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Refugee camps:

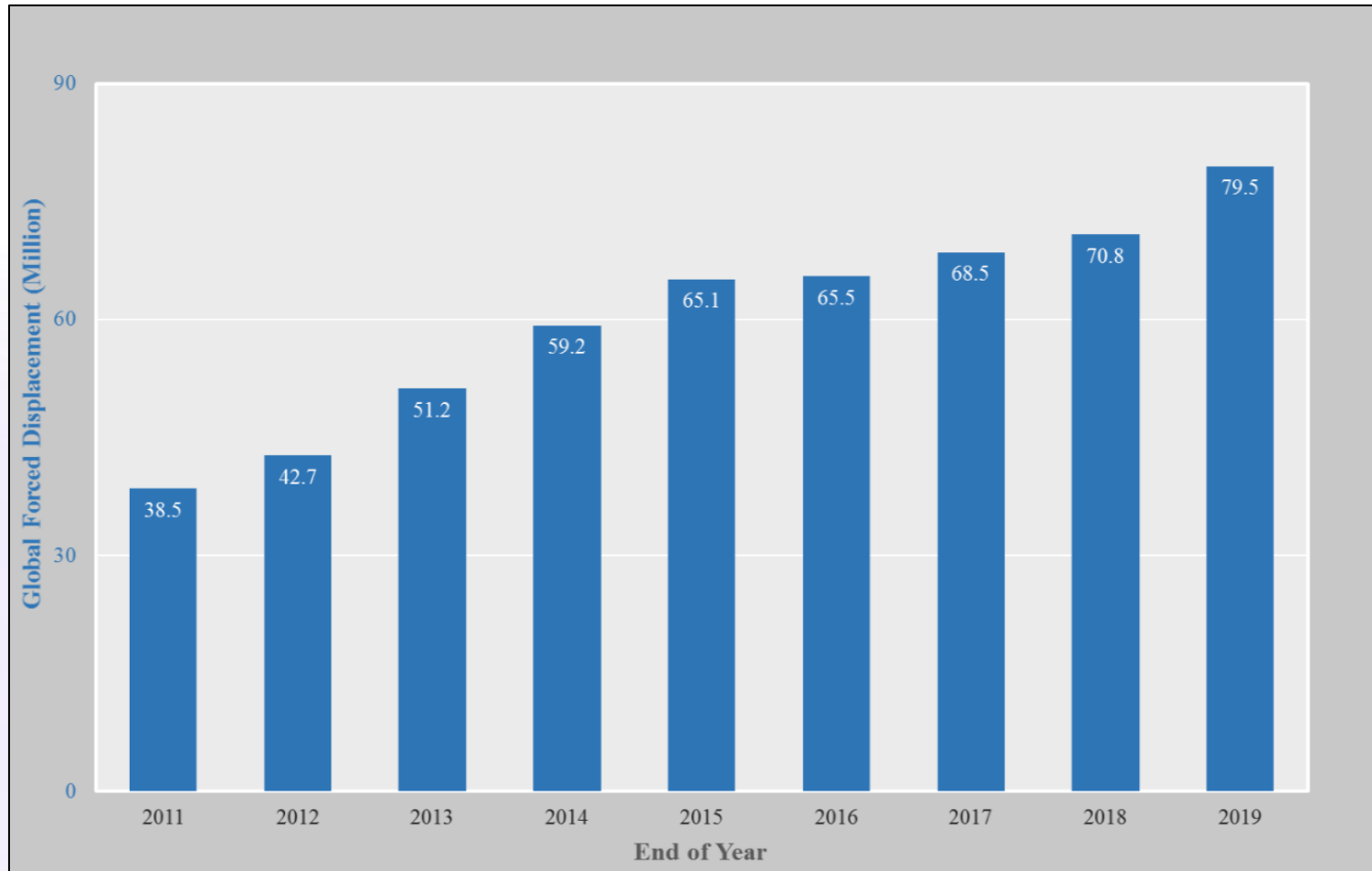
Modeling demand flexibility and tiered-resilience to reduce energy costs

- A Presentation by Manojit Ray

Worldwide Displaced Population



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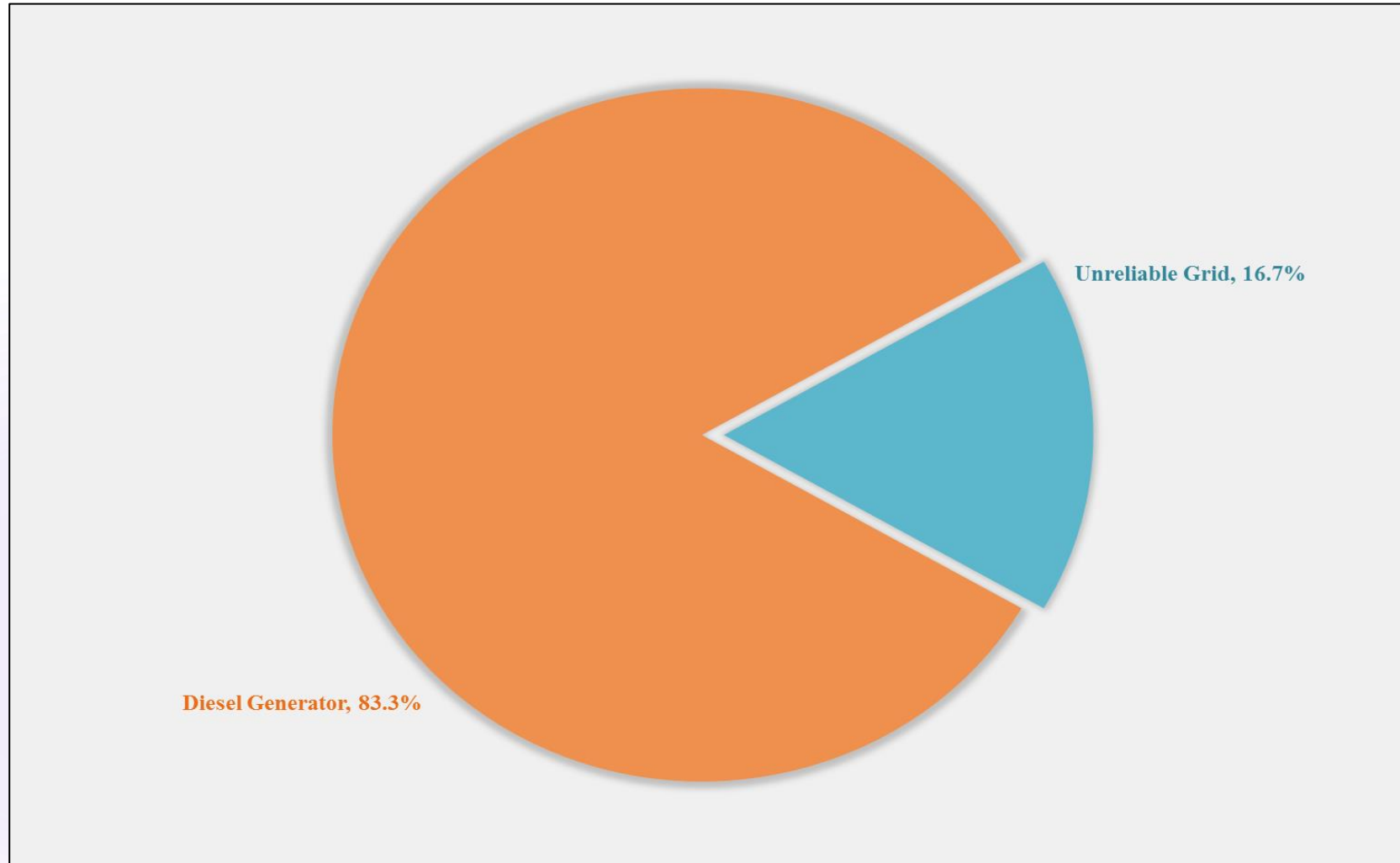


