1. Basics of Electricity, Energy Access, and Off-Grid Solar

Foundations of Off-Grid Solar in Haiti

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Overview

Foundations of Off-Grid Solar in Haiti

1. Basics of Electricity, Energy Access, and Off-grid Solar
2. Key Products and Quality Assurance for Off-grid Solar
3. Market Potential for Off-grid Solar in Haiti
4. Understanding Off-Grid Solar Customers
5. Designing and Modeling Off-Grid Solar Systems
6. Installation, Operations, and Maintenance of Off-Grid Solar Systems
7. Elements of Business Models for Off-Grid Solar
8. Financial Modeling for Off-grid Solar
9. Gender and Off-Grid Solar
10. Productive Use of Energy
11. Climate Adaptation and Resilience

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Overview

The objectives of this module are to provide an overview and key resources/tools for understanding:

- What are the basics of electricity and solar energy? (Go to section)
- What is energy access and off-grid solar? (Go to section)
- How is energy access measured? (Go to section)

What are the basics of electricity and solar energy?

Electricity Basics (Power vs. Energy)

Power

- **Definition:** The “ability to do work”
- **Units:** “Watts” (W)
- **Calculated:** Power (W) = Voltage (V) * Current (A)
- **How you will generally see it:** Ratings for how much electricity an appliance can potentially produce (e.g., 250 W solar panel) or how much electricity an appliance will potentially consume (e.g., 10 W lightbulb)

Energy

- **Definition:** Power over a period of time
- **Units:** “Watt-hours” (Wh)
- **Calculated:** Energy (Wh) = Power (W) * Time (t)
  - The energy consumed by a 10 W lightbulb turned on for 2 hours = 10 W * 2 hours = 20 Wh or .020 kilowatt-hours (kWh)
  - The energy consumed by a 360 W freezer plugged in for 10 hours = 360 W * 10 hours = 3600 Wh or 3.6 kilowatt-hours (kWh)
- **How you will generally see it:** Total consumption of electricity from an appliance (e.g., 10 Wh); electricity tariff (e.g., $0.36 / kWh)

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Electricity Units

Power

Watt (W)	Kilowatt (kW)	Megawatt (MW)	Gigawatt (GW)	Terrawatt (TW)
	1000 Watts	*1000 Kilowatts*	*1000 Megawatts*	*1000 Gigawatts*

Watt-hour (Wh)	Kilowatt-hour (kWh)	Megawatt-hour (MWh)	Gigawatt-hour (GWh)	Terrawatt-hour (TWh)
	1000 Watt-hours	*1000 Kilowatt-hours*	*1000 Megawatt-hours*	*1000 Gigawatt-hours*

Energy

If you are converting to a bigger unit (going from left to right), **divide** by 1000 per step;

If you are converting to a smaller unit (going from right to left), **multiply** by 1000 per step

Ohm’s Law: Voltage, Current, and Resistance

Voltage (V)

- The difference in charge between two points
- Measured in volts (V)

Current (I)

- The rate at which charge is flowing
- Measured in amperes (A)

Resistance (R)

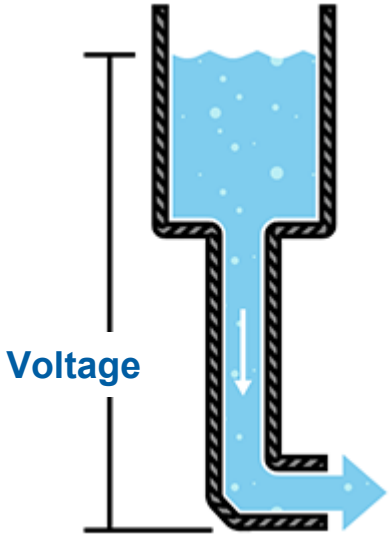
- A material's tendency to resist the flow of charge (current).
- Measured in Ohms (Ω)

