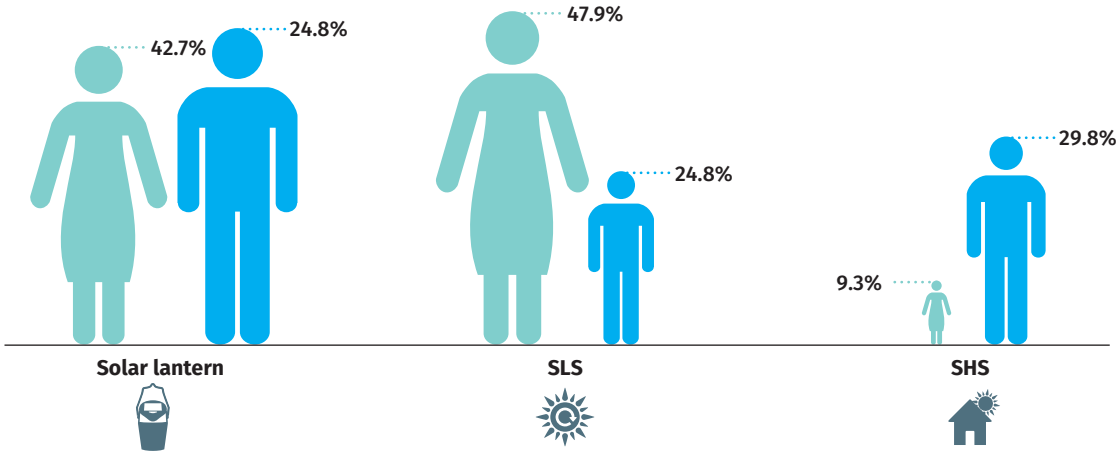
FIGURE 64 • **Female-headed households are much less willing to pay for a grid connection than male-headed households are**




Note: 1 U.S. dollar = 815 Rwandan francs (average exchange rate between November 14, 2016, and December 1, 2016).

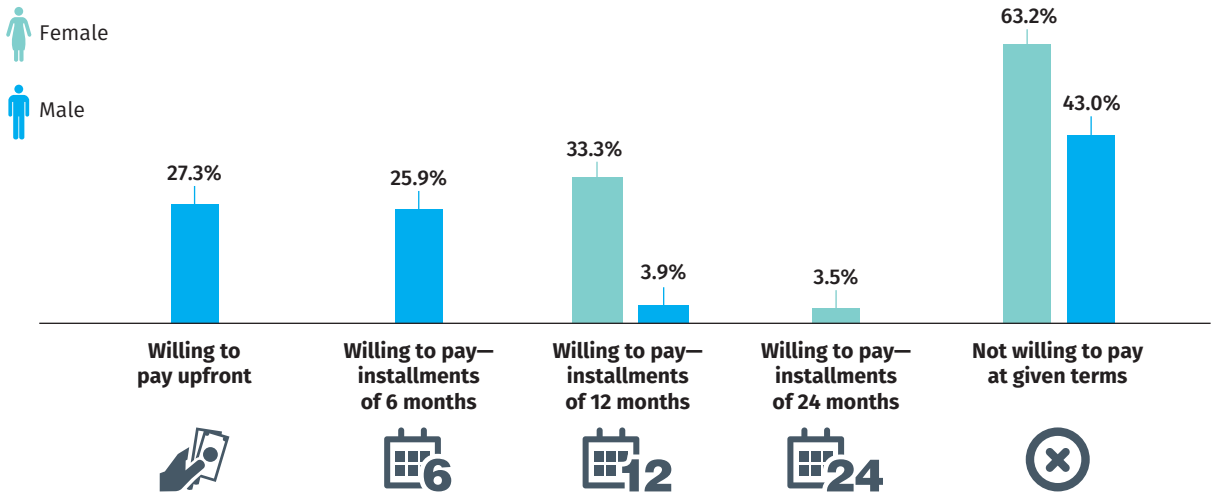
Female-headed households own smaller off-grid solar solutions than male-headed households do. Of female-headed households that access electricity through an off-grid solar solution, 52.7% use a solar lantern, and 47.9% use an SLS (figure 65). Only 9.3% use a larger solar home system (SHS), compared with 29.8% of male-headed households.

FIGURE 65 • **Less than 10% of female-headed households that use an off-grid solar solution use a larger solar home system, compared with nearly 30% of male-headed households**




WTP for an off-grid solar solution that allows a household to reach Tier 1 for access to electricity is significantly lower for female-headed households (63.2%) than for male-headed households (43%) (figure 66). The gender gap in WTP indicates that gender-targeted financing mechanisms are required to enable female-headed households to benefit equally from off-grid solar solutions.

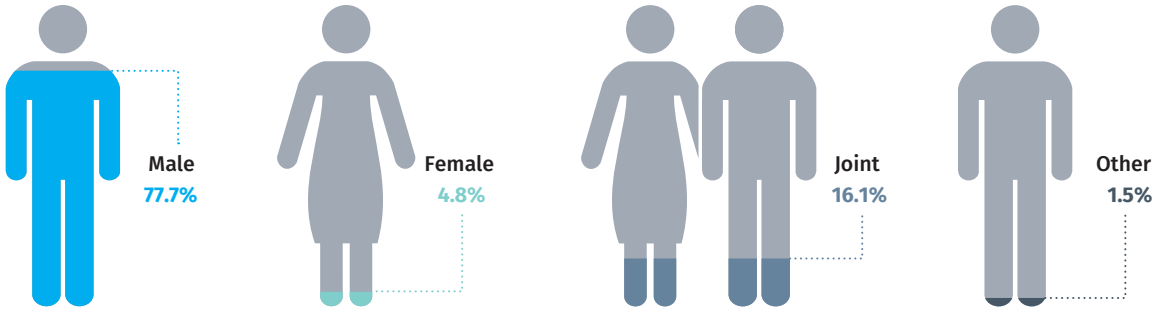
FIGURE 66 • **Female heads of household are not willing to pay for an off-grid solar solution that allows the household to reach Tier 1 unless a payment plan of at least 12 months is offered**




Note: 1 U.S. dollar = 815 Rwandan francs (average exchange rate between November 14, 2016, and December 1, 2016.