Source: UNHCR, 2020

Diesel Powered Water Pumping



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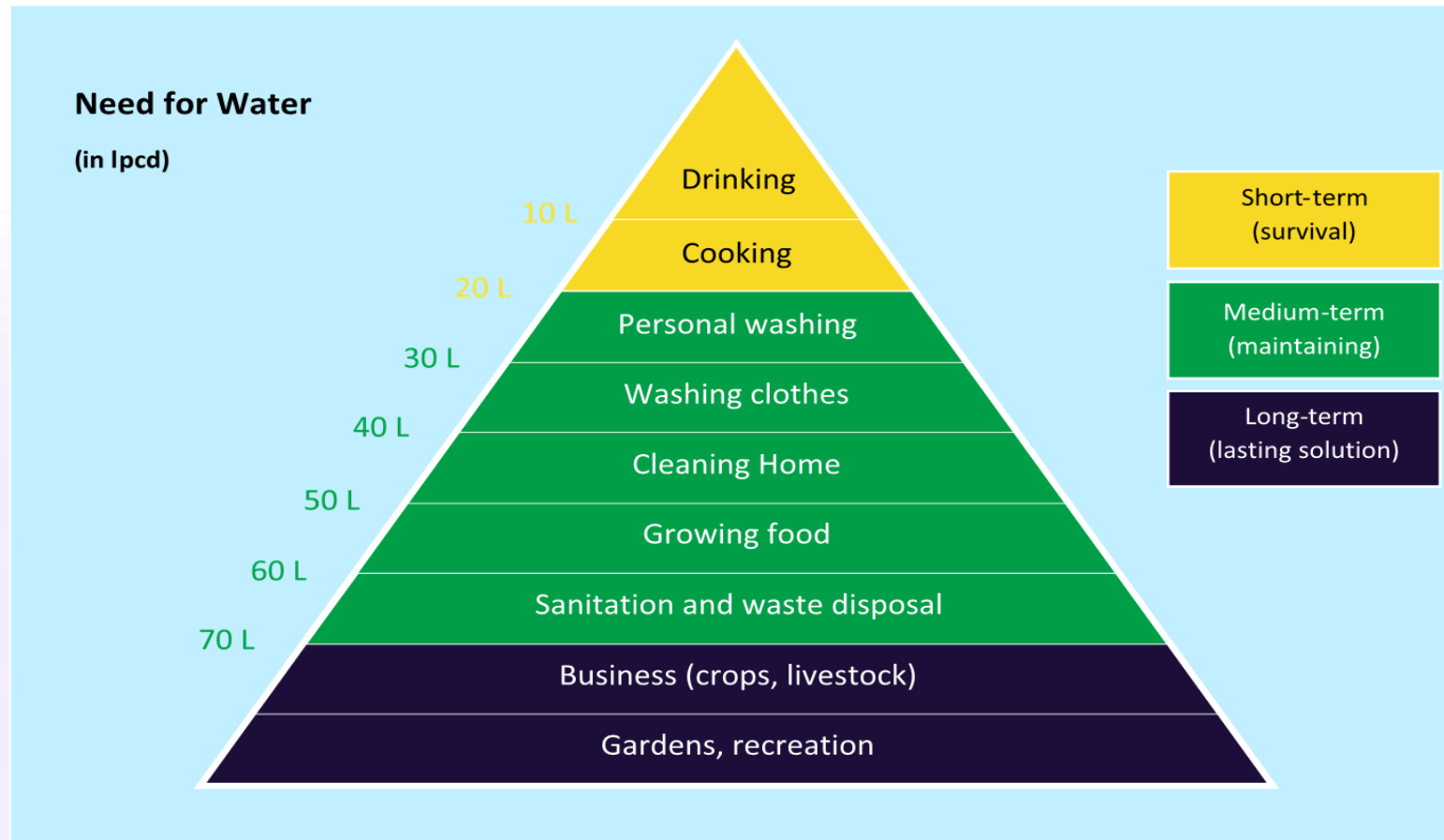


Source: UNHCR, 2020

Human Survival Necessity



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Source: WHO, 2010



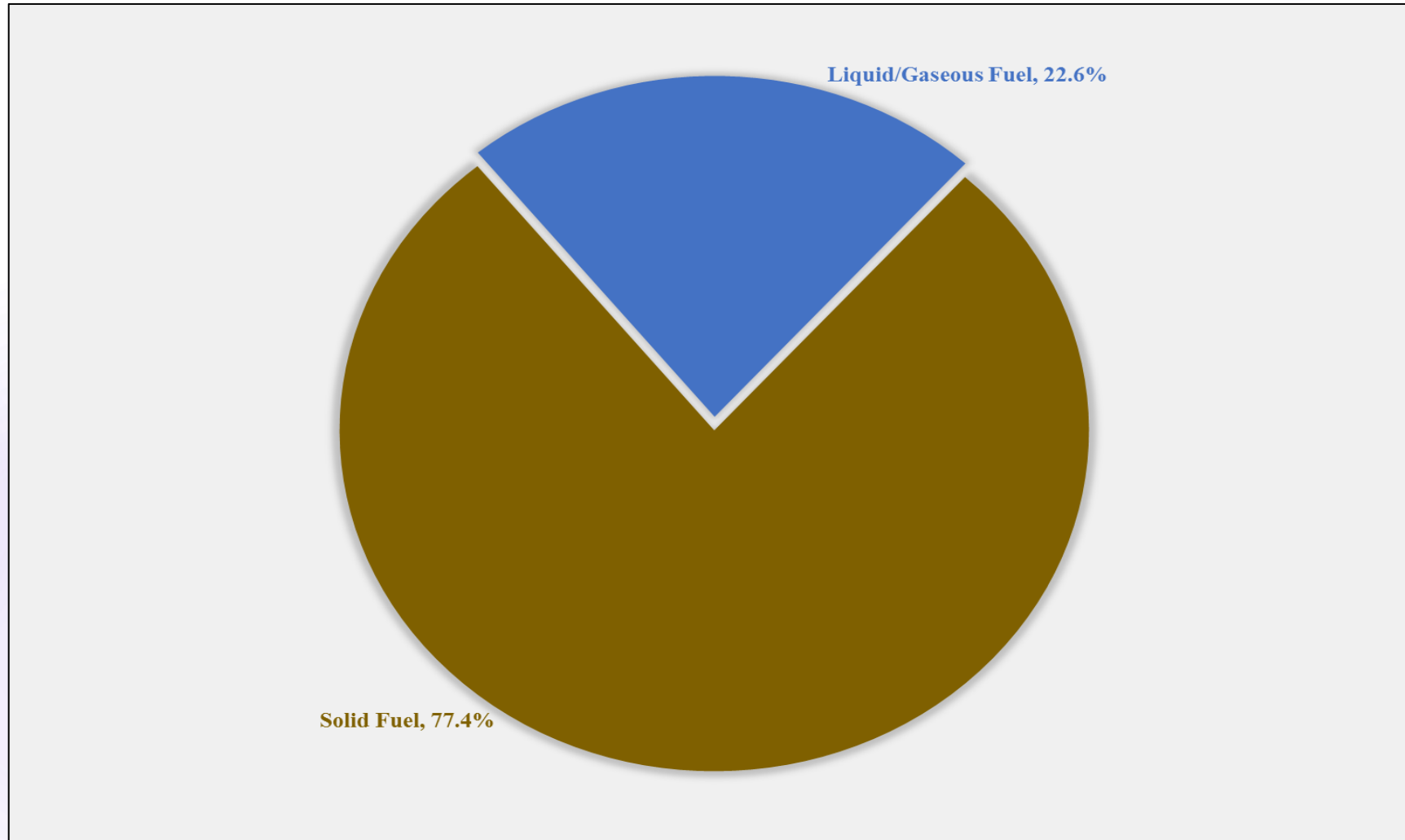
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Refugees Cook with Polluting Fuel



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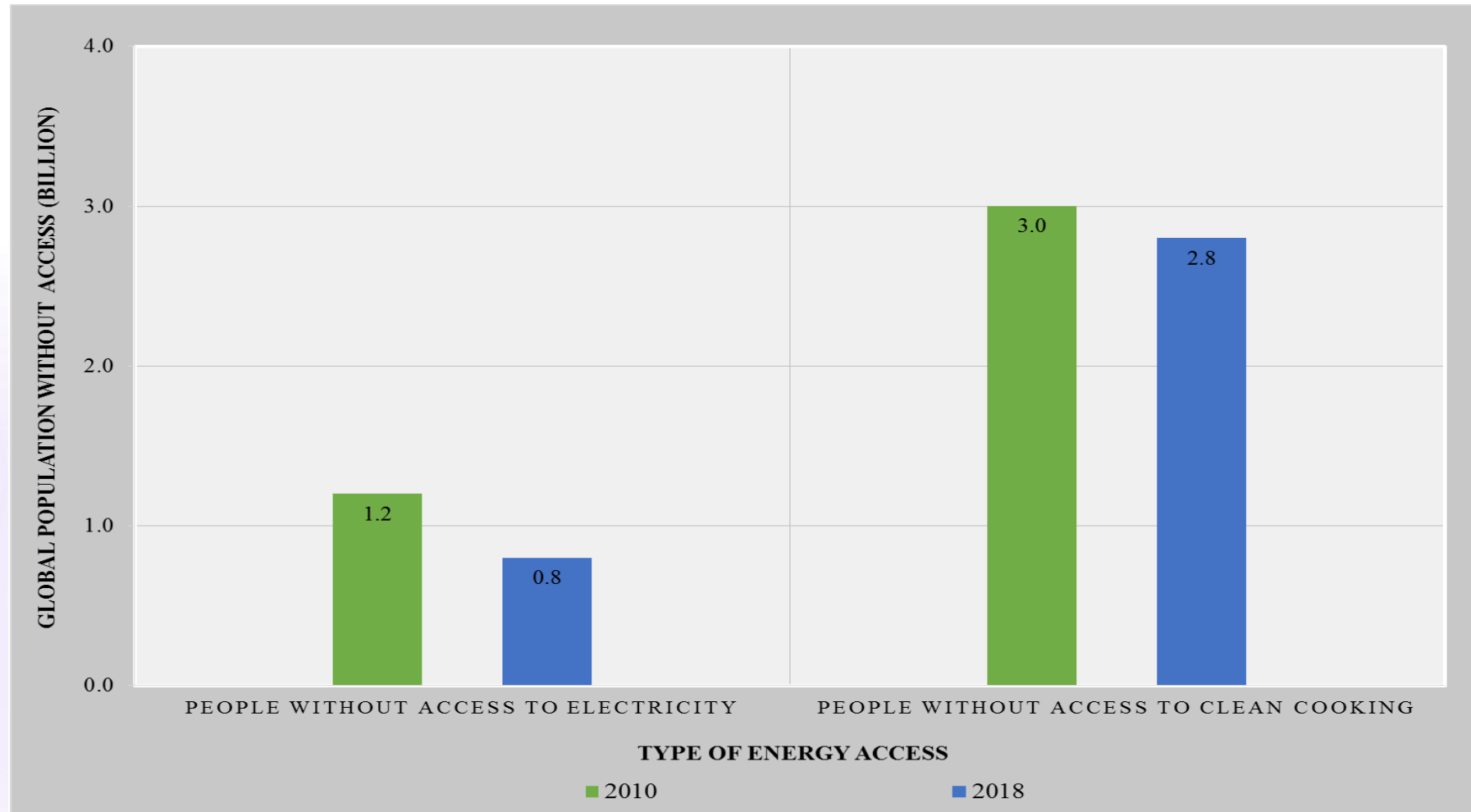