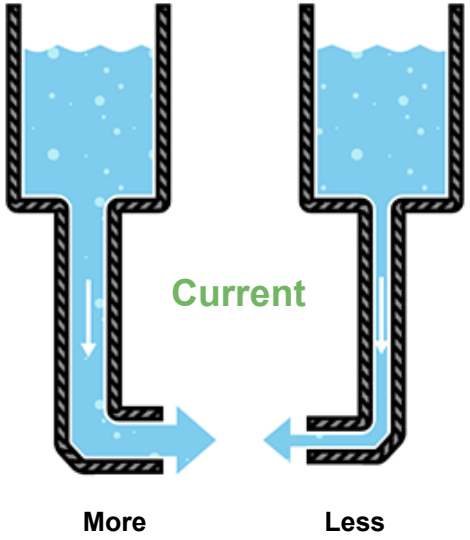
Ohm’s law

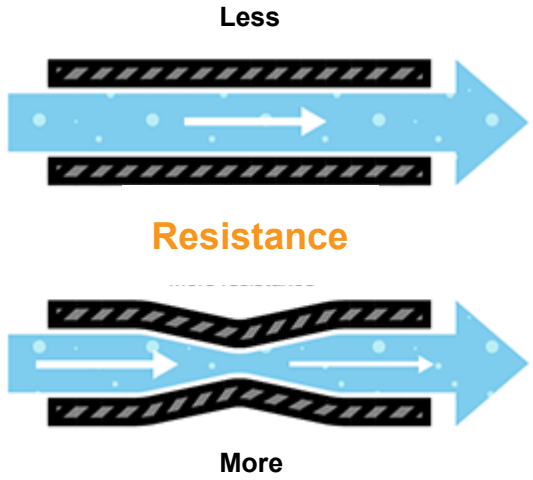
V = I * R

Voltage = Current * Resistance

An illustration of the Ohm’s law concepts using a water tank





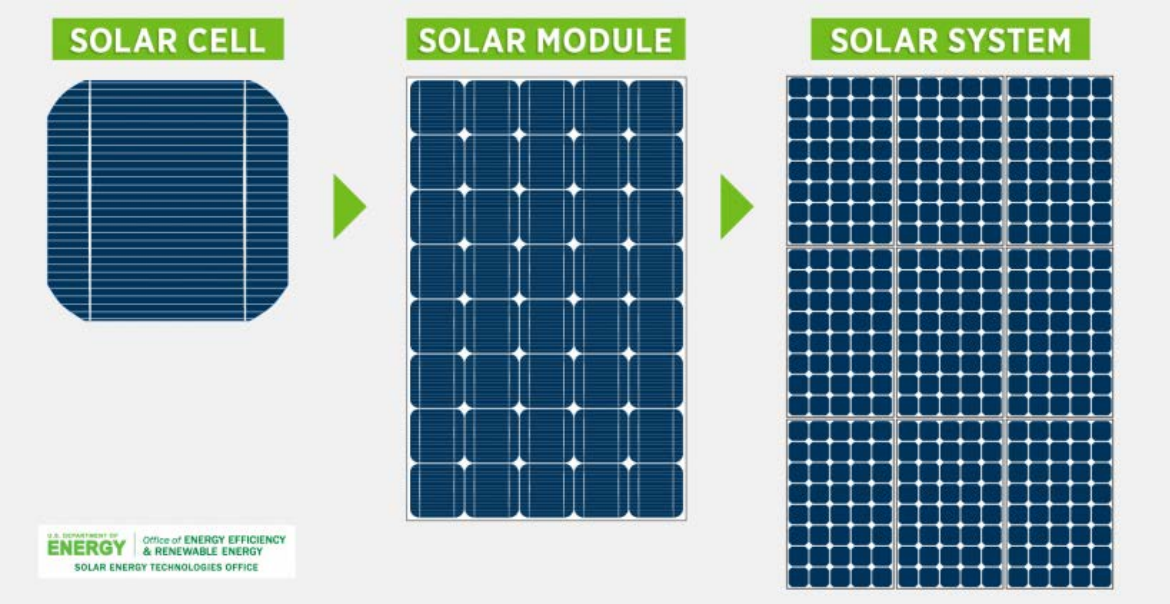


Source: *Intro to Voltage, Current, Resistance*

Solar Photovoltaics (PV)

Photo/light + voltage = photovoltaic

Solar panels absorb radiation from the sun's rays and generate electricity. They are made up of several layers of solar cells. When sunlight strikes the surface of these cells, they absorb photons and release electrons, which are then captured and converted to make electricity.



Cell – Solar cells absorb sunlight as a source of energy to generate electricity.

Module (panel) – A solar module is a single photovoltaic panel that is an assembly of connected solar cells.

System (Array) – A group of panels to generate electricity is known as a PV array or PV System.

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Solar Panel Spec Sheets

Solar photovoltaic (PV) panels and systems are given a rating in watts peak (Wp) which is the rate at which they generate energy at peak performance (**higher ratings = more electricity**)

To estimate electricity production:

Energy = Module Area * Module Efficiency * Average Solar Irradiance * Performance Ratio (losses)

An example calculation can be seen in the following slides

Solar Panel Rating (Wp)

Module Size (m^2)

Module Efficiency (%)

Sunmodule™

SW 250 mono / Version 2.0 and 2.5 Frame

PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)*

		SW 250
Maximum power	P_{max}	250 Wp
Open circuit voltage	V_{oc}	37.8 V
Maximum power point voltage	V_{mpp}	31.1 V
Short circuit current	I_{sc}	8.28 A
Maximum power point current	I_{mpp}	8.05 A

*STC: 1000W/m², 25°C, AM 1.5

PERFORMANCE AT 800 W/m², NOCT, AM 1.5

		SW 250
Maximum power	P_{max}	183.3 Wp
Open circuit voltage	V_{oc}	34.6 V
Maximum power point voltage	V_{mpp}	28.5 V
Short circuit current	I_{sc}	6.68 A
Maximum power point current	I_{mpp}	6.44 A

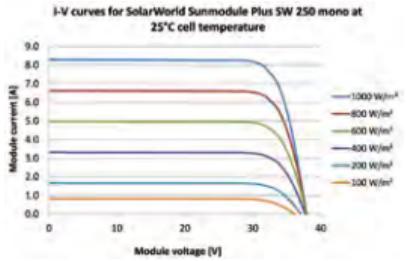
Minor reduction in efficiency under partial load conditions at 25°C: at 200W/m², 95% (+/-3%) of the STC efficiency (1000 W/m²) is achieved.

THERMAL CHARACTERISTICS

NOCT	46 °C
TC I_{sc}	0.004 %/K
TC V_{oc}	-0.30 %/K
TC P_{mpp}	-0.45 %/K
Operating temperature	-40°C to 85°C

COMPONENT MATERIALS

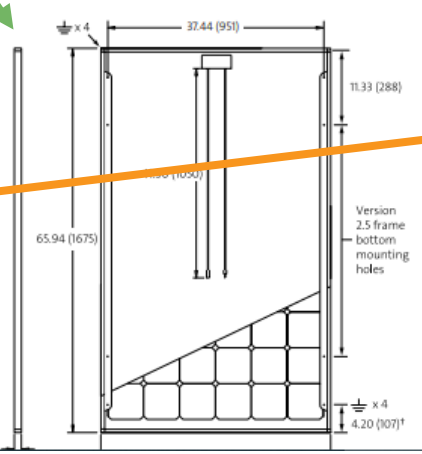
Cells per module	60
Cell type	Mono crystalline
Cell dimensions	6.14 in x 6.14 in (156 mm x 156 mm)
Front	tempered glass (EN 12150)
Frame	Clear anodized aluminum
Weight	46.7 lbs (21.2 kg)



SYSTEM INTEGRATION PARAMETERS

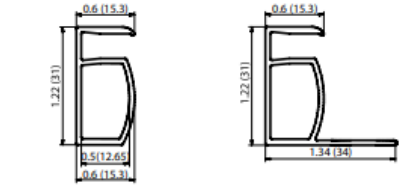
Maximum system voltage SC II		1000 V
Max. system voltage USA NEC		600 V
Maximum reverse current		16 A
Number of bypass diodes		3
UL Design Loads*	Two rail system	113 psf downward 64 psf upward
UL Design Loads*	Three rail system	170 psf downward 64 psf upward
IEC Design Loads*	Two rail system	113 psf downward 50 psf upward

*Please refer to the Sunmodule installation instructions for the details associated with these load cases.