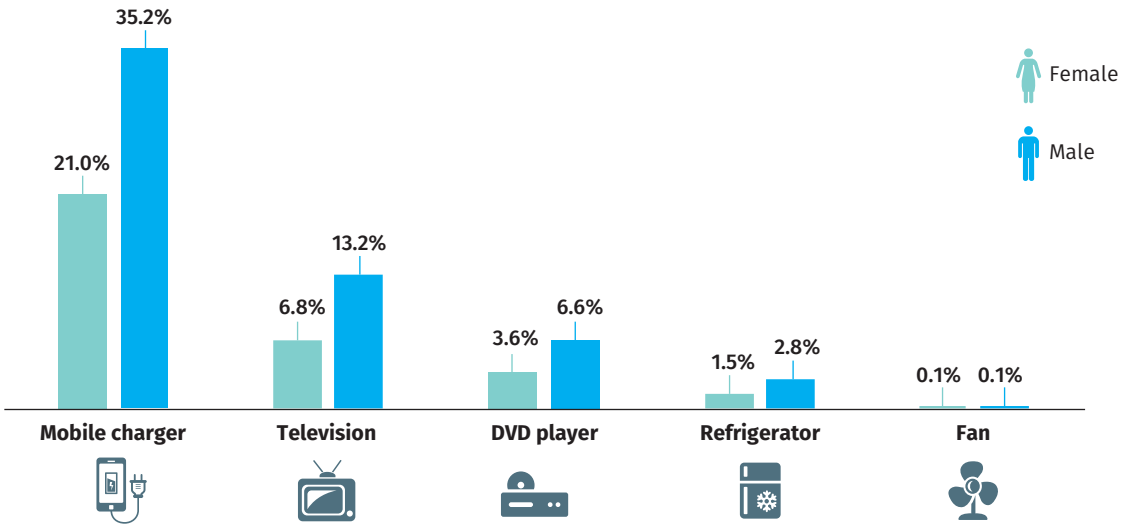
In male-headed households the decision to purchase an off-grid solar solution is usually made by men alone (figure 67). Women make the decision on their own in only 4.8% of male-headed households, and in 16.1% of male-headed household the decision is made jointly.

FIGURE 67 • **In nearly 78% of male-headed households, men decide alone to purchase household appliances**



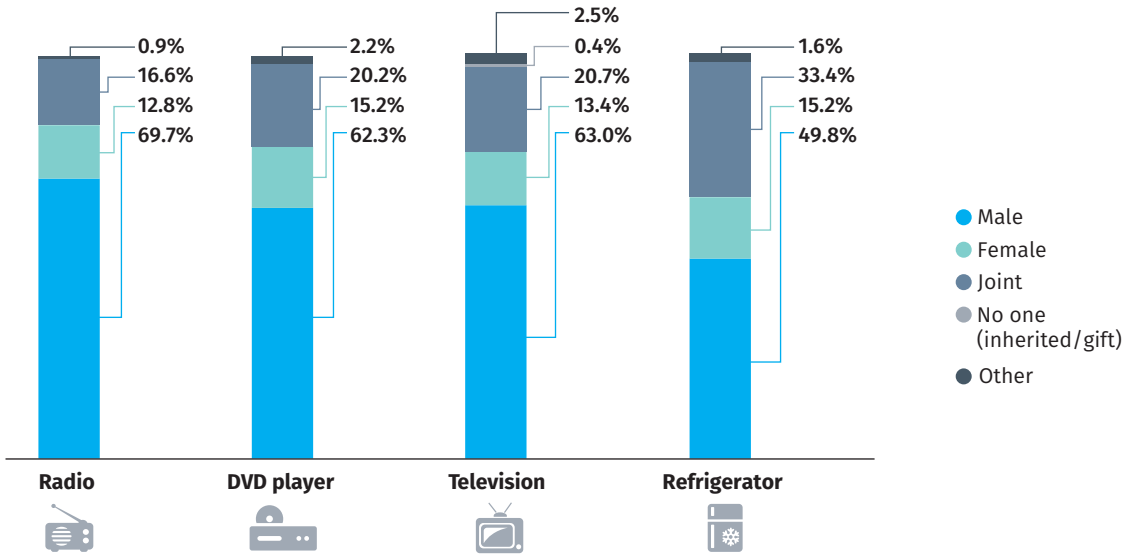

Female-headed households own fewer appliances, including phone chargers, than their male-headed households do (figure 68).

FIGURE 68 • **Appliance ownership is lower for female-headed households than for male-headed households**




In male-headed households women rarely make the decision to purchase household appliances (figure 69). Just 13%–15% of purchase decisions are made by women alone, and 17%–33% of purchase decisions are made jointly. The appliance with the highest share of women alone making the decision to buy or a joint decision to buy is a refrigerator, which suggests that women have higher decision-making power in higher income households.

FIGURE 69 • **Most of the time men decide alone to purchase household appliances**

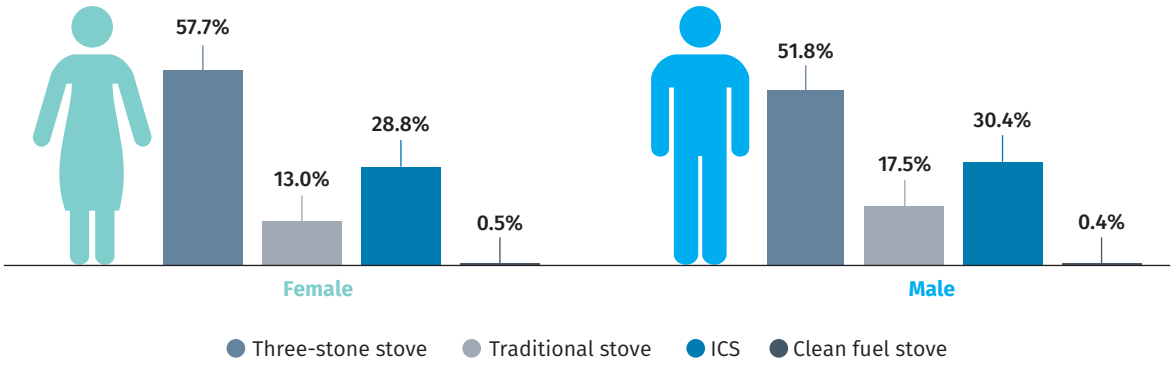



*Note:* Refers to a Neang Kangrey stove priced at $5.