Source: UNHCR, 2020

Approaching Universal Access



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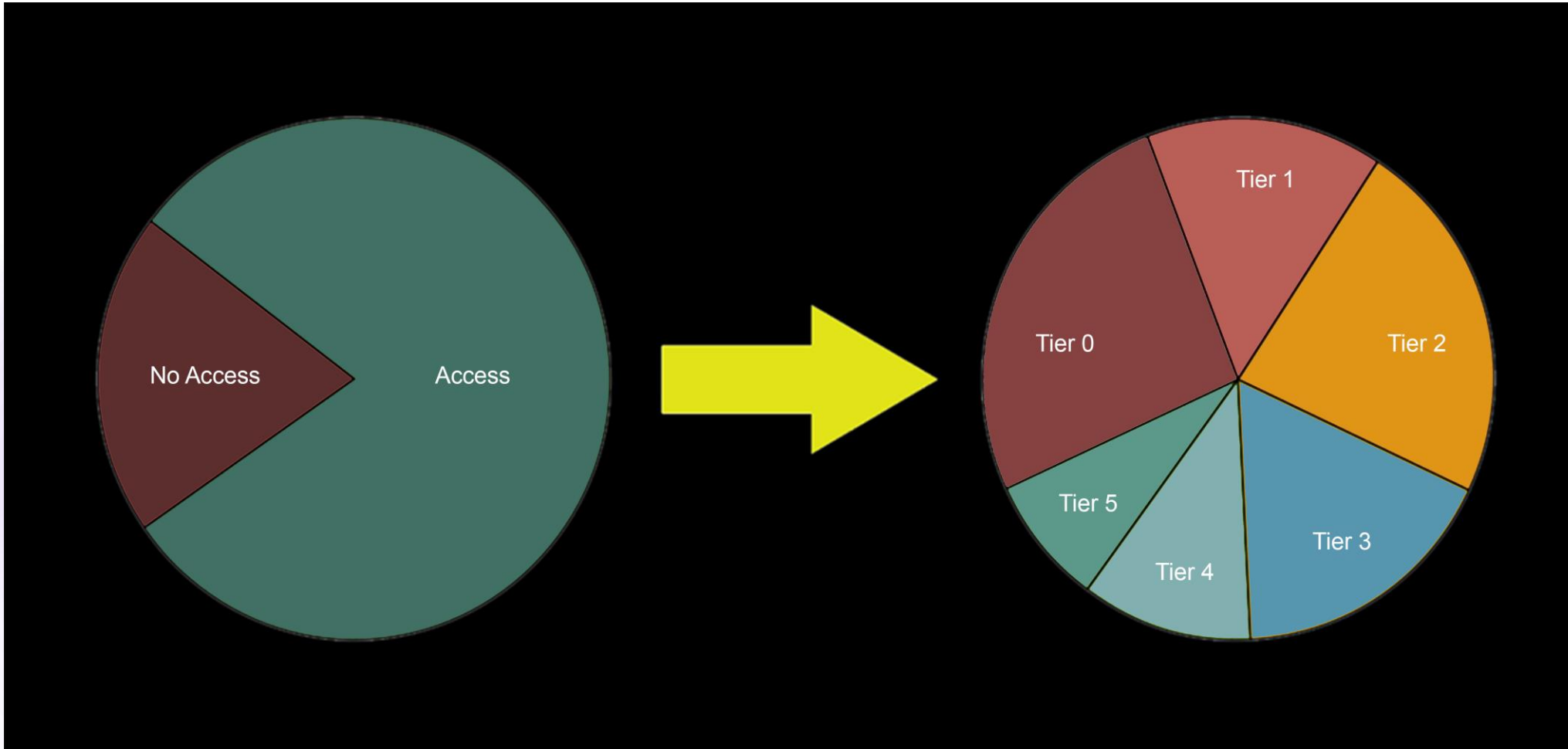


Source: IRENA, 2020

Evolution of Access Measurement



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Source: World Bank, 2015



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Multi-tier Framework (MTF) Tiers



Tier	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Service criteria	-	Task lighting, phone charging	General lighting, television, fan	Medium power appliance	High power appliance	Very high power appliance

Source: ESMAP, 2015



Multi-tier Framework - Electricity

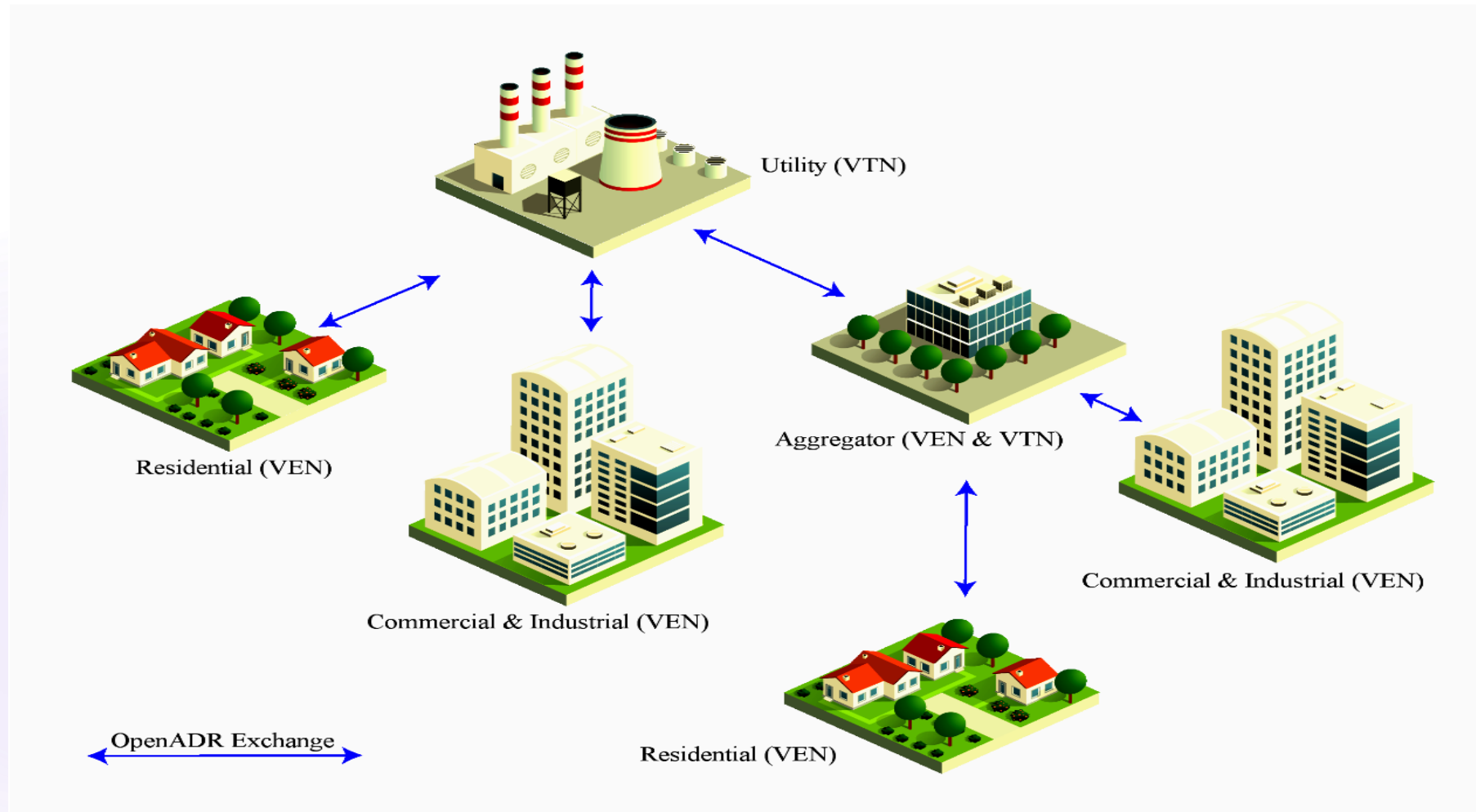


Attribute	Indicator	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Capacity	Minimum Power Requirement (W)		3	50	200	800	2000
	Minimum Energy Available per Day (Wh)		12	200	1000	3400	8200
Duration	Minimum Supply Per Day (Hours)		4	4	8	16	23
	Minimum Supply Per Evening (Hours)		1	2	3	4	4
Reliability	Maximum Disruptions Per Week (No)					14	3
	Maximum Total Duration of Disruption (Hours)						2
Quality	Desired Appliance Use Not Affected by Voltage					Yes	Yes
Affordability	365 kWh Energy Costs 5% or Less of Annual Income				Yes	Yes	Yes
Legality	Bill Paid to Utility or Other Legitimate Entities					Yes	Yes
Health & Safety	Absence of Past Accidents & Perceived High Risk					Yes	Yes

Source: World Bank, 2015



Demand Response



Source: LBNL, 2017

Evolving Power System



Characteristic	Traditional Grid	Early Smart Grid	Evolving Smart Grid
Role of <i>information technology</i>	Gradually expanding in diverse ways	Bidirectional control & monitoring communication	One-way monitoring but no central control
<i>Consumer engagement</i> in system regulation	Passive consumer without engagement	Binary ON/OFF demand response	Continuous autonomous demand response
<i>Generation mix</i> and distributed sources	Central generation led system	Centrally controlled distributed generation	Distributed generation dominated system
Cascading <i>system-wide failures</i>	Systemic intrinsic design defect	Reduced incidence but still cataclysmic	Locally-contained and effect-limited flaw

