MECS Modern Energy Cooking Services

Developing the CREST model for demand modelling in MECS

Appliance Data and Multi-Tier Framework for household electrical load modelling

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Introduction

The aim of this work is to develop a set representative appliance demands for the MECS-CREST model, using data from the Multi-Tier Framework (MTF) developed by the World Bank and reported in the *Beyond Connections* document [1], where possible. This report is based mainly on work in the *Beyond Connections* report and provides a summary of the MTF, with particular reference to electrical household appliances.

The work presented here starts with an overview of the MTF, then it presents a hierarchy of the different indices. Using this hierarchy as a guide the report drills down into the indices used to measure household access to energy and reports where the MTF can provide information on appliances that can be applied in the MECS-CREST model.

A working paper that describes the MECS-CREST model development is given in https://mecs.org.uk/wp-content/uploads/2020/07/Household-load-modelling_working-paper_30_07_20.pdf (available at the time of writing).

1 Description of the Multi-Tier Framework (MTF)

The Multi-Tier Framework (MTF) is a method for quantifying access to energy. It stems from work in the Global Tracking Framework [2] by SE4ALL which suggested further work was required in the area of multi-tier frameworks. Since the concept of 'energy access' is difficult to define the MTF describes several core concepts of energy access, summarized below:

1. ***Access to energy can mean many things:*** *access to energy supply, access to energy services, actual use of energy, access achieved through stacking of multiple energy solutions.*
2. ***Socioeconomic development is the primary objective of expanding energy access.***
3. ***Access to energy is needed at multiple locales:*** *households, productive engagements, and community facilities*
4. ***Access pertains to usability of supply rather than actual use of energy.***
5. ***Attributes of the energy supply affect the usability of energy for desired services:*** *The attributes of energy include capacity (adequacy), availability, reliability, affordability, quality, legality, health impact, safety, and convenience, among others*
6. ***Improvement in energy access refers to a continuum of improvements in attributes of energy supply****. This forms the basis of a multi-tier conceptualization of energy access to reflect the continuum versus a binary conceptualization.*
7. ***For standalone energy solutions, the collective attributes of the energy supply and conversion device are taken into account.*** *Standalone devices such as solar lanterns and cookstoves deliver a complete energy service (lighting or cooking) rather than just energy supply. In such a case, the collective attributes of the energy supply and the conversion device should be taken into account when examining energy access.*
8. ***All interventions in the energy sector can contribute to improved access by moving users to higher levels of attributes.*** *Such interventions not only include new household electricity connections and delivery of clean cookstoves, but other projects such as power generation, transmission, gas pipelines, liquefied petroleum gas (LPG) bottling, minigrid systems, solar home systems, biogas projects, fuel-wood plantations, and briquette manufacture, among others. In addition, soft aspects such as policy formulation, credit mechanisms, market structuring, regulatory reforms, institutional capacity development, consumer services enhancement, loss-*

reduction measures, efficiency improvement, and other aspects may also contribute to enhanced access to energy.

1.1 Hierarchy of the Multi-Tier Framework (MTF)

The Multi-tier framework is divided into three main indices:

- Household access to energy
- Access to energy for productive uses which increase income or productivity such as shops, barbers etc.
- Access to energy for community uses such as health centres and schools

As shown in in the left-hand side of Figure 1 the index of household and community use access to energy are further subdivided into three indices which are described in detail in section 2:

- Household electricity index (section 2.1)
- Household cooking index (section 2.3)
- Household heating index (section 2.4)

The Tier value for a household may be calculated as the mean of these three household sub-indexes, although this incorporation of different indices into a single value is less meaningful. The tier value, which ranges from 0 to 5, can be adjusted to a scale of 100 by multiplying the tier value by 20.

For any geographical area, an overarching index of access to energy can be calculated as the average of the indices across the three locales—households, productive uses, and community facilities.

The index for a larger geographical area can be obtained by calculating the population weighted average of indices across the smaller areas that constitute the larger area. For example, the index at the state level can be obtained by calculating the weighted average of the district-level indices.