ADDITIONAL DATA

Power tolerance[3]	-0 Wp / +5 Wp
J-Box	IP65
Connector	MC4
Module efficiency	14.91 %
Fire rating (UL 790)	Class C



VERSION 2.0 FRAME
- Compatible with "Top-Down" mounting methods
- Grounding Locations:

VERSION 2.5 FRAME
- Compatible with both "Top-Down" and "Bottom" mounting methods
- Grounding Locations:

Source: *Solarypsi Sunmodule Spec Sheet, Tritec Energy PV Guide*

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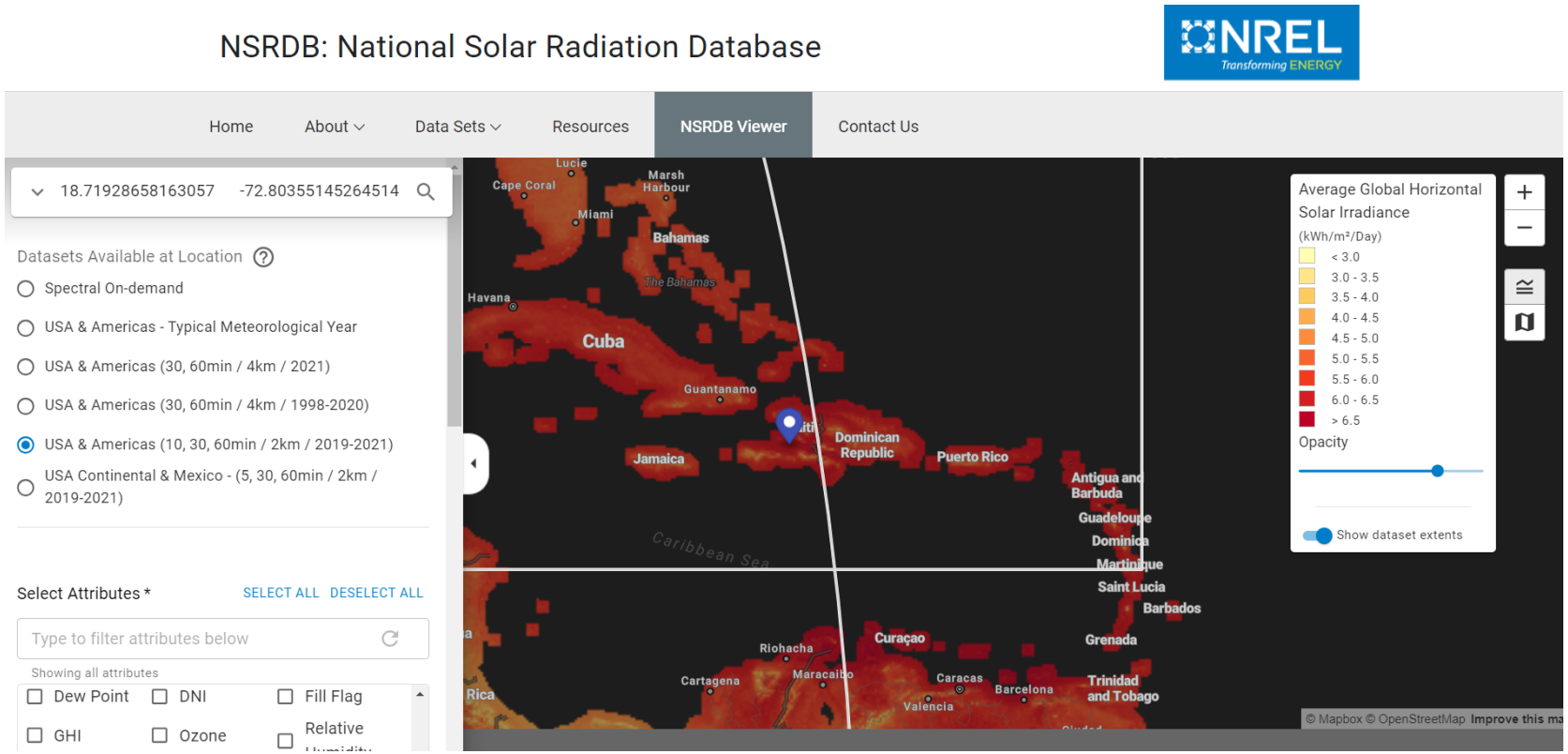
Average Solar Radiation

The National Solar Radiation Database provides in depth 2km resolution solar potential data for Haiti and the Caribbean



Source: National Solar Radiation Database

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Example

Assuming a standard 250W panel with an area of 1.65 m^2, an average efficiency of 15%, and an average performance ratio of 0.85, expected daily solar output in Haiti is estimated as:

Solar Radiation		Conversion of Megajoules (MJ - a measure of energy) to kWh (3.6 MJ/kWh)		Module Area		Module Efficiency		Performance Ratio		
20.13	$\frac{MJ}{m^2 * day}$	0.2778	$\frac{kWh}{MJ}$	1.65	m^2	15	%	0.85	=	1.176 $\frac{kWh}{Day}$

Source: National Solar Radiation Database

Additional Resources for Electricity/Solar Basics

Electricity

US Department of Energy: Electricity 101

EATON “Electricity 101 Basics Series”

Solar

National Renewable Energy Laboratory – “Solar Basics”

US Department of Energy “Solar PV 101”

US Department of Energy “How does solar work”

International Renewable Energy Agency “Solar Energy Transition Basics”

FORME Solar “Beginners Guide to Solar”

AE-Solar “Reading a Solar Panel Datasheet”

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What is energy access and off-grid solar?

Sustainable Development Goal 7 (SDG7)

Affordable, reliable, sustainable and modern energy for all by 2030.

SDG 7.1 - Access to energy

By 2030, ensure universal access to affordable, reliable and modern energy services.