Source: Zhong Q C, 2020



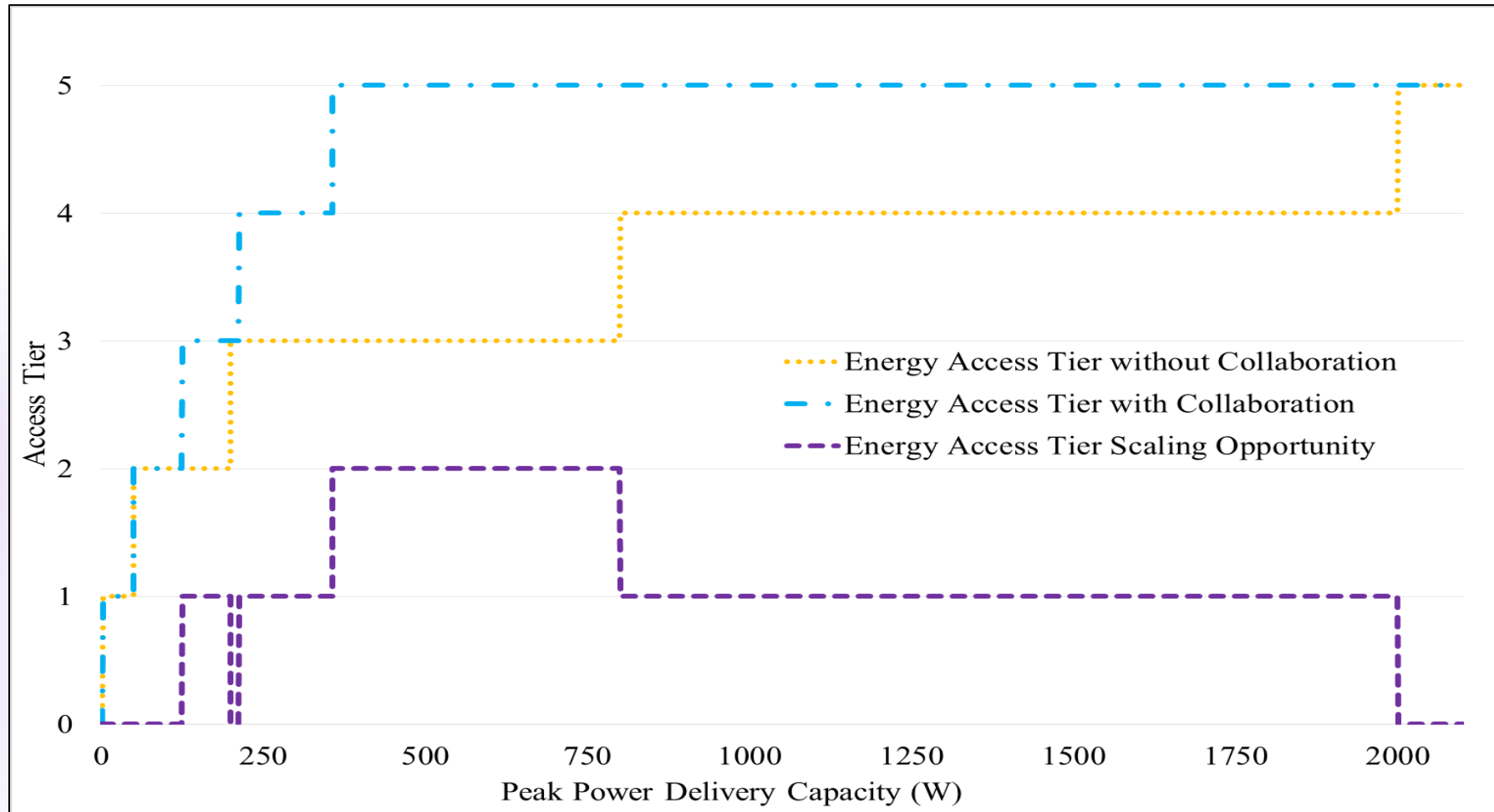
Consumer Engagement with MTF



Access tier requirement vis-à-vis potential	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Access tier peak power required (W)	3	50	200	800	2000
Daily supply duration required (Hrs)	4	4	8	16	23
Daily energy supply potential at peak power (Wh)	12	200	1600	12800	46000
Actual energy supply capacity required (Wh)	12	200	1000	3400	8200
Share of time required with peak power (%)	100	100	62.5	26.6	17.8
Maximum collaboration potential for powering loads	1:1	1:1	1.6:1	3.7:1	5.6:1
Peak power supply provision per household (W)	3	50	125	212.5	356.5

Source: Ray et. al, 2019

Collaborative Access-tier Scaling



Source: Ray et. al, 2019



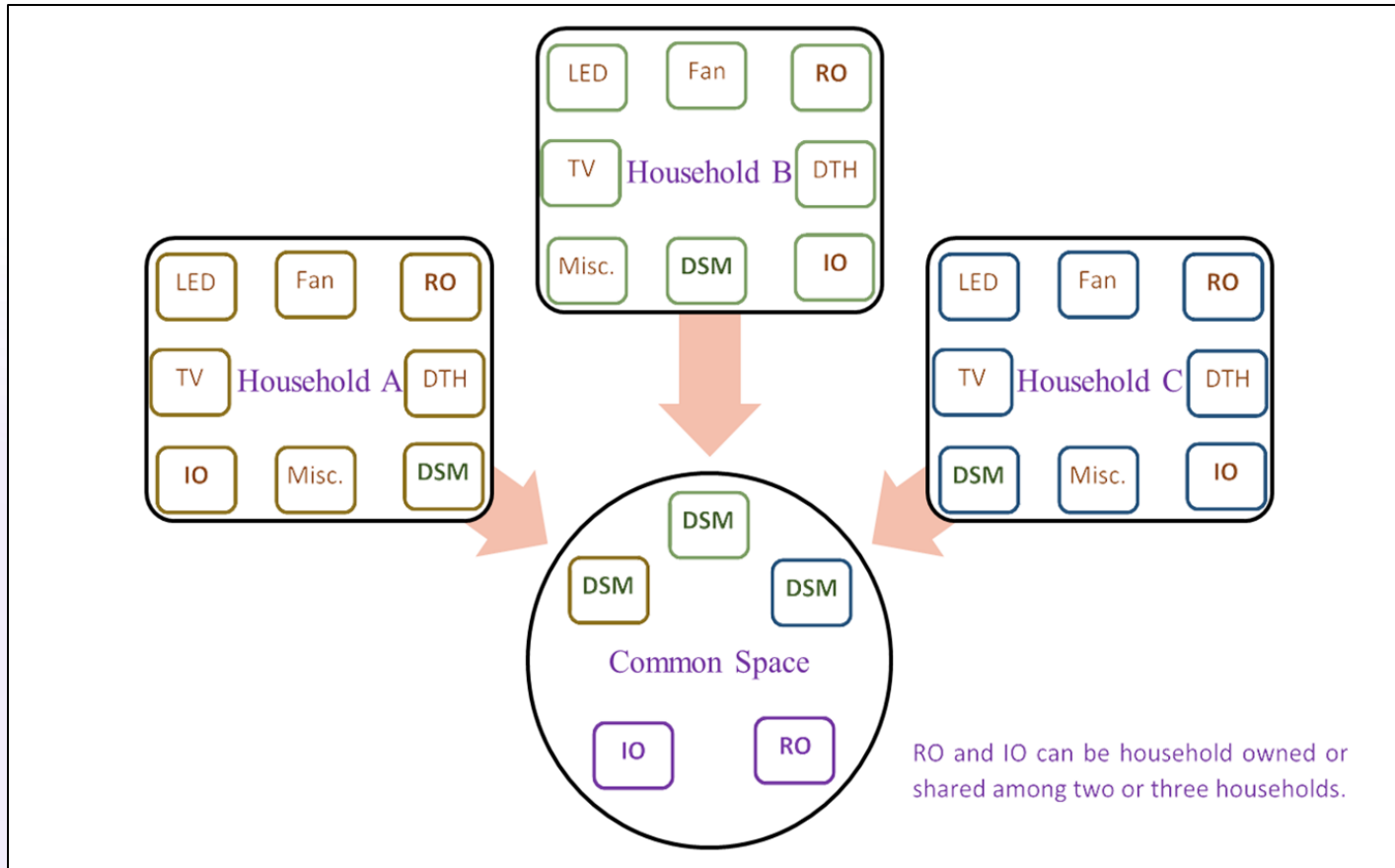
Control Schemes in Off-Grid



Energy Supply	DR Anchored	Consumer Awareness	Demand Following
Control Scheme	Collaborative Control	Manual Control	No Control
Supply Certainty	High Certainty	Medium Certainty	No Certainty
Supply Failure	Measured & Gradual	Human Frailty - Sudden	Abrupt Failure