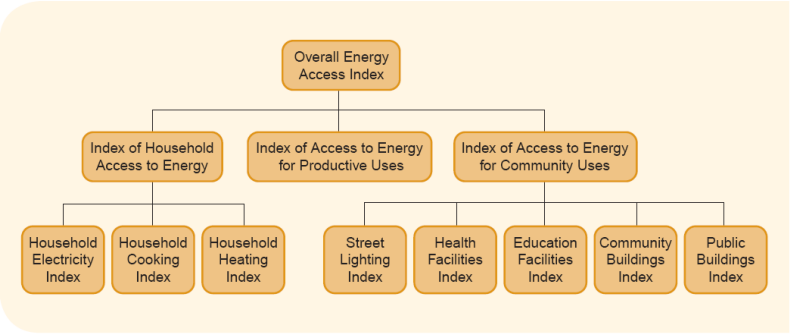

Figure 1 Hierarchy of energy access indices [1]

The MTF can be applied at different levels of detail:

- Comprehensive
- Simplified
- Minimalistic

Table 1 describes these detail levels in terms of the access indices in [1]. Comprehensive MTF data and reports are available at [3] for:

- Cambodia
- Ethiopia
- Myanmar
- Nepal
- Rwanda
- Sãn Tomé y Príncipe
- Zambia

TABLE 11.1
Comparison of Frameworks for Global Assessment

	COMPREHENSIVE FRAMEWORK	SIMPLIFIED FRAMEWORK	MINIMALISTIC FRAMEWORK
Key Purpose	Detailed survey questionnaire for country-level assessment that can be used for diagnostic review	Reduced number of questions that may be used for global assessment of energy access under SE4All	Minimum number of questions that may be incorporated in existing household surveys (e.g., DHS and LSMS)
Household Characteristics	Covered in detail, including, inter alia, education, social, occupational, basic income, and expenditure characteristics	Covered in a simplified manner without assessment of income and expenditure	Not covered separately (already covered by existing surveys)
Household Access to Electricity	Comprehensive assessment based on all attributes: capacity, duration, reliability, quality, affordability, legality, convenience, safety, and health	Simplified assessment based on reduced set of attributes: capacity, duration, reliability, quality	Minimalist assessment-only based on two attributes: capacity and duration
Household Access to Lighting	Comprehensive assessment based on lumen hours of lighting as well as phone charging capability, including use behavior	Simplified assessment based on type of lighting device and phone charging capability	Minimalist assessment based on use of electrical lighting and phone charging capability
Household Access to Cooking	Comprehensive assessment based on all attributes as well as information about ventilation, cooking area, conformity to standards, and maintenance	Simplified assessment based on primary and secondary cooking solutions as well as ventilation, convenience, and affordability	Minimalist assessment based on type of primary and secondary cooking solutions
Household Access to Heating	Comprehensive assessment based on all attributes	Simplified assessment based on capacity, duration, and convenience of primary heating solution	Not included
Energy Access for Productive Uses	Detailed assessment based on all relevant activities and sources of energy	Simplified assessment based on electricity access	Not included
Energy Access for Community Uses	Detailed assessment based on survey of institutions	Simplified assessment based on household interviews	Not included

Table 1 how different levels of detail apply under different categories of the MTF index [1]

2 Household access to energy

The following sections describe the MTF indices for household access to energy, which is on the left side of the hierarchy shown in Figure 1. These cover the following:

- Household electricity index
- Household cooking index
- Household heating index

The following sections describe how these indices can be applied to the MECS demand modelling work.

2.1 Household electricity index in the Multi-Tier Framework (MTF)

This section of the report describes how the MTF can be used to specify appliance demands for for use in the MECS-CREST model.

For the first stage of the MECS-CREST model we seek to model 'baseline demand' for a specific household, "*with a specified number of residents, a specified set of lightbulbs and appliances, a specified cooking pattern (eg for each meal, how many people fed and the general timing) and in a place with a specified pattern of irradiance".*

The baseline demand is diversified to give multiple instances of the same household type. This is achieved within the MECS-CREST by varying various characteristics within the model and by varying the appliances assigned to each (household) instance.

The appliance data in the MTF can be used to populate the MECS-CREST model. Electric cooking (eCook) devices will be added to the model separately later, in order to determine the effect of eCook uptake on the electricity infrastructure (solar home system, mini-grid or electrical network). Specifically the MTF household electricity index can be used to describe a superset of *possible* appliances in a household for households at different MTF Tier levels, as shown in the following sections.