- **Indicator 7.1.1:** Proportion of population with access to electricity.
- **Indicator 7.1.2:** Proportion of population with primary reliance on clean fuels and technology.

SDG 7.2 - Renewable energy

By 2030, increase substantially the share of renewable energy in the global energy mix.

- **Indicator 7.2.1:** Renewable energy share in the total final energy consumption.

SDG 7.3 - Energy efficiency

By 2030, double the global rate of improvement in energy efficiency.

- **Indicator 7.3.1:** Energy intensity measured in terms of primary energy and GDP.

Source: UN Sustainable Development Goal 7

Global Energy Access Deficit

- In 2021, 91 percent of the global population had access to electricity, leaving **675 million people still unserved.**
- Without acceleration, an expected **660 million people will still be unserved in 2030** (92% access).
- Between 2010 and 2020, **1.3 billion people became connected** — an average of 125 million people per year (outpacing annual population growth of 83 million people).

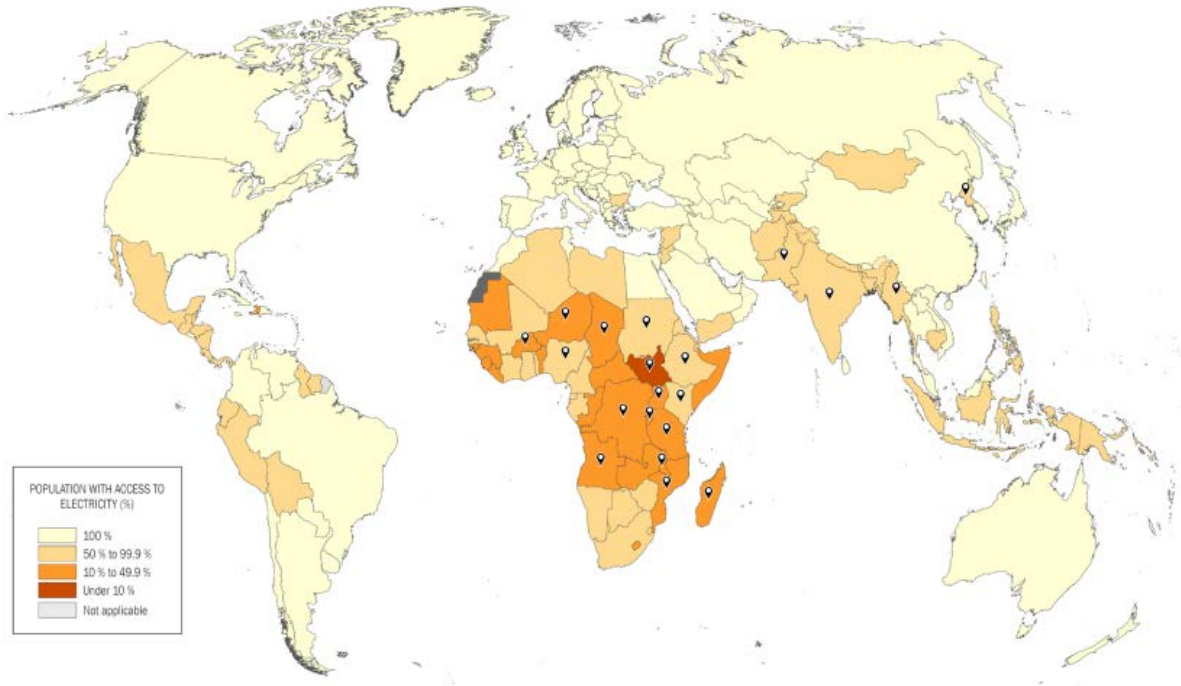

Figure 1.1 • Percentage of population with access to electricity

Source: SDG7 Tracking Report 2023

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Electricity Consumption is Highly Correlated with Income

Figure 10: The Strong Relationship Between Electricity Consumption and Income

Source: [GEAPP P3 Report 2022]

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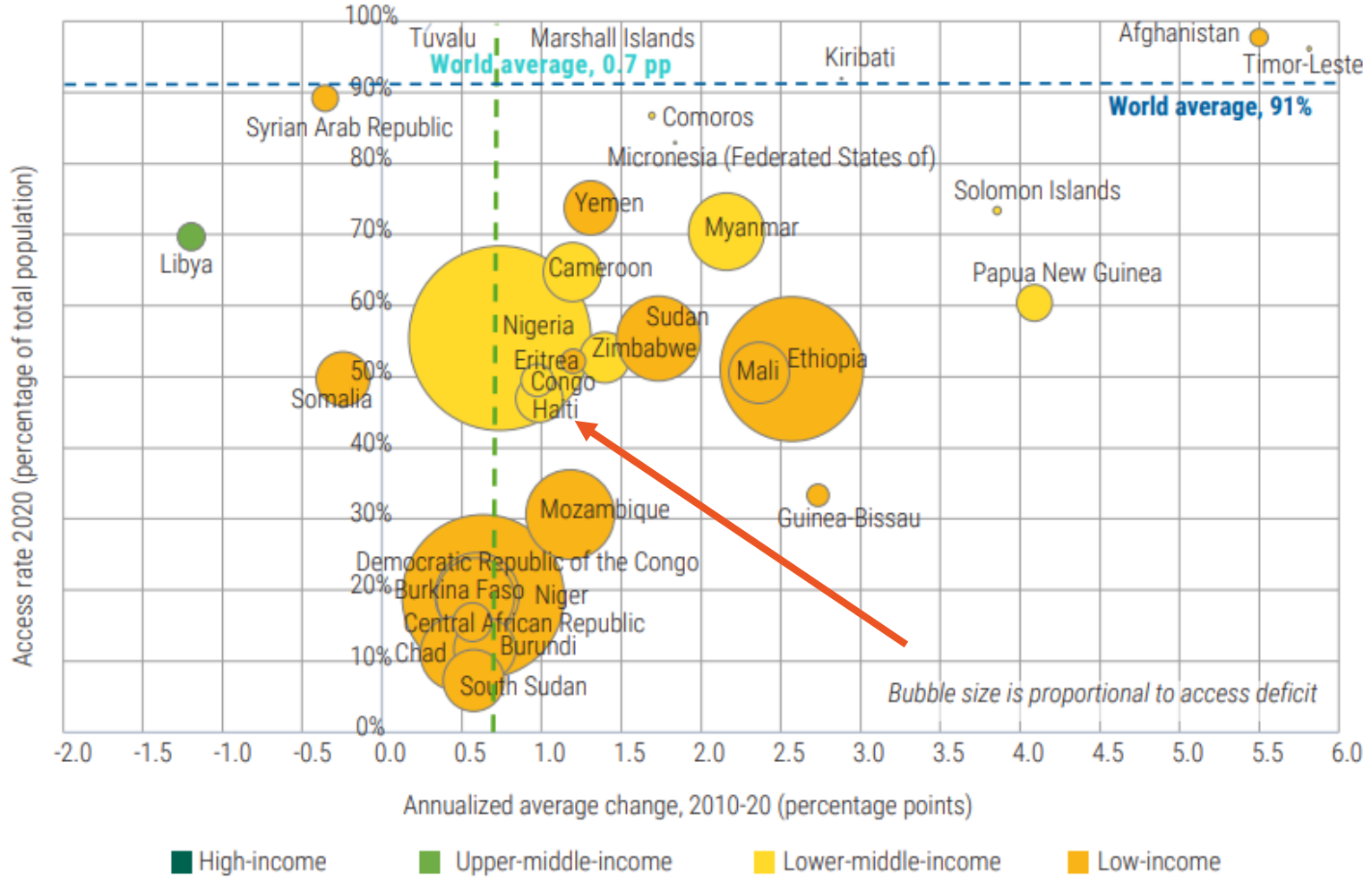
Haiti is Among the Highest Energy Poverty Countries