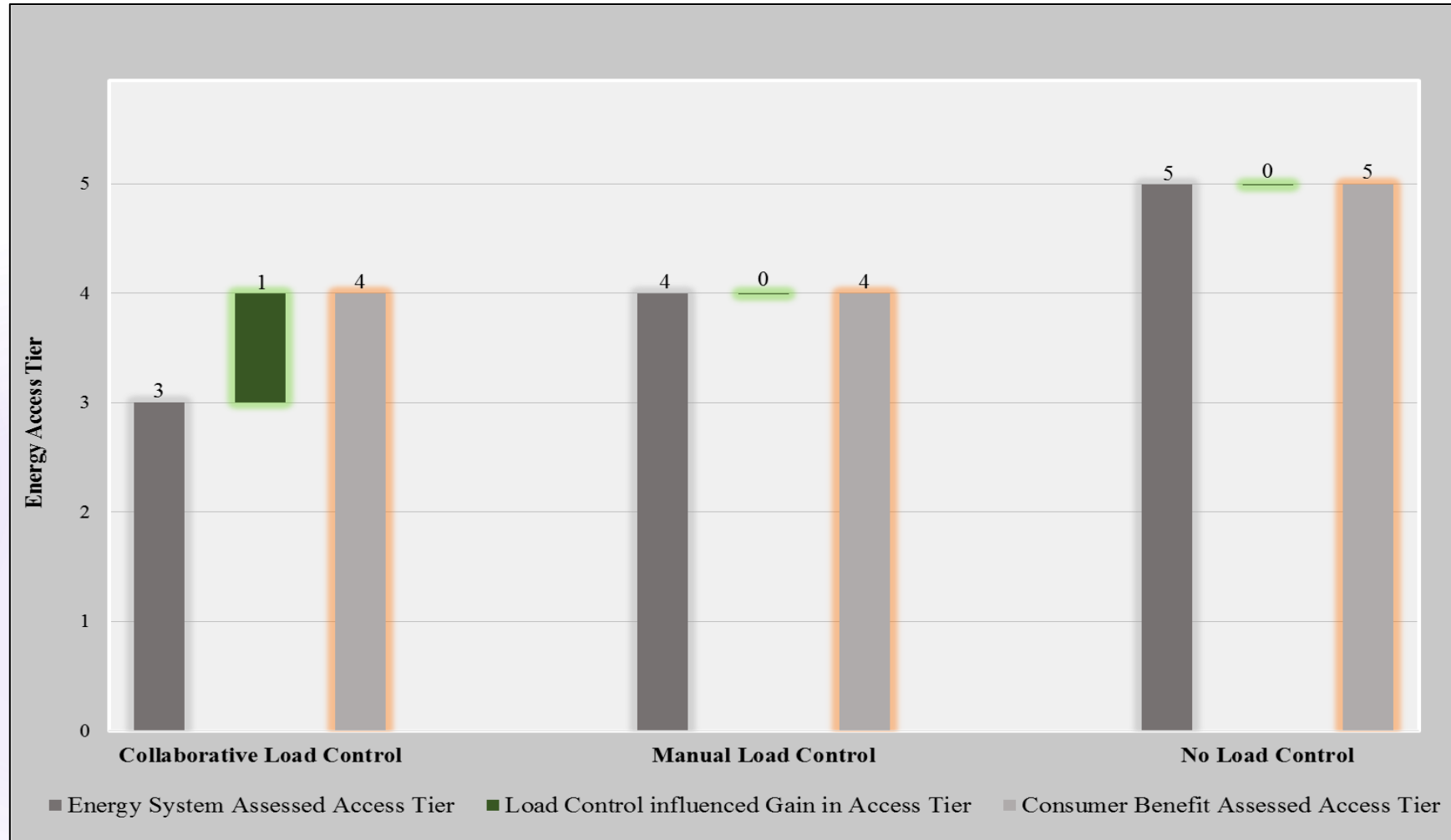
Source: Ray et. al, 2021

Shared Resource and Appliance



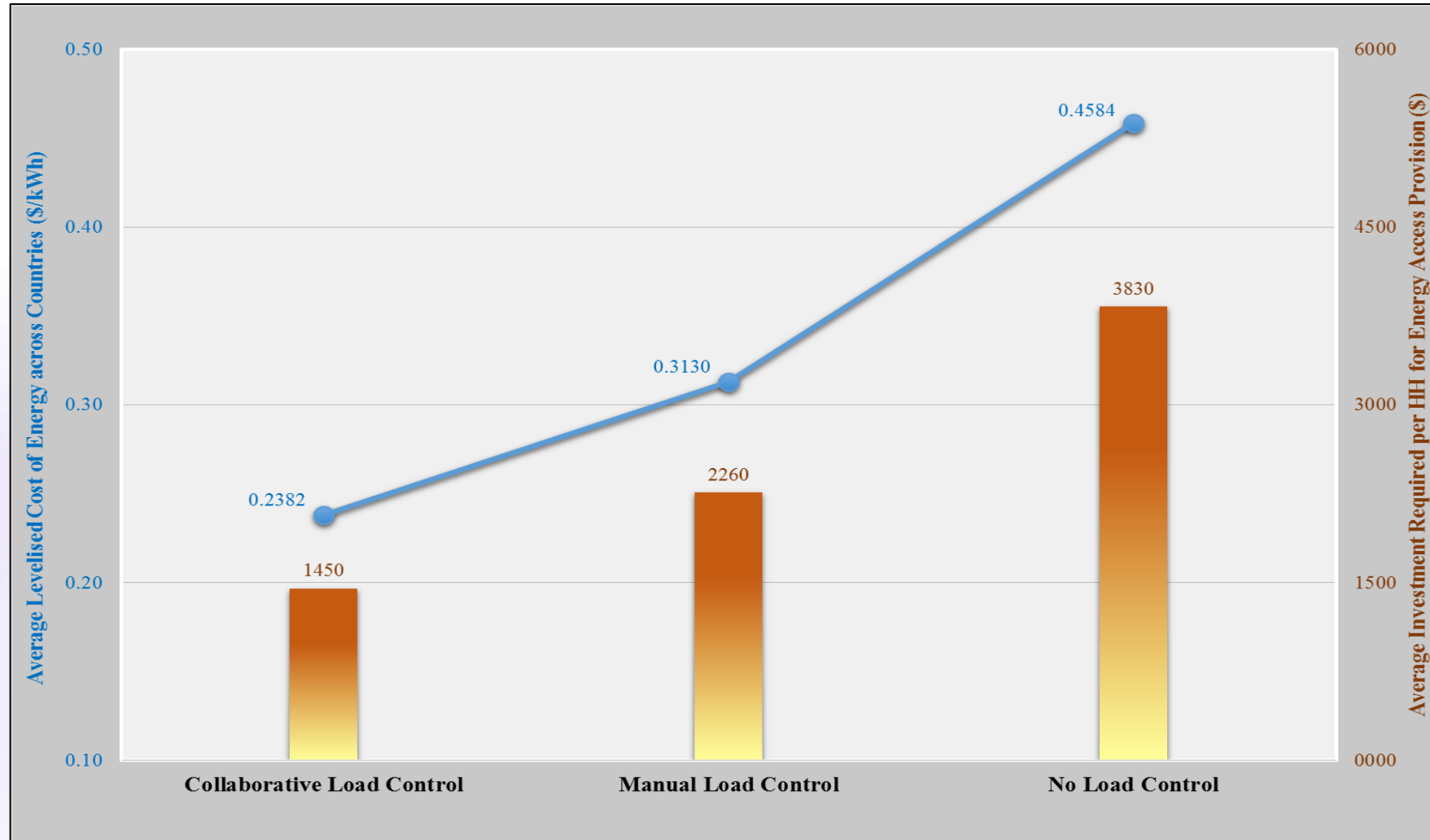
Source: Ray et. al, 2021

Control Scheme Supports Tier-gain



Source: Ray et. al, 2021

Control Scheme Influences LCOE



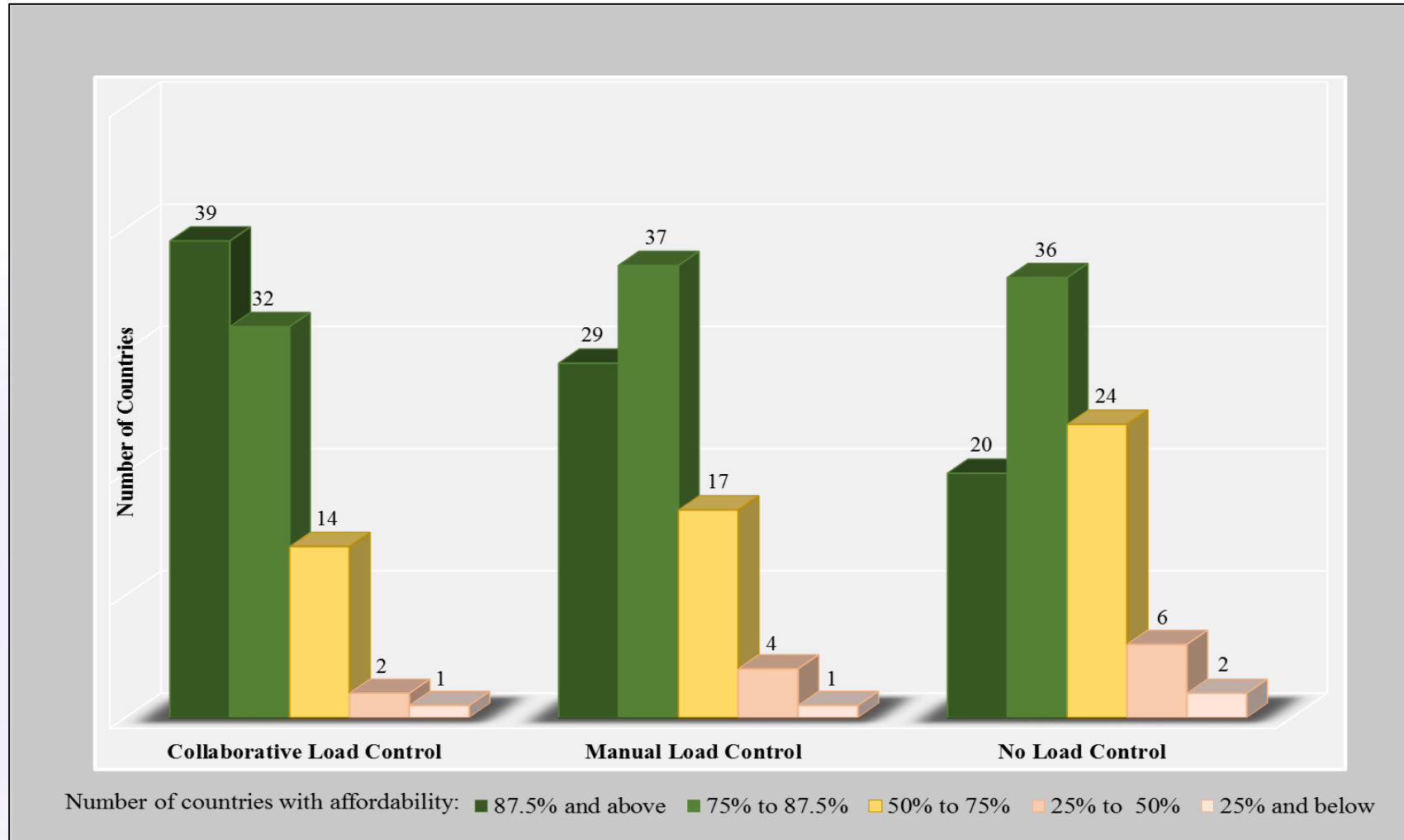
Source: Ray et. al, 2021



Affordability Gain from Scheme



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Source: Ray et. al, 2021



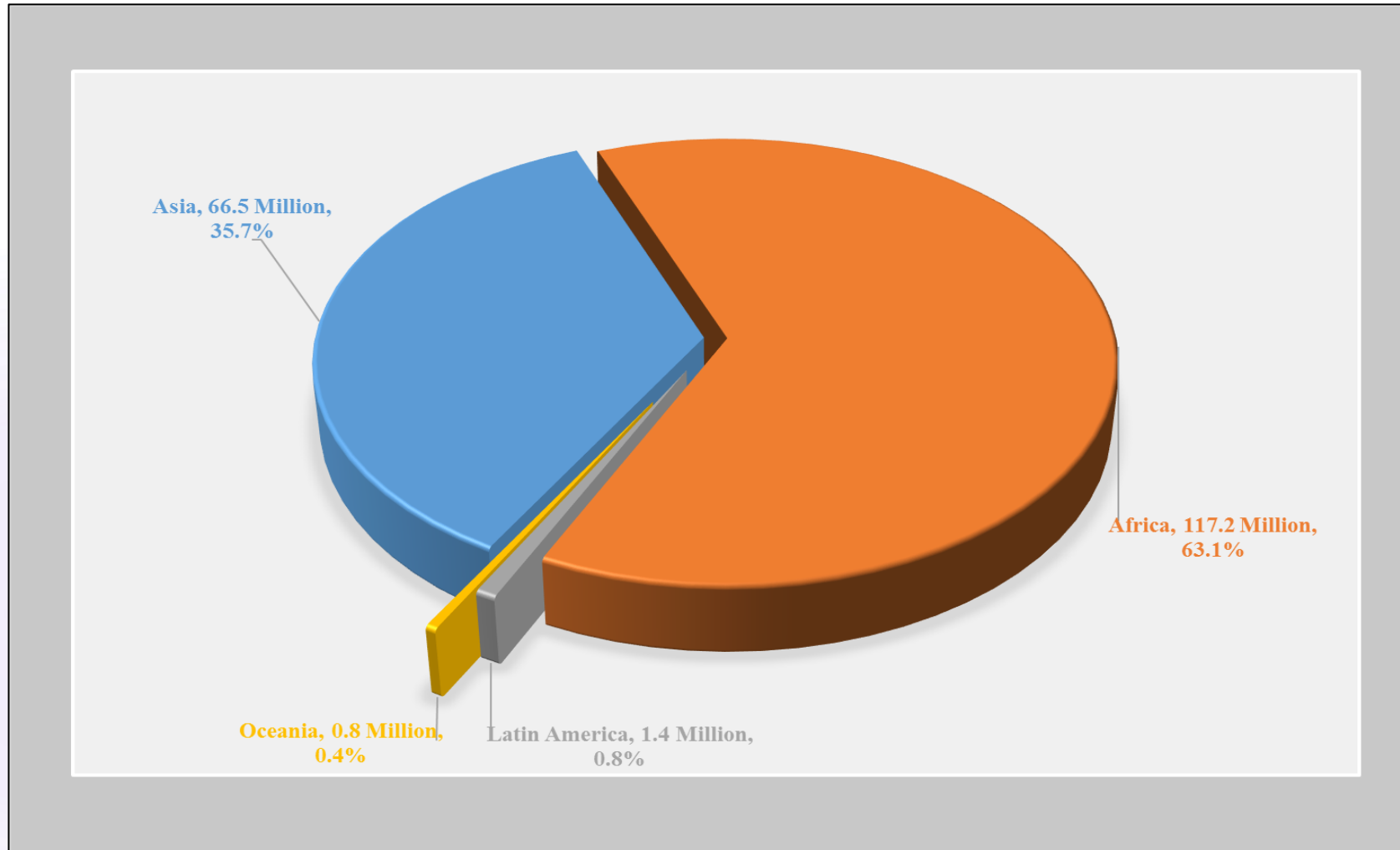
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Large Gain in Africa and Asia



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Source: Ray et. al, 2021



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UNHCR Initiatives



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- ▶ UN is attempting to support its operation with clean-energy