In order to obtain appliance rating data from the MTF for the MECS-CREST the household electricity index (far left bottom in Figure 1) is used. For this index the MTF assesses 7 attributes [1]:

1. Peak capacity (power cap in W or Wh, OR Services)
2. Availability (hours/day, hours/evening)
3. Reliability (number of disruptions per week)
4. Quality (voltage problems)
5. Affordability
6. Legality (who pays)
7. Health & Safety

This is shown in Table 2 along with the categorisation values for different tiers. The only attribute relevant specifically to appliance rating is *Peak Capacity* which can be applied in three ways:

1. Peak capacity as power in Watts
2. Peak capacity as energy per day in Wh/day
3. Services as different categories in a narrative description

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Peak Capacity	Power capacity ratings[27] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/ day	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Affordability					Cost of a standard consumption package of 365 kWh/year <5% of household income		
	6. Legality						Bill is paid to the utility, prepaid card seller, or authorized representative	
	7. Health & Safety						Absence of past accidents and perception of high risk in the future	

Table 2 MTF for measuring access to household electricity supply [1, Sec. Table 6.10]

There are several tables in [1] that contain similar but slightly different information, as described in the following paragraphs.

Peak capacity is related to descriptive power ratings (*very low power, low power, etc.*) and typical appliances in Table 3.

Table 4 attributes some appliance types to the descriptive power ratings in Table 3.

Table 5, developed by the author, brings together all the information in Table 2, Table 3 and Table 4.

CAPACITY	TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Power Capacity Ratings (minimum in W or daily Wh)		3 W	50 W	200 W	800 W	2,000 W
		12 Wh	200 Wh	1.0 kWh	3.4 kWh	8.2 kWh
Supported Appliances		Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
Typical Supply Technologies		Solar lantern	Rechargeable battery, SHS	Medium SHS, fossil fuel-based generator, mini-grid	Large SHS, fossil fuel-based generator, mini-grid, central grid	Large fossil fuel-based generator, central grid

Table 3 Tiers of capacity of electricity supply [1, Sec. Table 6.3]

TABLE 6.2
Typical Household Electric Appliances by Power Load

	VERY LOW-POWER APPLIANCES	LOW-POWER APPLIANCES	MEDIUM-POWER APPLIANCES	HIGH-POWER APPLIANCES	VERY HIGH-POWER APPLIANCES
Lighting	Task lighting	Multipoint general lighting			
Entertainment & Communication	Phone charging, radio	Television, computer, printer			
Space Cooling & Heating		Fan	Air cooler		Air conditioner,[a] space heater[a]
Refrigeration			Refrigerator,[a] freezer[a]		
Mechanical Loads			Food processor, water pump	Washing machine	Vacuum cleaner
Product Heating				Iron, hair dryer	Water heater
Cooking			Rice cooker	Toaster, microwave	Electric cooker

[a]Continuous load

Table 4 Typical household appliances by power demand [1, Sec. Table 6.2]

MECS Modern Energy Cooking Services

Developing the CREST model for demand modelling in MECS

		Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Peak Capacity	Power Capacity ratings in W or daily Wh		min 3 W	min 50 W	min 200 W	min 800W	min 2 kW
			min 12 Wh	min 200 Wh	min 1.0 kWh	min 3.4 kWh	min 8.2 kWh
	OR Services		Lighting of 1,000 lmhr/day	Electrical lighting, air circulation, television and phone charging are possible			
Descriptive	Supported Appliances		Very low-power appliances	Low-power appliances	Medium-power appliances	High-power appliances	Very high-power appliances
	Typical Supply Technologies		Solar lantern	Rechargeable battery, SHS	Medium SHS, fossil fuel based generator, mini-grid	Large SHS, fossil fuel based generator, mini-grid, central grid	Large fossil based generator, central grid
Typical Household Electric Appliances	Lighting		Task lighting	Multi-point general lighting			
	Entertainment and Communication		Phone charging, radio	Television, computer, printer			
	Space Cooling and Heating			Fan	Air cooler		Air conditioner, space heater
	Refrigeration				Refrigerator, freezer		
	Mechanical Loads				Food processer	Washing machine	Vacuum cleaner
	Product Heating					Iron, hairdryer	Water heater
	Cooking				Rice cooker	Toaster, microwave	Electric cooker
Availability (Duration)	Hours per day		min 4 hrs	min 4 hrs	min 8 hrs	min 16 hrs	min 23 hrs
	Hours per evening		min 1 hr	min 2 hrs	min 3 hrs	min 4 hrs	min 4 hrs