## ACCESS TO MODERN ENERGY COOKING SOLUTIONS

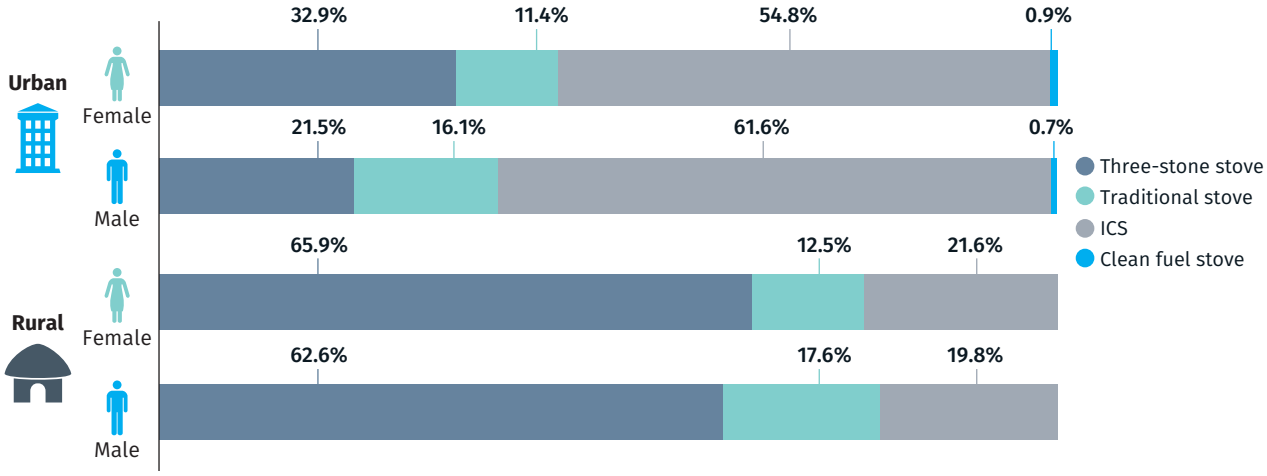
Female-headed households are more likely to use a three-stone stove than male-headed households are, and male-headed households are more likely to use a traditional stove than female-headed households are (figure 70). Female- and male-headed households are nearly equally likely to use an improved cookstove (ICS), despite the higher stove price.

FIGURE 70 • **Female- and male-headed households use similar primary cooking solutions**



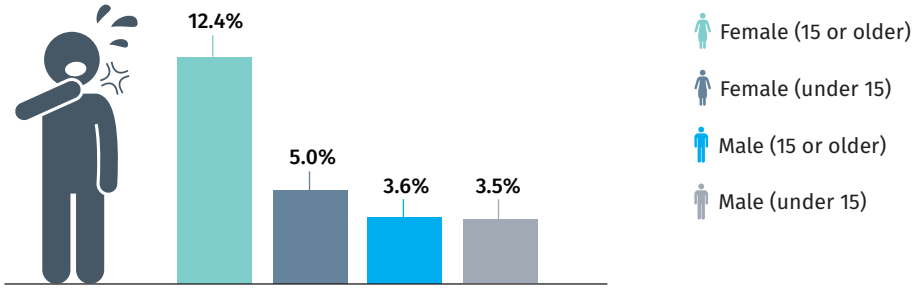

In urban areas 54.5% of female-headed households use an ICS as their primary stove, compared with 61.6% of male-headed households (figure 71). In both urban and rural areas male-headed households are less likely to use a three-stone stove as their primary stove and more likely to use an ICS.

FIGURE 71 • **In both urban and rural areas male-headed households are less likely to use a three-stone stove as their primary stove and more likely to use an improved cookstove**



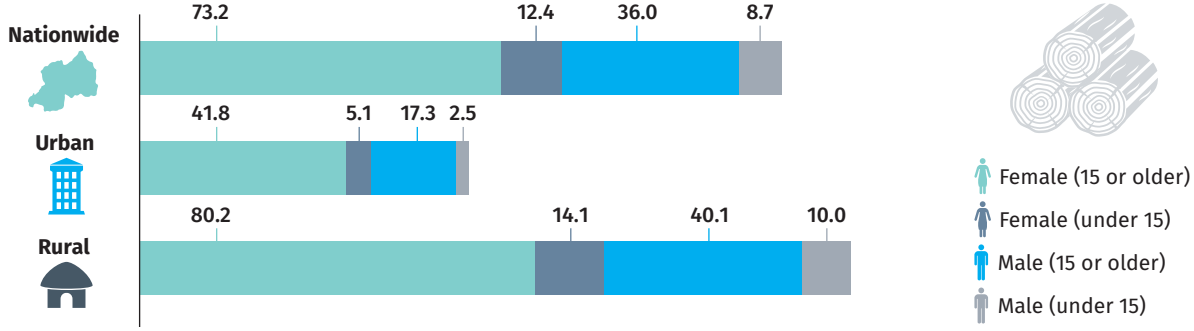

In line with the fact that women are the main cook in 78% of households, they also suffer more from health issues associated with indoor air pollution: 12.4% of women age 15 or older experienced cough in the last 14 days, compared with 3.6% of men age 15 or older (figure 72). Similarly, 5% of young girls under age 15 experienced cough in the last 14 days, compared with 3.5% of young boys under age 15.