- ▶ UNHCR has partnered IRENA to use Solar PV for water pumping
- ▶ UNHCR has started PPA framework creation for market operation
- ▶ Off-grid PPA includes the daily minimum guaranteed energy
- ▶ Matching granular time-specific demand and supply missing



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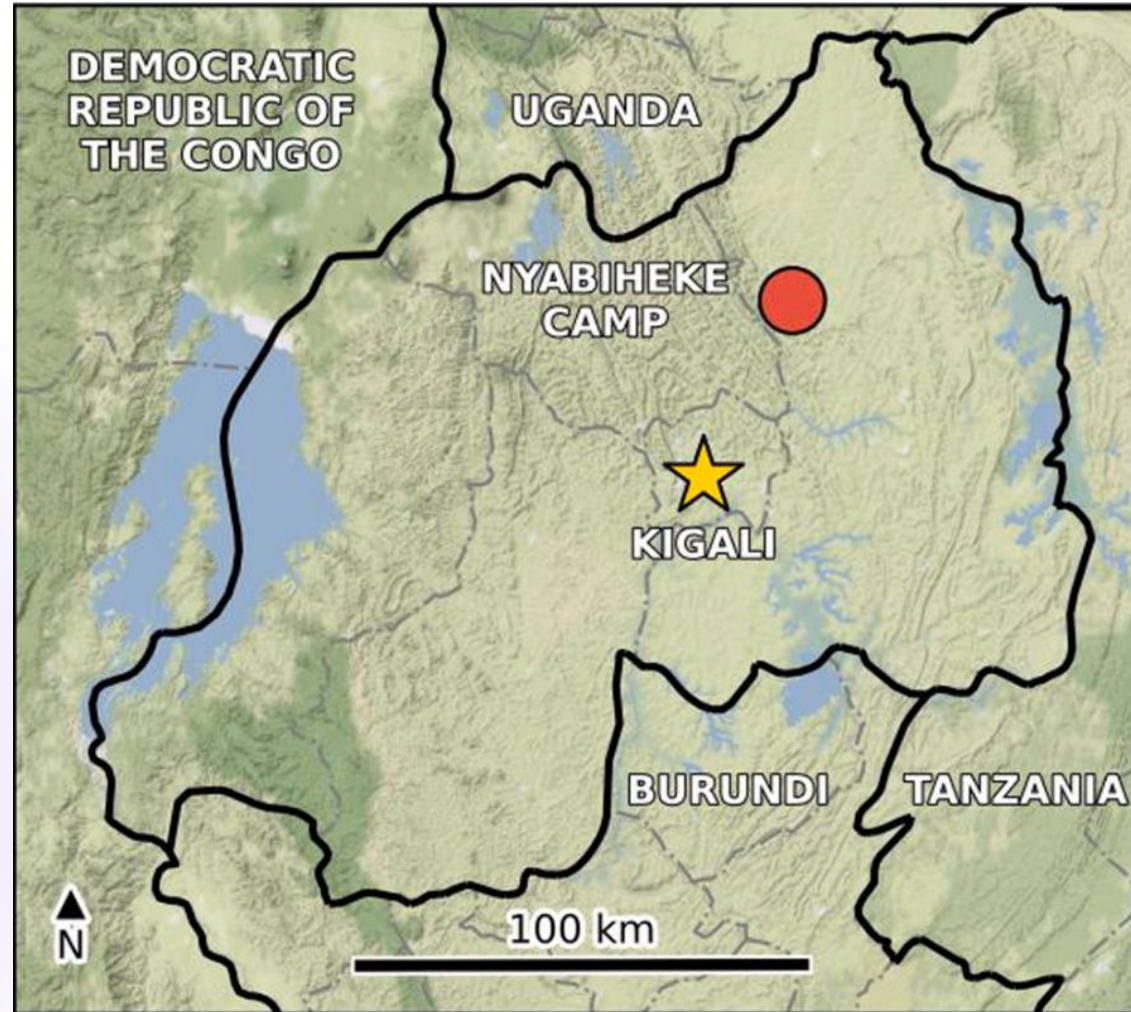
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PPA, Flexibility and Resilience



- ▶ Energy service company invests in the solar plant
- ▶ UNHCR pays for the contracted electricity consumption
- ▶ Take-or-pay principle guides PPA scripting and operation
- ▶ Reducing storage reduces UNHCR payable energy charges
- ▶ Demand flexibility reduces investment and cuts energy cost
- ▶ Tiered resilience avoids simplistic resilience-impacted costs