Table 5 Summary of miniumum requirements of power capacity and services and durations by Tier with appliances

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Table 6, taken from[1] gives appliance ratings and usage time related to the tier levels. In contrast to Table 5, which gives the minimum tier for each appliance, Table 6 shows how usage increases for higher tiers. Note that for most appliances in Table 4 the descriptive power rating maps to the minimum Tier level (e.g. *very low power appliances* maps to Tier 1). However, there is an inconsistency for Washing Machine and Refrigeration, which would be expected to map to Tier 4 and 3 respectively from Table 4, but have minimum of Tier 3 and 4 respectively in Table 6.

Table 6 is also found in the previous work in Annex 5 of [2] but has some additions/differences:

- power demand and duration of use for some appliances are given as a range, rather than a single value
- values for minimum annual consumption for some appliances is different
- the annual consumption for some appliances increases with increasing tier level (e.g. indicating more light bulbs in higher tier households). Previously this value remained constant across the tiers.

The differences between the datasets in [1] and [2, Ch. Annex 2] summarised in Table 7.

APPLIANCES	WATT EQUIVALENT PER UNIT	HOURS PER DAY	MINIMUM ANNUAL CONSUMPTION, IN kWh				
			TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
Task lighting	1/2	4/8	1.5	2.9	2.9	5.8	5.8
Phone charging	2	2/4	1.5	2.9	2.9	2.9	2.9
Radio	2/4	2/4	1.5	5.8	5.8	5.8	5.8
General lighting	12	4/8/12		17.5	17.5	35.0	52.5
Air circulation	20/40	4/6/12/18		29.2	87.6	175.2	262.8
Television	20/40	2		14.6	29.2	29.2	29.2
Food processing	200	0.5			36.5	36.5	36.5
Washing machine	500	1			182.5	182.5	182.5
Refrigerator	300	6				657.0	657.0
Iron	1,100	0.3				120.5	120.5
Air conditioner	1,500	3					1,642.5
Total			4.5	73	365	1,250	3,000

Table 6 Indicative calculation of electricity consumption by Tier, from [1]

Appliance	Demand Rating	Increased Demand with Tier level
Task Lighting	Increased	
Phone Charging	Increased	
Radio	Increased	Yes
General Lighting	Decreased	
Air Circulation	Increased	
Television	Same at Tier 2	Yes
Food Processing	Decreased	
Washing Machine	Same	
Refrigerator		
Iron	Same	
Air Conditioner	Increased	

Table 7 Differences between the data in [2] and [1]

Table 8 attributes appliance power rating and duration of use to each Tier level based on back calculating from the minimum annual consumption (kWh) in Table 6 and using the range values for duration and rating. For example, task lighting is 1 or 2 W and for 4 to 8 hours per day. Using these values minimum and maximum values in combination consumption values of 4 Wh/day, 8Wh/day (two combinations give this result), and 16 Wh/day. These equate to 1.46 kWh/year, 2.920 kWh/year, 5.840 kWh/year which match with Tier 1, Tiers 2 to 3 and Tiers 4 to 5 respectively in Table 6.

This table can be used to attribute appliances along with their rating and usage (duration) to the MECS-CREST model based on the MTF tier level of the household.

Appliance	Tier 1			Tier 2			Tier 3			Tier 4			Tier 5		
	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)
Task Lighting	1	4	1.5	2	4	2.9	2	4	2.9	2	8	5.8	2	8	20
Phone Charging	2	2	1.5	2	4	2.9	2	4	2.9	2	4	2.9	2	4	2.9
Radio	2	2	1.5	4	4	5.8	4	4	5.8	4	4	5.8	4	4	5.8
General Lighting				12	4	17.5	12	4	17.5	12	8	35.0	12	12	52.5
Air Circulation				20	4	29.2	40	6	87.6	40	12	175.2	40	18	262.8
Television				20	2	14.6	40	2	29.2	40	2	29.2	40	2	29.2
Food Processing							200	0.5	36.5	200	0.5	36.5	200	0.5	36.5
Washing Machine							500	1	182.5	500	1	182.5	500	1	182.5
Refrigerator										300	6	657.0	300	6	657.0
Iron										1100	0.3	120.5	1100	0.3	120.5
Air Conditioner													1500	3	1642.5