FIGURE 72 • **Women are three times as likely as men to suffer from health issues associated with indoor air pollution, such as cough**



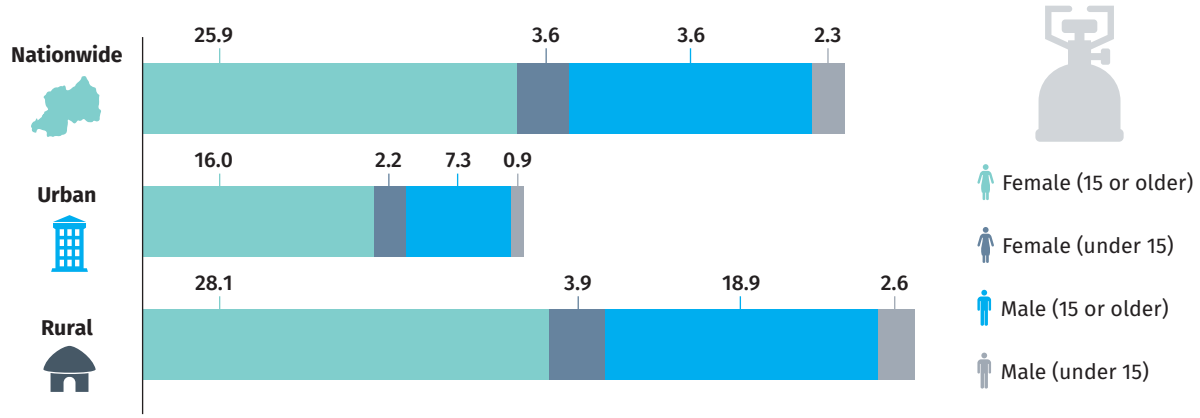

In rural areas women spend an average of 80 minutes a day acquiring fuel, compared with 40 minutes for men (figure 73). In urban areas time spent acquiring fuel is halved, but the gap between men and women remains.

FIGURE 73 • **Women spend twice as much time as men acquiring fuel for cooking**



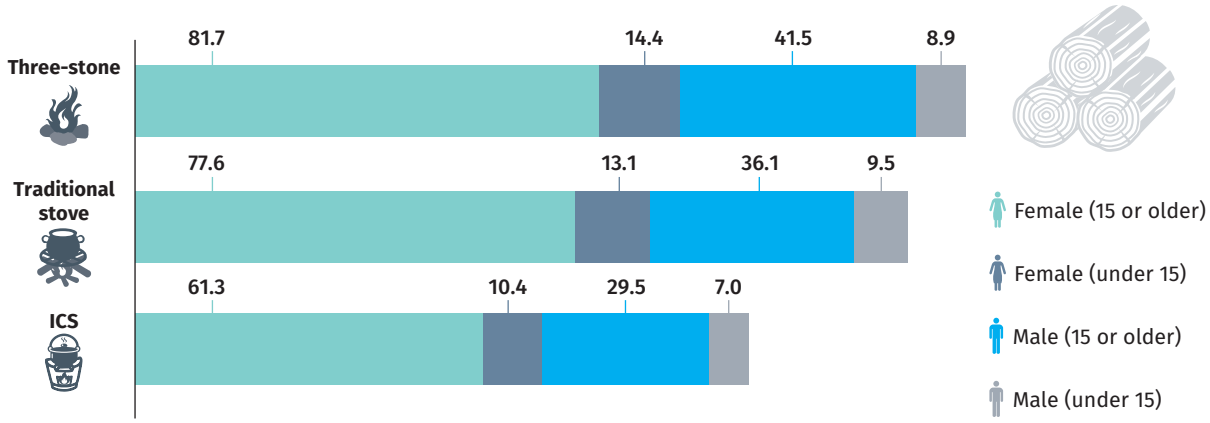
In rural areas women spend an average of 28 minutes a day preparing fuel, compared with 19 minutes for men (figure 74). The gender gap is smaller than for time spent acquiring fuel, indicating that men are more involved in activities such as chopping wood.

FIGURE 74 • **Women spend more time preparing fuel than men do**



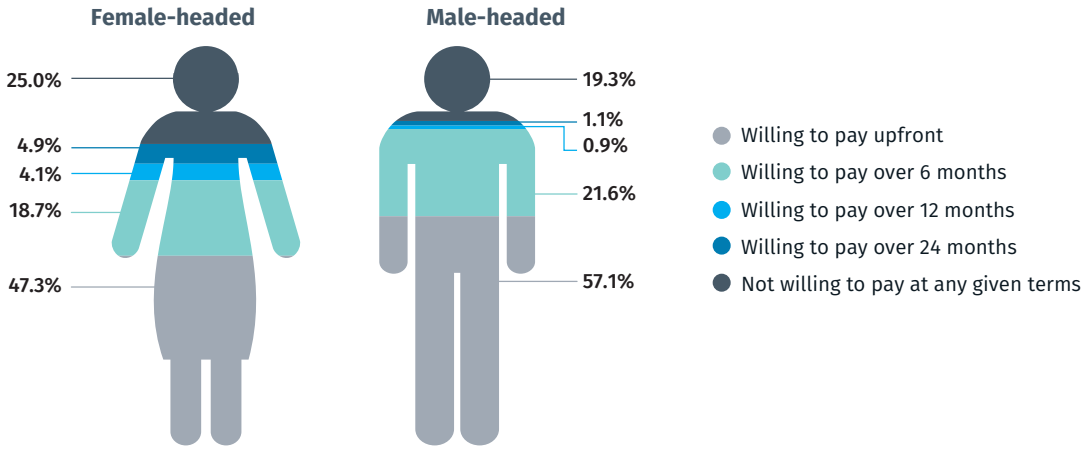

Women who use an ICS spend an average of 61 minutes a day acquiring fuel, compared with 81 minutes for women who use a three-stone stove and 78 minutes for women who use a traditional stove (figure 75).