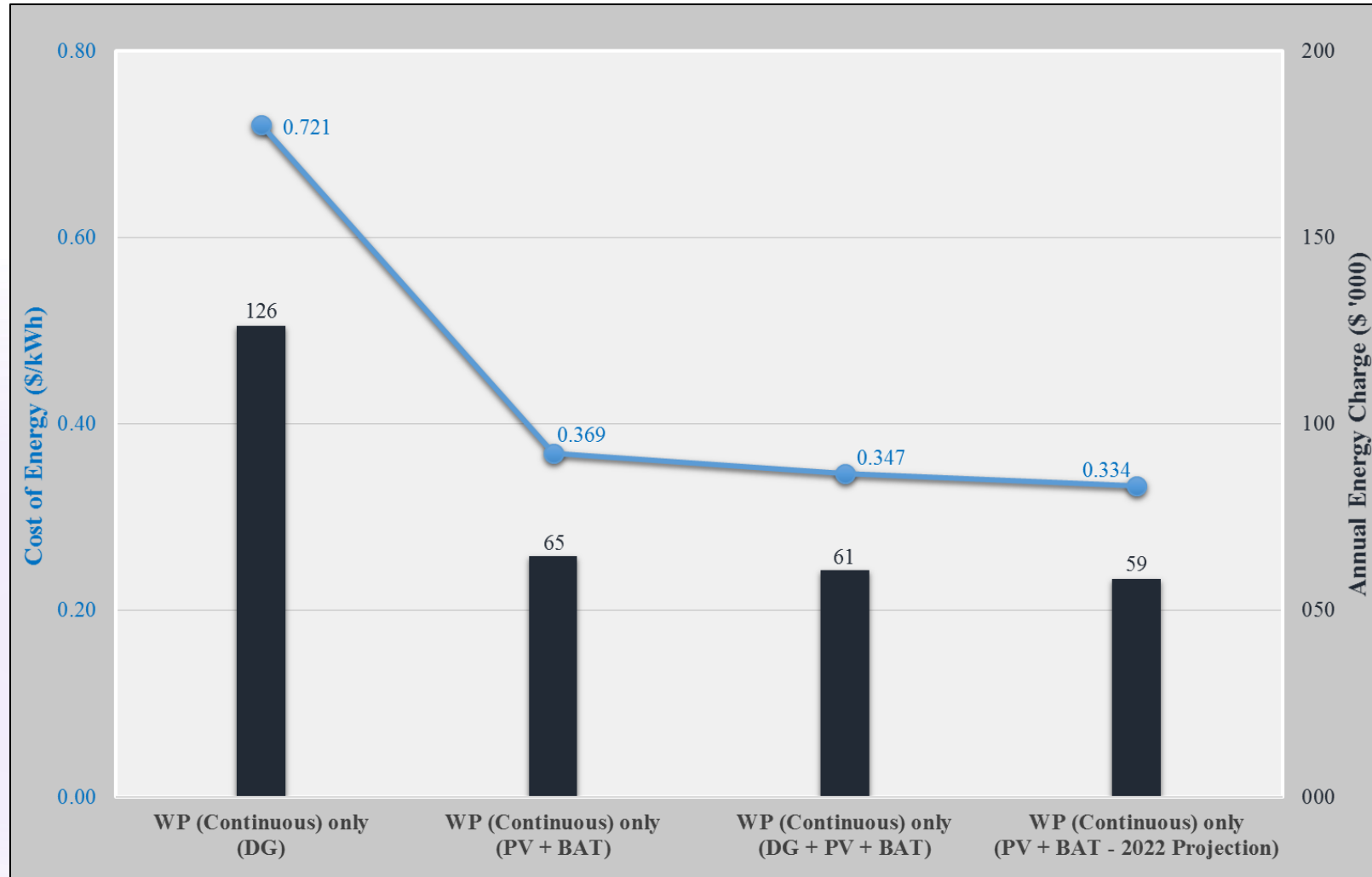
Nyabiheke Refugee Camp



Source: Alonso et. al, 2021

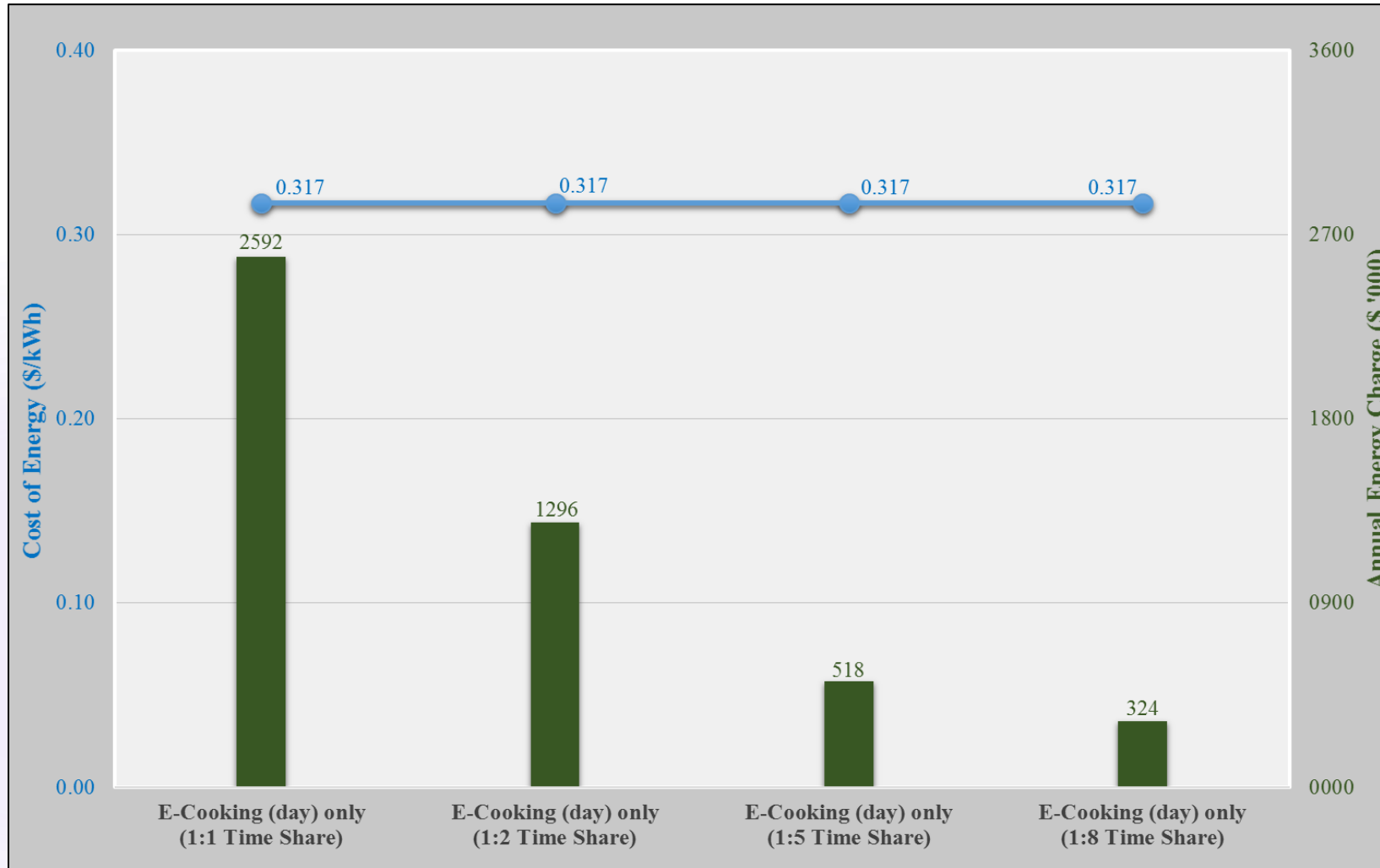


Cheaper Solar PV Water Pump



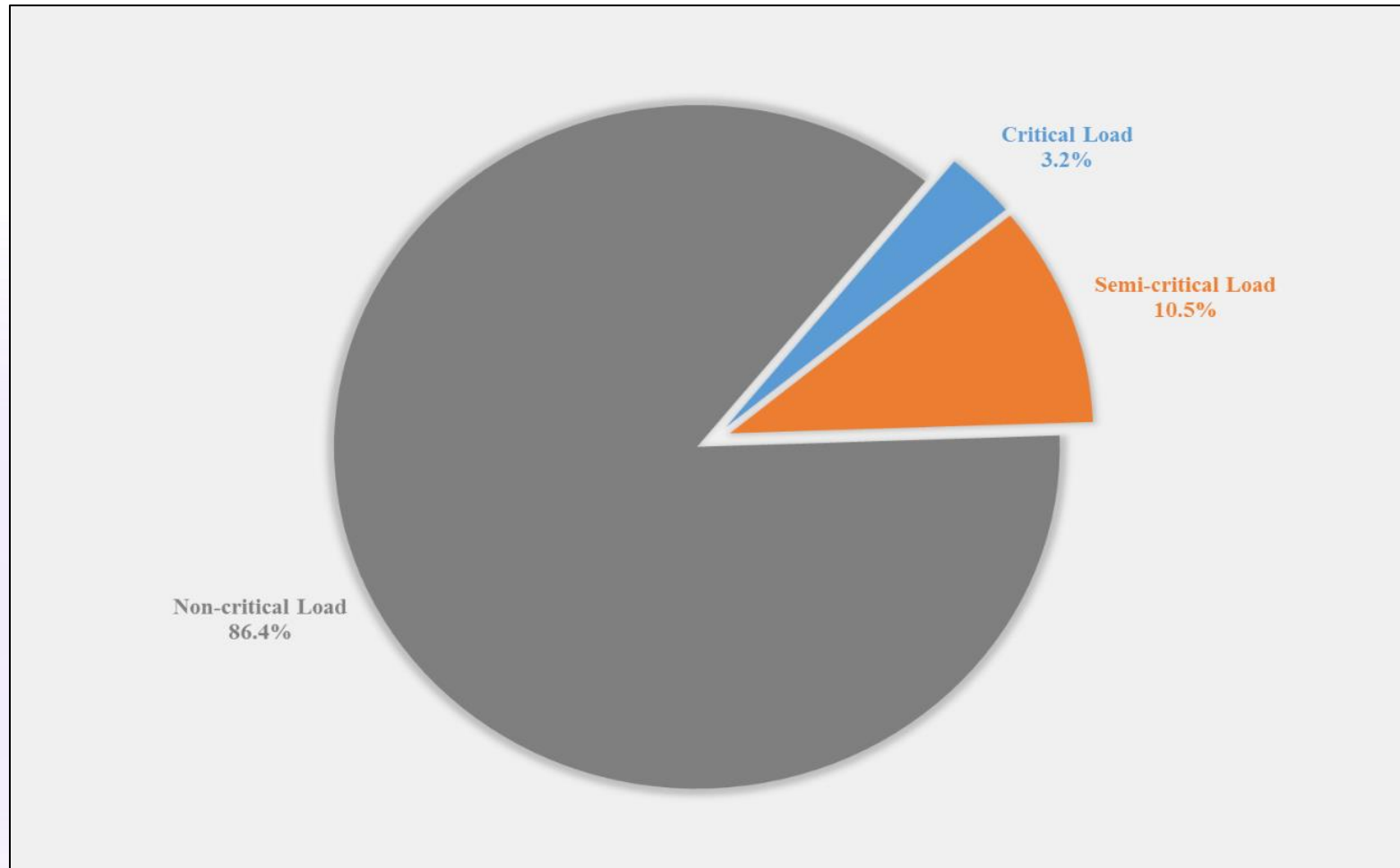
Source: Ray et. al, 2021

Shared Electric Pressure Cooking



Source: Ray et. al, 2021

Critical Load and Resilience

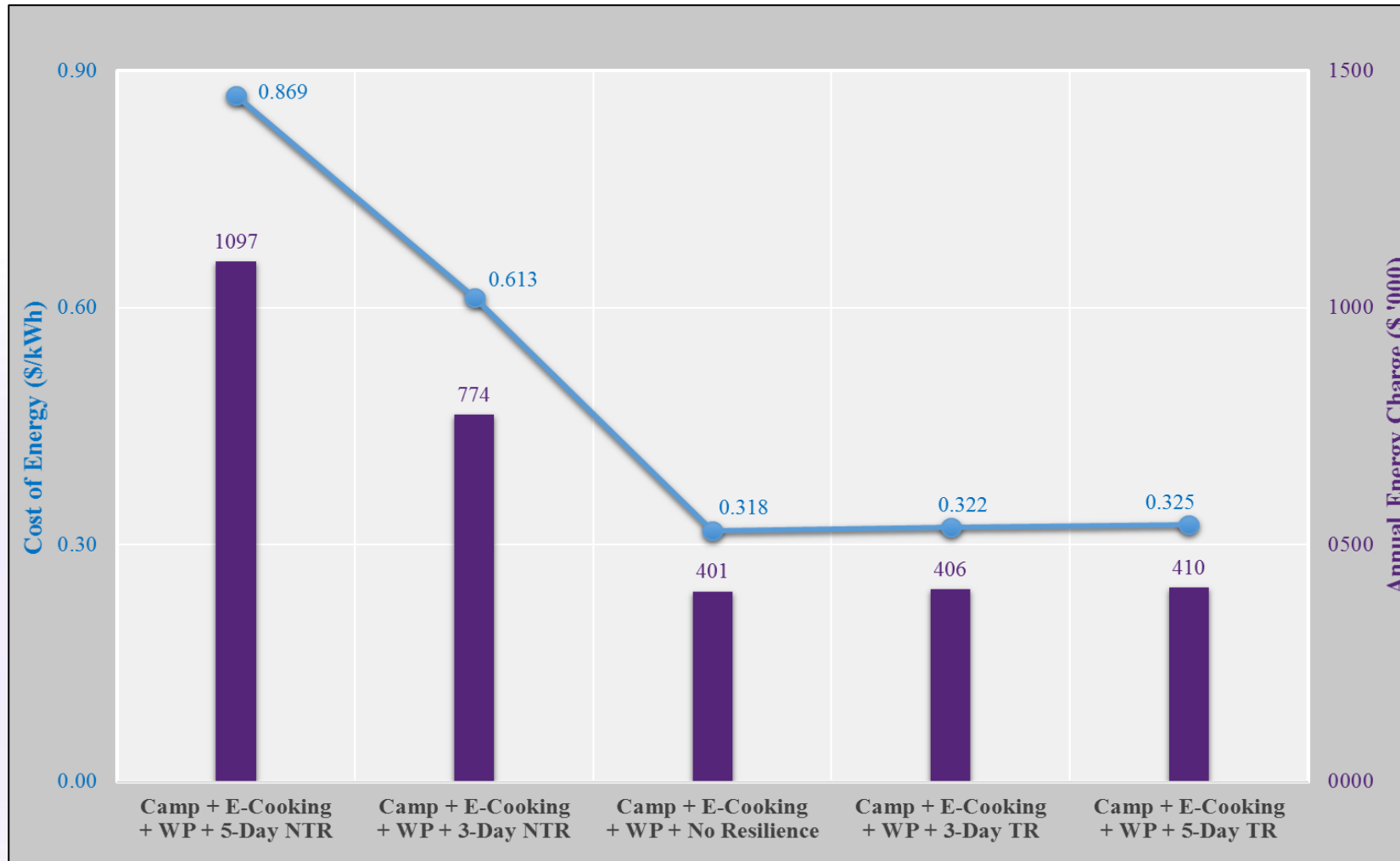


Source: Ray et. al, 2021

Energy Management and LCOE



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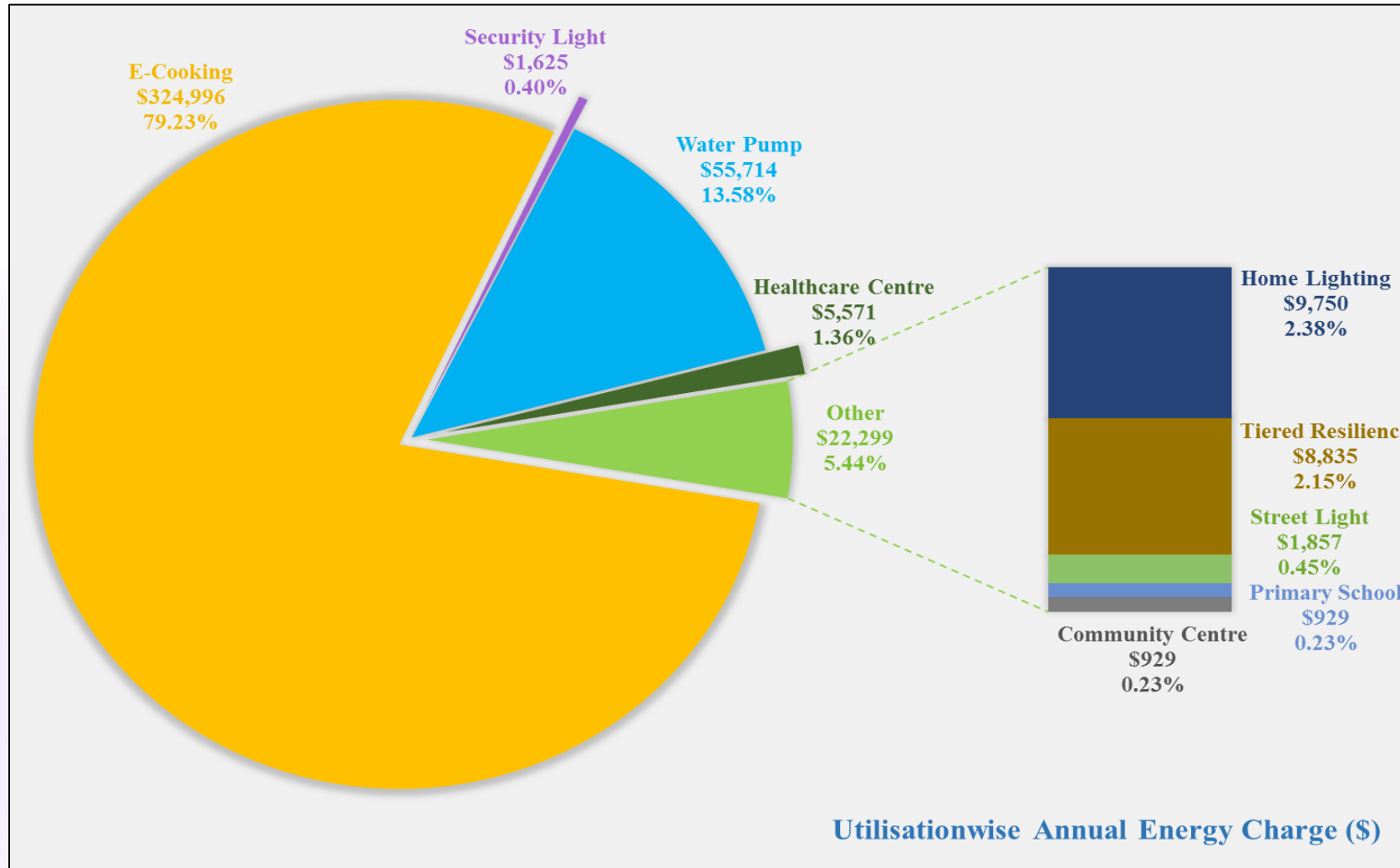


Source: Ray et. al, 2021

All Essential Needs Efficiently Met



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Source: Ray et. al, 2021

Conclusions



- ▶ Consumers can engage and share with demand response
- ▶ Mini-grids can gainfully employ household loads to be viable
- ▶ Solar PV powered refugee camps need energy management
- ▶ Smart-crafted Power Purchase Agreements improve affordability

Refugee Camps: Modeling Demand Flexibility and Tiered-resilience to Reduce Energy Costs



The views and opinions expressed in this work are those of the author's and do not represent the official position of UL.