Figure 1.20 • Share of population with access to electricity in 2020 and average annual growth rate of access in fragile and conflict-affected countries between 2010 and 2020



Source: [SDG7 Tracking Report 2022]

Energy Poverty Snapshot for Haiti

~2% access to electricity in rural areas

Even the 80+% of urban areas with access to electricity in urban areas experience significant reliability challenges.

$13.04 and $42.80 USD per month

Expenditures for baseline energy sources for rural households with more than 50% of households spending more than $20 USD/month. **Over 6 million Haitians live below the poverty line with less than USD2.41 per day**. These costs have risen significantly (in some cases almost doubling) due to COVID and the socio-political situation in Haiti.

<30 kWh / per capita / year

This electricity consumption per capita is **more than 80 times lower** than the average for the Latin America and the Caribbean Region. In 2020, LAC had 99% electrification, and 92% of the more than 6 million people without electricity were in Haiti.

Source: SREP Investment Plan, Boston University Electricity Sector Assessment, Limestone Analytics CBA of the Power Sector, WB PAD for Haiti Energy Access, NRECA Haiti / DR Energy Sector WTP

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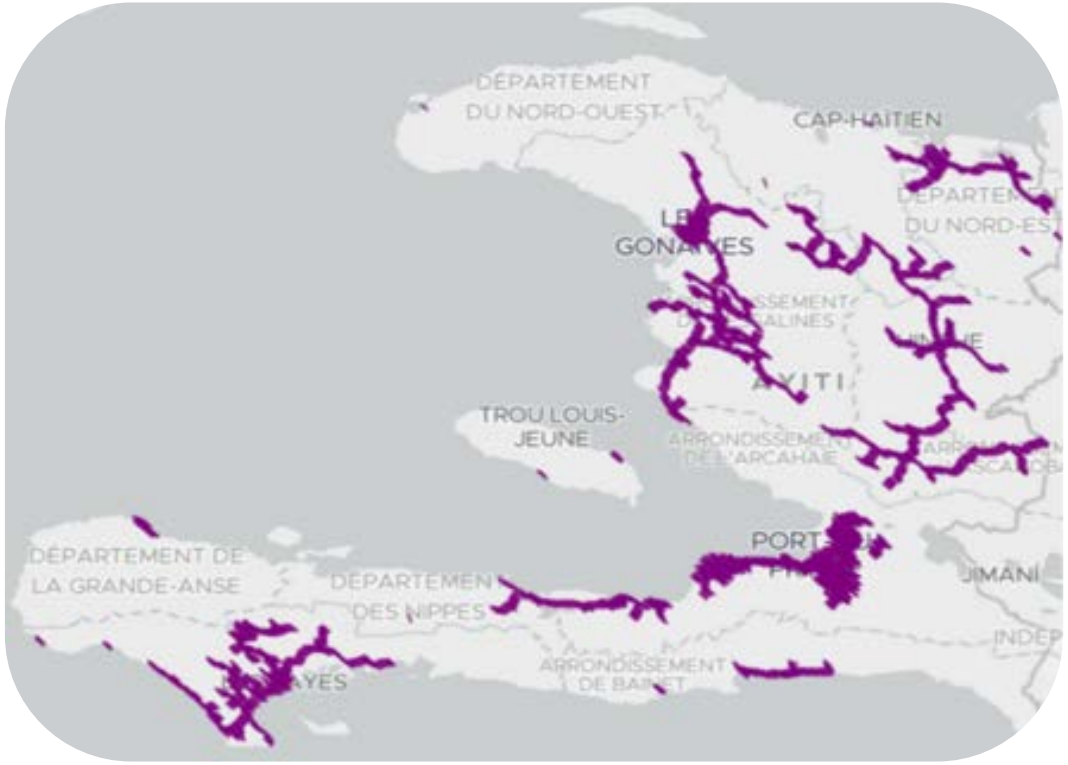
Electricité D'Haiti (EDH) Grid is Limited

Outside Port-Au-Prince area, EDH electricity service is very sparse, with approximately 10 regional grids with a size between 2 to 20 MW serving some of the largest cities and nearby areas, plus approximately 30 village-level grids, each with less than 500 kW of generating capacity.

If the current trajectory isn't accelerated, Haiti is not projected to achieve universal electrification until after 2150.