FIGURE 75 • **Women who use an improved cookstove spend less time acquiring fuel than women who use a three-stone or traditional stove**



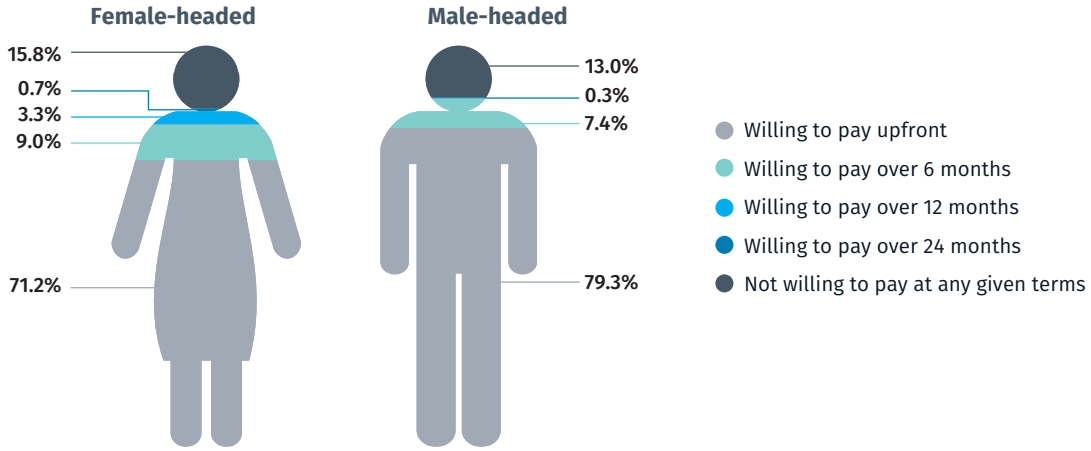

Female-headed households are less willing to pay for an ICS than male-headed households are, especially at the full price of 3,000 Rwandan francs. While WTP increases when a payment plan is offered, 25% of female-headed households will not pay for a cookstove under any given terms, compared with 19.3% of male-headed households (figure 76).

FIGURE 76 • **Female-headed households are less willing to pay for an improved cookstove at full price than male-headed households are**



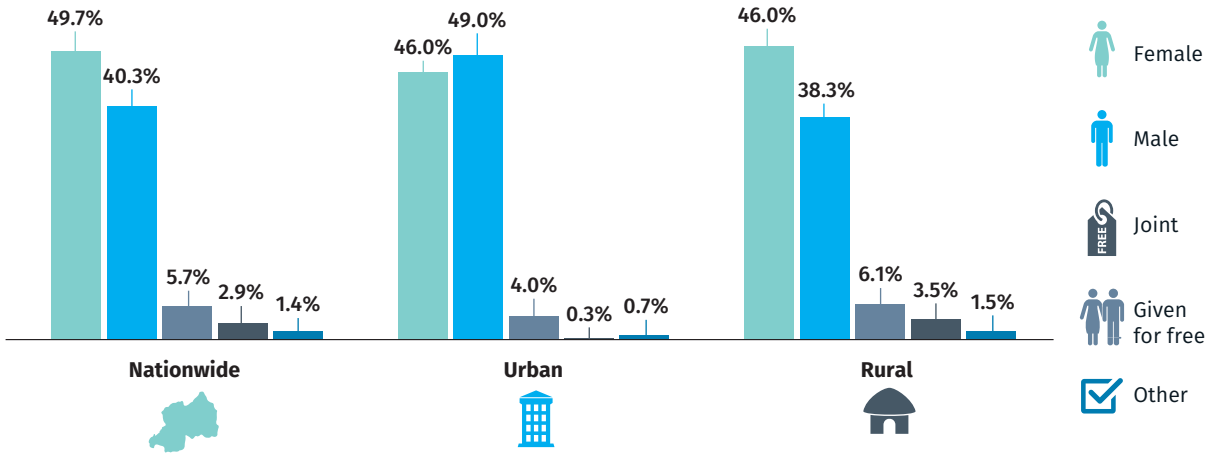

For female-headed households WTP increases significantly if the price of the ICS is reduced to 1,000 Rwandan francs: 83.5% will pay upfront or with a payment plan of 6 or 12 months (figure 77). Gender-targeted subsidies for ICSs could significantly improve access to ICSs.

FIGURE 77 • **The difference in willingness to pay between male- and female-headed households is smaller if the price of the improved cookstove is reduced to 1,000 Rwandan francs**



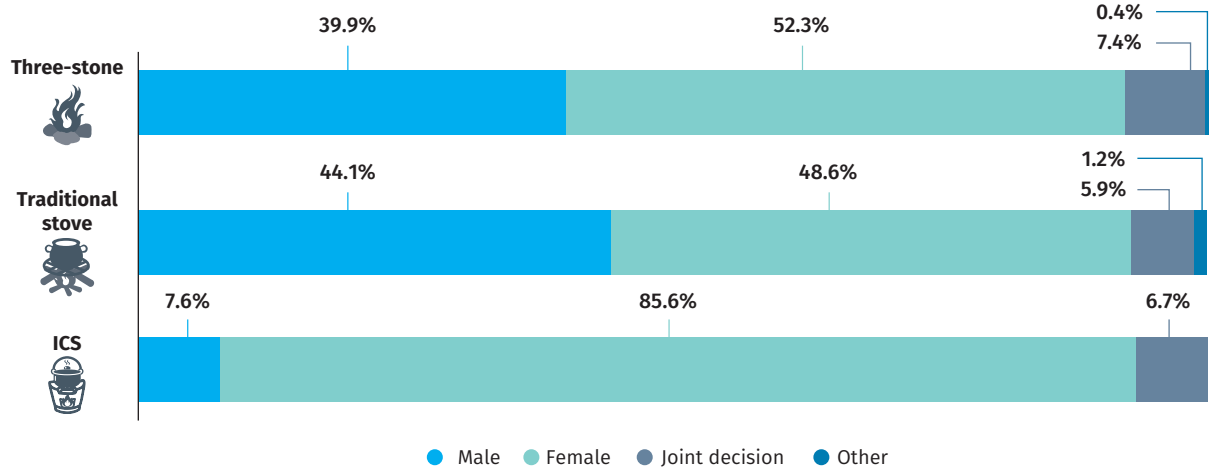

Women alone make the decision for 49.7% of cookstove purchases (figure 78). Women are more likely to be the decision-makers for cookstove purchases in rural areas, while men are more likely to be the decision-makers in urban areas.

FIGURE 78 • **The decision to purchase a cookstove is more often made by women**




Women alone make the decision for 85.6% of clean fuel stove purchases (figure 79). This could reflect stronger decision-making power for women in higher income households. Decision-making power for ICSs is more balanced between men and women, implying that cookstove-related campaigns and dissemination efforts should be adequately tailored to both a male and female audience.

FIGURE 79 • **Women alone make the decision to purchase a clean fuel stove in more than 85% of households**



# ANNEX 1:
# Multi-Tier Frameworks

## TABLE A1.1 • Multi-Tier Framework for measuring access to electricity

| ATTRIBUTES | | TIER 0 | TIER 1 | TIER 2 | TIER 3[b] | TIER 4 | TIER 5 |
|---|---|---|---|---|---|---|---|
| Capacity | Power capacity ratings (W or daily Wh) | Less than 3 W | At least 3 W | At least 50 W | At least 200 W | At least 800 W | At least 2 kW |
| | | Less than 12 Wh | At least 12 Wh | At least 200 Wh | At least 1 kWh | At least 3.4 kWh | At least 8.2 kWh |
| | Services | | Lighting of 1,000 lmhr per day | Electrical lighting, air circulation, television, and phone charging are possible | | | |
| Availability[a] | Daily Availability | Less than 4 hours | At least 4 hours | | At least 8 hours | At least 16 hours | At least 23 hours |
| | Evening Availability | Less than 1 hour | At least 1 hour | At least 2 hours | At least 3 hours | At least 4 hours | |
| Reliability | | More than 14 disruptions per week | | | At most 14 disruptions per week or At most 3 disruptions per week with total duration of more than 2 hours" | (> 3 to 14 disruptions / week) or ≤ 3 disruptions / week with > 2 hours of outage | At most 3 disruptions per week with total duration of less than 2 hours |
| Quality | | Household experiences voltage problems that damage appliances | | | | Voltage problems do not affect the use of desired appliances | |
| Affordability | | Cost of a standard consumption package of 365 kWh per year is more than 5% of household income | | | Cost of a standard consumption package of 365 kWh per year is less than 5% of household income | | |
| Formality | | No bill payments made for the use of electricity | | | | Bill is paid to the utility, prepaid card seller, or authorized representative | |
| Health and Safety | | Serious or fatal accidents due to electricity connection | | | | Absence of past accidents | |

*a.* Previously referred to as "Duration" in the 2015 Beyond Connections report, this MTF attribute is now referred to as "Availability," examining access to electricity through levels of "Duration" (day and evening). Aggregate tier is based on lowest tier value across all attributes

** Color signifies tier categorization.*

*Source:* Bhatia and Angelou 2015.

## TABLE A1.2 • **Multi-Tier Framework for measuring access to modern energy cooking solutions**

| ATTRIBUTES | | TIER 0 | TIER 1 | TIER 2 | TIER 3 | TIER 4 | TIER 5 |
|---|---|---|---|---|---|---|---|
| **Cooking Exposure** [a] | Emission: Fuel | Firewood, dung, twigs, leaves, rice husks, processed biomass pellets or briquette, charcoal, kerosene | | | | Biogas, ethanol, high quality processed biomass pellets or briquettes | Electricity, solar, LPG |
| | Emission: Stove Design | Three-stone fire, tripod, flat mud ring, traditional charcoal stove | Conventional or old generation ICS | ICS+ chimney, rocket stove or ICS + insulation | Rocket stove with high insulation or with chimney, advanced insulation charcoal stoves | Rocket stove with chimney (well sealed), Rocket Stove gasifier, Advanced secondary air charcoal stove, forced air | |
| | Ventilation: Volume of Kitchen [b] | Less than 5 $m^3$ | More than 5 $m^3$ | More than 10 $m^3$ | More than 20 $m^3$ | More than 40 $m^3$ | Open air |
| | Ventilation: Structure | No opening except for the door | 1 window | More than 1 window | Significant openings (large openings below or above height of the door) | Veranda or a hood is used to extract the smoke | Open air |
| | Ventilation Level | Bad | | | Average | Good | |
| | Contact Time [c] | More than 7.5 hours | Less than 7.5 hours | Less than 6 hours | Less than 4.5 hours | Less than 3 hours | Less than 1.5 hours |
| | | Bad | | | Average | Good | |
| **Cookstove Efficiency** | ISO's Voluntary Performance Targets (TBC) | Less than 10% | More than 10% | More than 20% | More than 30% | More than 40% | More than 50% |
| **Convenience** | Fuel acquisition (through collection or purchase) and preparation time (hours per week) | More than 7 hours | | Less than 7 hours | Less than 3 hours | Less than 1.5 hours | Less than 0.5 hour |
| | Stove preparation time (minutes per meal) | More than 15 minutes | | Less than 15 minutes | Less than 10 minutes | Less than 5 minutes | Less than 2 minutes |
| **Safety of Primary Cookstove** | | *Serious accidents over the past 12 months* | | | | No serious accidents over the past year | |
| **Affordability** [d] | | Levelized cost of cooking solution (fuel) more than 5% of household income | | | | Levelized cost of cooking solution (fuel) less than 5% of household income | |
| **Fuel Availability** | | *Primary fuel available less than 80% of the year* | | | | Primary fuel is readily available 80% of the year. | Primary fuel is readily available throughout the year |

a. Determined by combination of fuel and stove design, ventilation of cooking space, and contact time

b. Not used in the analysis of Cooking Exposure in Cambodia.

c. Not used to calculate an individual stove's tier for Cooking Exposure but used to weight each stove's tier for Cooking Exposure in the calculation of a household's tier for Cooking Exposure.

d. In this report, cookstove cost was not considered when calculating the Affordability tier due to data limitations which hindered making this calculation.