EDH and microgrid coverage

Source: USAID Haiti Off-grid Solar Market Assessment (internal study not available online, available from USAID on request)

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Three Main Pathways for Electricity Access

Grid Expansion and Densification

Expanding centralized, large scale utility service usually from national or private utility companies (e.g. Electricité D'Haiti in Haiti), utilizing large scale electricity transmission networks.

Mini-Grids

An off-grid system (sometimes referred to as a micro-grid or isolated grid) that involves small-scale electricity generation (usually 10 kW to 1MW) which serves a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission networks (e.g. EarthSpark International, Sigora, CEAC, etc. in Haiti).

Off-Grid Solar (Stand-Alone Solar)

Stand-alone systems are small electricity systems, which are not connected to an electricity distribution system and provide electricity to individual appliances, homes or businesses. This includes “pico-solar” products like solar lighting products as well as solar home systems and stand-alone commercial and industrial systems.

Focus of this training

Source: Left to Right: EdH, EarthSpark International, Solengy

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Spectrum of Off-Grid Solar Solutions

Off-Grid Solar Kits

Solar lights

Solar lanterns

Simple solar home system kit

Large solar home system kit

Stand-Alone Solar

Stand-alone Solar

Source: VeraSol Off-Grid Solar Quality Framework, Solengy

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Key Components of Off-Grid Solar

PV Modules

Converts the sun's irradiation to usable electricity.

Racking / Mounting

Secures the PV module in place either on the ground or on a rooftop.

Charge Controller

Regulates how the PV modules charge the batteries to ensure safety and optimal health of the batteries.

Battery

Stores electricity produced by solar panels.

Inverter

Converts direct current (DC) electricity, which is what a solar panel/battery generates, to alternating current (AC) electricity, which is what most appliances use.

Electricity to appliances and users.

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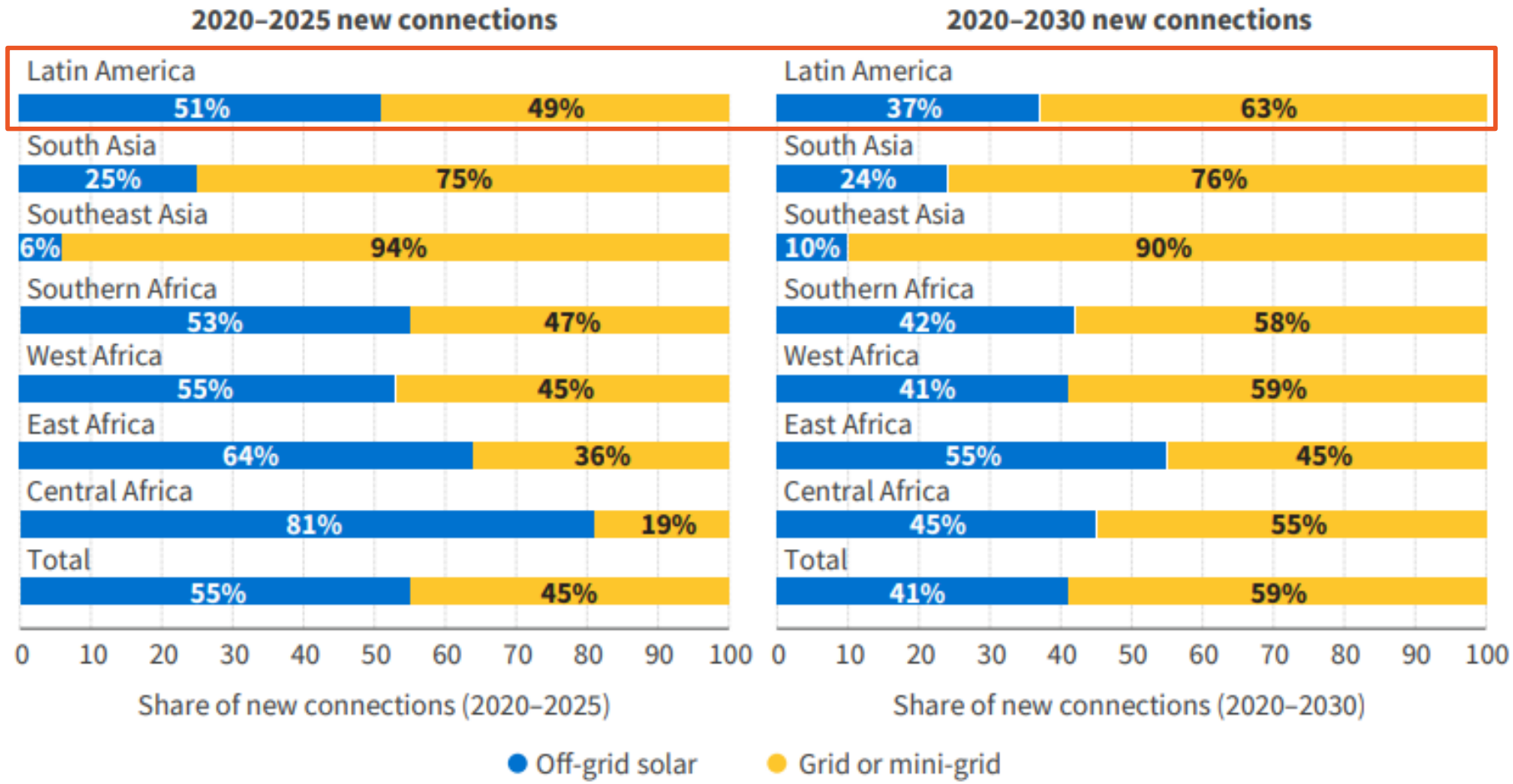
Role of Off-Grid Solar in Least Cost Electrification

Figure 4: Estimated role of off-grid solar in least cost electrification[12]



Source: [Off-Grid Solar Market Trends Report 2022]

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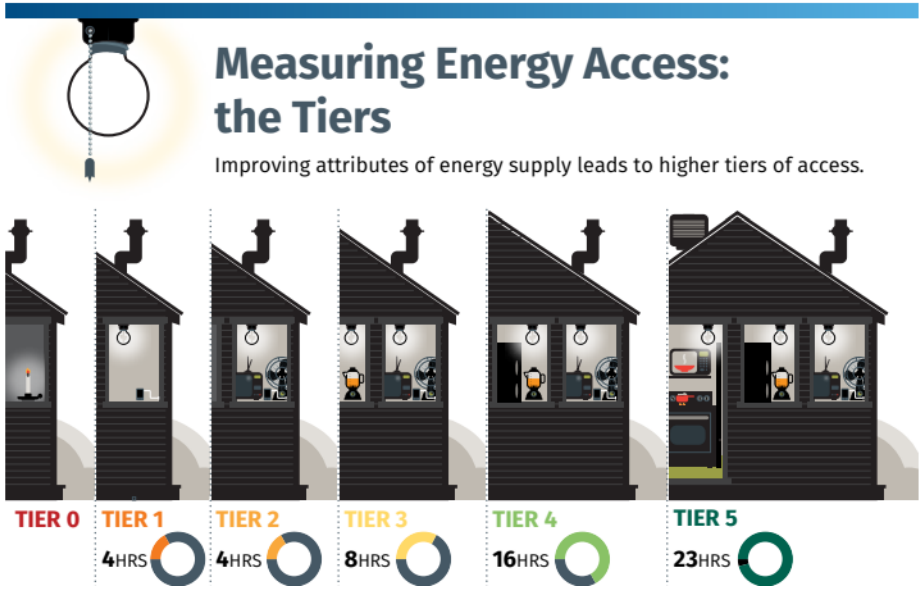
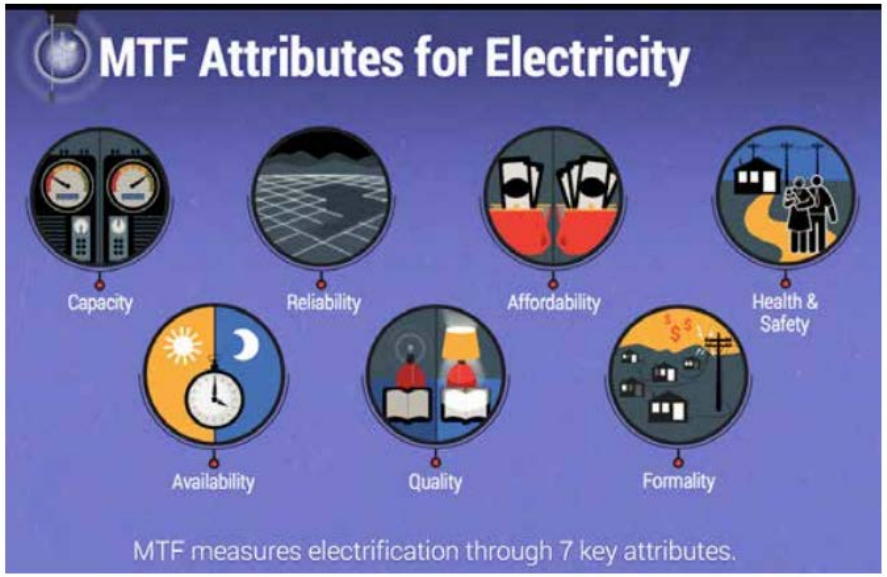
How is energy access measured?

World Bank Multi-Tier Framework (MTF)

The Multi-Tier Framework (MTF) redefines energy access from traditional binary accounting (connected or not connected) to a multidimensional concept that considers whether energy services are adequate, available when necessary, reliable, of good quality, convenient, affordable, legal, healthy, and safe for all.





Source: World Bank Beyond Connections Report; Ethiopia MTF Report

MTF Framework

Attributes		Tier 0	Tier 1	Tier 2	Tier 3	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
	Services	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
Availability	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 per week or <3 disruptions per 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 seller, or authorized representative	
Health and Safety		Serious or fatal accidents due to connection				Absence of past accidents	

Source: World Bank Beyond Connections Report

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Supported Appliances by Tier of Electricity Access

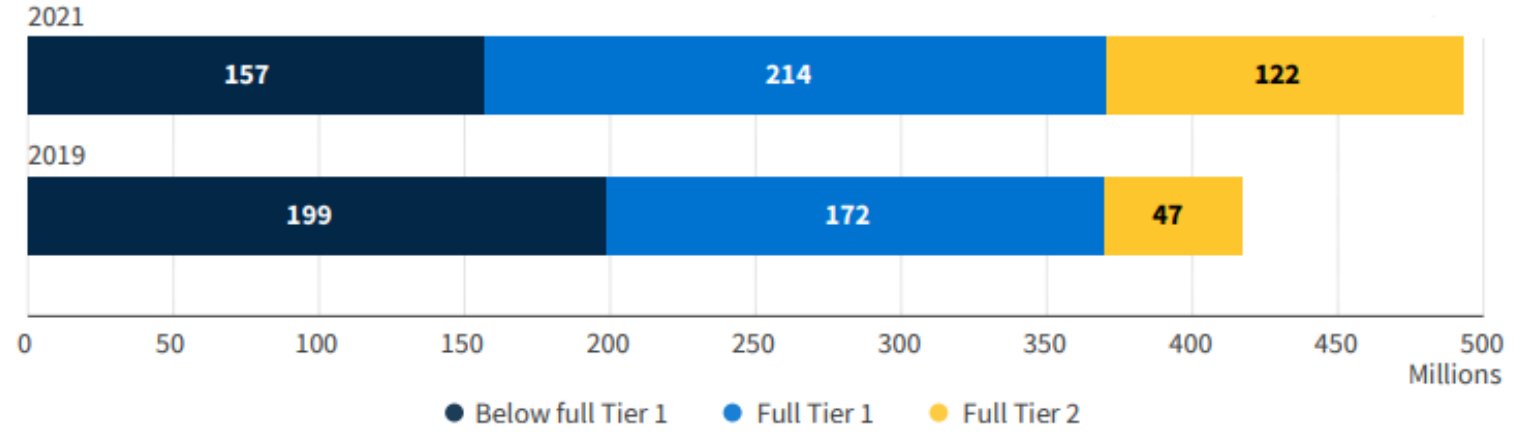
Tiers	Type of products	Average power (W)	Autonomy Day	Autonomy Night	Applications
Tier 0	Solar lanterns, Solar panels, Batteries	<= 3			
Tier 1	Solar Lanterns, Solar Panels, Batteries, Kit SHS entry level	3	4	2	
Tier 2	Kit SHS – Basic level	50	4	2	
Tier 3	Kit SHS, SHS - Component Based System – Medium level	200	8	3	
Tier 4	SHS - Component Based System - High-capacity level	800	16	4	
Tier 5	Large Systems	2 kW	23	4	