# ANNEX 2:
# Cookstove Typology

## Cookstoves found in Rwanda

- Clean fuel stove
- Traditional stove
- Improved stove
- Three-stone stove

**Gas (LPG) stove and Electrical stove**

**Biogas stoves**

**Rocket stove**

**Gisafuriya**

**All metal stove**

**Round mud stove**

**Double and triple movable metal charcoal stove**

**Canamakeivuguruye**

**Darfour 1**

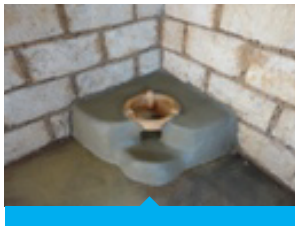
**Darfour 2**

**Saw dust/rice husks stove**

**Double and triple movable *(Canamakeitavuguruye)***

**Canamakeitavuguruye**

**Fixed Canamakeitavuguruye**



**Canarumwe**

**Three-stone stove**

# ANNEX 3:
# Sampling strategy

The sample size was designed to obtain precise estimates of the percentage of households in each tier at the national and zonal (urban and rural) levels. This annex first discusses the factors taken into consideration in determining the sample size, then justifies the proposed sample size, explains the stratification process, provides the sample frame, and discusses the structure of the sample and the sampling procedure.

## DETERMINING THE SAMPLE SIZE

There are three major issues in determining the appropriate sample size for a survey:

- The precision of the survey estimates (sampling error).
- The quality of the data collected by the survey (nonsampling error).
- The cost in time and money of data collection, processing, and dissemination.

### *The precision of the survey estimates*

The precision of a survey estimate is crucial in determining the sample size. By definition, a sample from a population is not a complete picture of it. However, an appropriately drawn random sample of reasonable size can provide a clear picture of the characteristics of that population, certainly sufficient for policy implications or decision-making. From a sample of households, one can collect data and generate a sample (or survey) estimate of a population parameter. The population parameter value of characteristics of interest is generally unknown.

The formula to calculate sample size is:

$$n = \frac{z^2 r\,(1-r)\,fk}{e^2} = \frac{z^2 r\,(1-r)[1+\rho(m-1)]k}{e^2} \quad \text{(A3.1)}$$

where:

- $n$ is the sample size in terms of number of households to be selected.
- $z$ is the z-statistic corresponding to the confidence level desired. The commonly used level of confidence is 95%, for which $z$ is 1.96.
- $r$ is the estimate of the indicator of interest to be measured by the survey.
- $f$ is the sample design effect, which represents how much larger the squared standard error of a two-stage sample is than the squared standard error of a simple random sample of the same

size. Its default value for infrastructure interventions is 2.0 or higher, which should be used unless empirical data from similar surveys suggest a different value. The sample design effect has been included in equation A3.1 and is defined as: $f = 1 + \rho\ (m - 1)$.

- $\rho$ is the intracluster correlation coefficient, which measures the tendency of households within the same primary sampling unit to behave alike with respect to the variable of interest. ρ is almost always positive and normally ranges from 0 (no intracluster correlation) to 1 (when all households in the same primary sampling unit are exactly alike). For many variables of interest in Living Standards Measurement Surveys, ρ ranges from 0.01 to 0.10, but it can be 0.5 or larger for infrastructure-related variables.
- $m$ is the average number of households selected per primary sampling unit.
- $k$ is a factor accounting for nonresponse. Households are not selected using replacement.[29] Thus, the final number of households interviewed will be slightly less than the original sample size eligible for interviewing. For most developing countries the nonresponse rate is 10% or less. So a value of 1.1 (= 1 + 10%) for $k$ would be conservative.
- $e$ is the margin of error, sampling errors, or level of precision. It depends mostly on the size of the sample and very little on the size of the population.

### *The quality of the data collected by the survey*

In addition to sampling errors, data from a household survey are vulnerable to other inaccuracies from causes as diverse as refusals, respondent fatigue, measurement errors, interviewer errors, or the lack of an adequate sample frame. These are collectively known as nonsampling errors. Nonsampling errors are harder to predict and quantify than sampling errors, but good planning, management, and supervision of field operations are the most effective ways to keep nonsampling errors under control. Moreover, management and supervision are likely to be more difficult for larger samples than for smaller ones (Grosh and Muñoz 1996). Thus, nonsampling errors are generally expected to increase with sample size.

### *The cost of data collection, processing, and dissemination*

The sample size can affect the cost of survey implementation dramatically. It can also affect the time in which the data can be collected, processed, and made available for analysis. The availability of the firm conducting the survey and cost for each country also affect the total cost of survey implementation. Thus, the cost of data collection, processing, and dissemination should be considered when determining the sample size for each country.

[29] The sample size should reflect the experience from the country in question. Hence, certain households may be replaced in particular countries, if needed. In this case, a different weight will be considered when preparing the estimates.

## SAMPLE SIZE CALCULATION

Sample surveys are appropriate for collecting national and relatively large geographic domain-level data on topics that need to be extensively explored. The main purpose of this survey is to identify and analyze the energy access tiers (Tiers 0–5) at both the national and zonal (urban and rural) levels. Equation A3.1 indicates the formula to calculate the sample size. Given that the concept of the MTF has been recently introduced and the aim of this global survey is to establish the baseline of monitoring energy access globally, the indicator of interest ($r$) is unknown. Thus, the sample size for each selected country is calculated using the prevalence rate of 50% as the most conservative choice and to achieve the minimum margin of error (standard errors are inversely proportional to the square root of the sample size: $e=z^*\sigma\sqrt{n}$). Since the nonresponse rate is typically under 10% in developing countries (United Nations 2011), a value of 1.1 for $k$ (nonresponse rate) would be considered a conservative choice (United Nations 2011). The number of households selected per primary sampling unit ($m$) is 12 (Demographic and Health Surveys normally visit 20–35 households per primary sampling unit, while socioeconomic surveys rely on 6–16 households per primary sampling unit); however, it can be modified depending on the homogeneity in a given primary sampling unit and community. Due to the characteristics of infrastructure variables and indicator, .45 was selected for the intracluster relation coefficient ($\rho$); consequently, the design effect ($f$) will be equal to 6 ($f = 1 + \rho\ (m - 1)$) (Grosh Muñoz 1996).

The number of analytic domains also has a large impact on the sample size and strategy. An analytic domain can be defined as the analytic subgroups for which equally reliable data are required for the analysis. The sample size is increased by a factor equal to the number of domains desired because it does not depend on the size of the population itself.

When defining a strategy to calculate the sample size for the selected countries, two approaches were considered: one calculating first the national sample size as one analytic domain and then allocating the sample size proportional to urban and rural population; the other calculating first the sample size using the distribution between urban and rural as two analytic domains and then adding these two values to obtain the national sample size. These two approaches have taken into consideration data on sample size by a margin of error, ranging from approximately 4% to 5.5% at the national level and from nearly 5% to 11% at the zonal level. Considering the results obtained, the second approach was used, which for a margin of error of 6% at the urban and rural levels gives a national sample size of roughly 3,300 households, with an error of 4.2%.

Within each cluster/state, primary sampling units were selected with a probability proportional to their measure of size, and households were selected with equal probability within each primary sampling unit (the definition of this approach is reported in United Nations 2011).

## STRATIFICATION

Once the sample size was determined, the stratification strategy—the process of dividing households into homogeneous smaller groups called strata and then sampling separately for each stratum following certain rules—was developed. Stratification often improves the sample's representativeness

by reducing sampling error. Each stratum is treated as an independent population. Sampling weights need to be used to analyze the data reflecting the stratification strategy adopted. This section provides guidelines on stratification for the MTF global survey.

The guidelines provided in this section are general, and ideally, this is what the stratification of the sample for the selected countries aims to achieve. However, these guidelines may not apply identically to all 17 countries where MTF surveys will be implemented because countries may vary in geographical structure and population distribution within and across geographic units.

It is useful to review the criteria that guide the overall stratification strategy. This stratification is important for the tier analysis and capturing the diversity in different energy solutions and services. The criteria are:

1 | Equal allocation between urban and rural areas. This is established during sample size calculation. This will help conduct disaggregated and in-depth analyses for urban and rural areas that are statistically sound.

2 | While the parameters of interest for the MTF study are access to electricity and access to modern energy cooking solutions, only access to electricity is used in the stratification. To make the analysis representative of the underlying population, sampling weights are applied to reflect the actual distribution of grid-connected households and households with access to modern energy cooking solutions in the population.

3 | A sample will have distribution of grid users and non-users. This will help us conduct in-depth analysis of both groups. As mentioned, sample weights will be used in the analysis to compensate for oversampling of either group.

4 | Twelve households will be sampled from each village or urban block (PSU).

## SAMPLING FRAME

The sampling frame is the complete list of all sampling units in the target population. In this case the perfect sampling frame will use the 2012 Rwanda Population and Housing Census because it covers the entire survey area, without omission or overlap. The census frame is also ideal since it is as current, complete, and accurate as any household list could be. Due to its geographic arrangement, stratifying it for proper geographical distribution of the sample was relatively straightforward.

TABLE A3.1 • **Distribution of villages by province, locality, and electrification status**

| City or province | Locality | Village not electrified[a] | Village electrified | Total |
|---|---|---|---|---|
| Kigali City | Urban | 11 | 750 | 761 |
| | Rural | 238 | 162 | 400 |
| Southern Province | Urban | 10 | 188 | 198 |
| | Rural | 2,830 | 473 | 3,303 |

| City or province | Locality | Village not electrified[a] | Village electrified | Total |
|---|---|---|---|---|
| Western Province | Urban | 7 | 316 | 323 |
| | Rural | 2,572 | 715 | 3,287 |
| Northern Province | Urban | 2 | 131 | 133 |
| | Rural | 2,084 | 527 | 2,611 |
| Eastern Province | Urban | 18 | 171 | 189 |
| | Rural | 2,561 | 1,036 | 3,597 |
| **Total** | | **10,333** | **4,469** | **14,802** |

a. Based on the 2012 Rwanda Population and Housing Census, non-electrified villages where less than 3% of households use electricity were identified.

## STRUCTURE OF THE SAMPLE AND THE SAMPLING PROCEDURE

The sample for the survey was a stratified sample selected in two stages. The first stage selected 275 villages in the sampling frame; the second stage selected 12 households in each sample village. It is important to divide the sampling frame of villages into strata in which households are homogeneous. Stratification can increase the efficiency of the sample for the survey. Stratification is achieved by separating urban and rural villages and electrified and non-electrified villages in each province; the urban and rural and electrified and non-electrified villages in each province each form a sampling stratum. In total, 20 sampling strata were created. Samples were selected independently in each sampling stratum, by selection of one stage.

In the first stage, 275 villages were selected using the probability proportional to size selection procedure for the entire country. In the second stage, in each selected village a fixed number of 12 residential households were selected among the residential households listed. Thus, 3,300 households were selected to be enumerated.

TABLE A3.2 • **Sample allocation in the first and second stage by province, locality, and electrification status**

| Province | Urban | | | | Rural | | | | Nationwide | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Electrified | | Not electrified | | Electrified | | Not electrified | | | |
| | Villages | HHs | Villages | HHs | Villages | HHs | Villages | HHs | Villages | HHs |
| **Kigali City** | 57 | 684 | 11 | 132 | 9 | 108 | 2 | 24 | 79 | 948 |
| **Southern Province** | 8 | 96 | 10 | 120 | 12 | 144 | 17 | 204 | 47 | 564 |
| **Western Province** | 11 | 132 | 7 | 84 | 17 | 204 | 13 | 156 | 48 | 576 |
| **Northern Province** | 5 | 60 | 2 | 24 | 9 | 108 | 12 | 144 | 28 | 336 |
| **Eastern Province** | 6 | 72 | 18 | 216 | 37 | 444 | 12 | 144 | 73 | 876 |
| **Total** | **87** | **1,044** | **48** | **576** | **84** | **1,008** | **56** | **672** | **275** | **3,300** |

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