Source: USAID Haiti Off-grid Solar Market Assessment (internal study not available online, available from USAID on request)

People Benefiting from Off Grid Solar by Tier

The number of people accessing solar energy kits has grown from 420 million people in 2019 to **over 490 million people at the end of 2021**, with more people gaining higher ‘Tier 2’ levels of access.

Figure 40: People benefiting from access to electricity through solar energy kits (millions)[117]



Source: *Off-Grid Solar Market Trends Report 2022*

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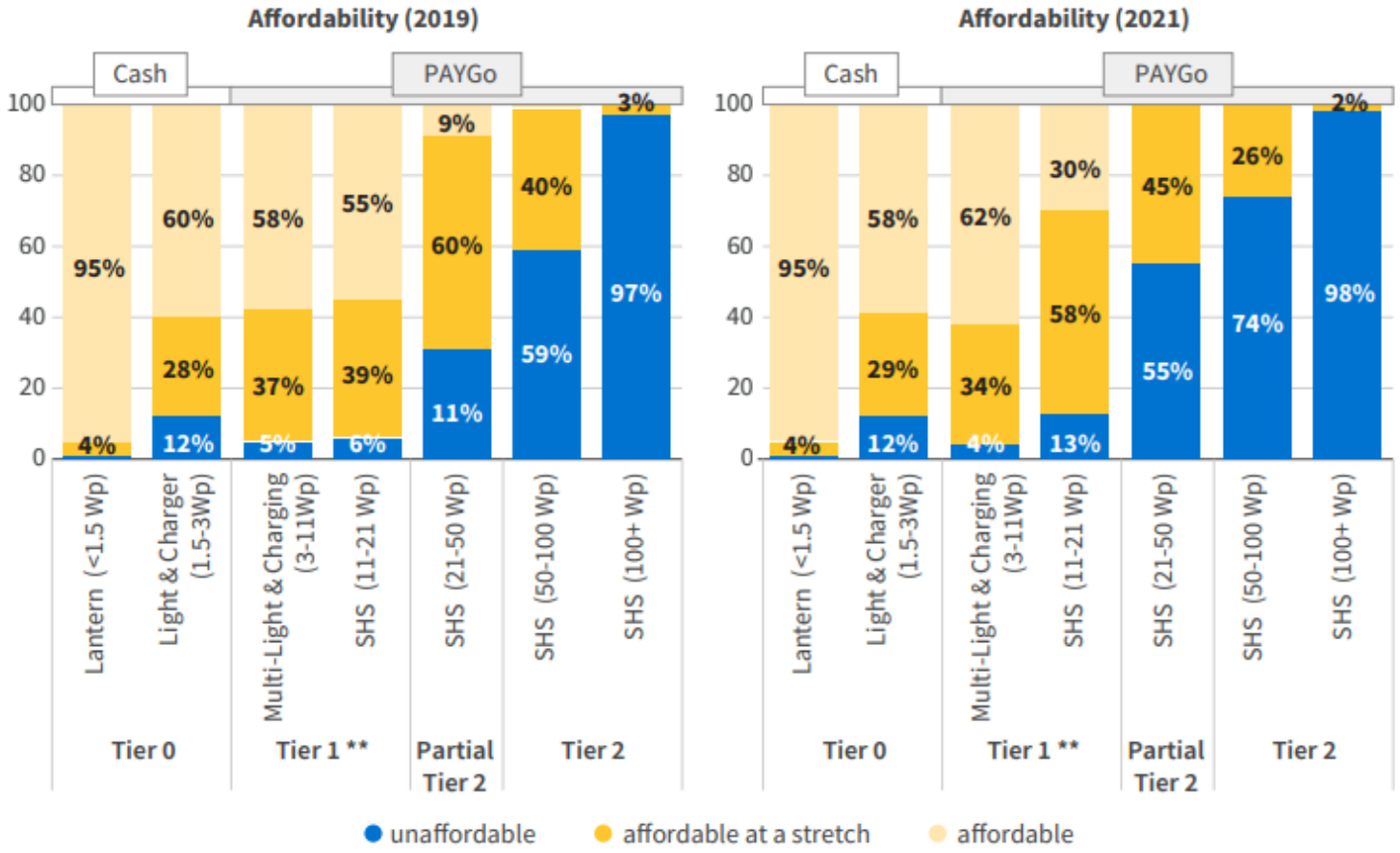
Ability to Pay for Off-Grid Solar Solutions

Between 566 million and 730 million unserved people would be unable to afford the full cash price of a Tier 1 solar energy kit.

Pay as you go financing (PAYGO – discussed in Module 7) helps to bridge affordability gap, but most underserved households can't afford a Tier 2 system or partial Tier 2 system.

Ability to pay - conservative demand estimates

Figure 5: Affordability of off-grid solar technologies - 'conservative' for the bottom of the pyramid[14]



Source: Off-Grid Solar Market Trends Report 2022

Key Challenges and Considerations

1. Most energy access customers have Tier 1 or Tier 2 needs, but affordability is an extreme challenge and companies don't see strong enough returns supporting those customers.

2. Providing access to power is only half the battle – most households, especially for Tier 1, don't have the appliances to actually consume power. Bridging this gap is critical, particularly providing pathways for consumer and asset-based financing to support access.

3. It is important to grow with customers providing modular approaches that allow them to increase their service as their ability to pay increases and/or they gain access to appliances.

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Thank you

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