Table 8 Power and duration by Tier derived from data in Table 6

2.2 Extending the appliances considered

Table A2.1 of [1] gives Electricity Supply Requirements for *Electricity Services* which is one of the ways the MTF attributes Electricity Peak Capacity (seeTable 2). This is a summary of appliance rating values from various sources, in a narrative form. The aim of the table is to establish a power rating for different appliances. The table contains more appliances than Table 6 but only considers the power demand and not duration of use. Therefore, unlike the data in Table 8, the energy consumption cannot be calculated.

The appliances A2.1 include all those given in the indicative calculation of electricity consumption by Tier, Table 6 (also Table 7, Table 8), and give similar power rating values. A summary of the the appliances not included in Table 6 (also Table 7, Table 8) is given in Table 9, along with a minimum tier rating and estimated time duration of use. The minimum tier is assigned as follows:

- the appliance name is cross referenced with appliances in the *Typical Household Electric Appliances* section of Table 5 (which is slightly different to the appliances given in Table 8). If there is a match, the tier assigned according to the appliance position in the table. This is the case for most appliances.

- If the tier rating is not found as above, the power rating is used to assign the tier according to the *Power Capacity Ratings (W)* in Table 5

Since no usage durations are given for these appliances, it is estimated and the basis of the estimation is also given in Table 9. Lastly, the author evaluates whether the duration of usage should increase with increasing tier level or not. Rows in green indicate those appliances that are included, whilst rows in red signify dis-included appliances. The reason for dis-including an appliance are given in Table 10.

Appliance	Reference Power (Watts)	Minimum tier	Basis for Minimum Tier	Estimated duration (hours/day)	Basis for Estimated duration	Increases with tier level	Basis for Annual Consumption
Computer	70	2	Named appliance in Table 5	0 - 8	Estimate by author	Y	Daily energy x 365
Printing	45	2	Named appliance in Table 5			n/a	Not included
Hair Dryer	1,200	4	Named appliance in Table 5	0.1[1]		N	Daily energy x 365
Water Pump	500	3	Power rating in Table 5	0.2[2]		N	Daily energy x 365
Rice Cooker	400	3	Named appliance in Table 5			N	Not included
Electric Toaster	1,000	4	Named appliance in Table 5			N	Not included
Microwave	1,250	4	Named appliance in Table 5			N	Not included
Electric Stove (burner/hotplate only)	1,500	4	Power rating in Table 5			N	Not included
Water Heating	3500[3]	5	Entry in Table 5	1	From Table A2.1 of [1]	N	Daily energy for half the time (x182)
Air cooling	240	3	Entry in Table 5	1 - 3	Same as air conditioning at Tier 5	Y	
Room heaters		5	Entry in Table 5			Y	

Table 9 Additional appliance ratings (only) from [1, Ch. Annex 2]

[1] Hair dryer may not be used every day. The value 0.1 (6 minutes) is an estimate.

[2] Table A2.1 of [1] states less than 30 minutes collection time per person. The value of 0.2 (12 minutes) is an estimate.

[3] The figure for water heating (3.5kW for 1 hour) seems high. The calculation for this in Appendix 2 of [1] may be incorrect.

Appliance	Tier 1			Tier 2			Tier 3			Tier 4			Tier 5		
	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)
Task Lighting	1	4	1.5	2	4	2.9	2	4	2.9	2	8	5.8	2	8	20
Phone Charging	2	2	1.5	2	4	2.9	2	4	2.9	2	4	2.9	2	4	2.9
Radio	2	2	1.5	4	4	5.8	4	4	5.8	4	4	5.8	4	4	5.8
General Lighting				12	4	17.5	12	4	17.5	12	8	35.0	12	12	52.5
Air Circulation				20	4	29.2	40	6	87.6	40	12	175.2	40	18	262.8
Television				20	2	14.6	40	2	29.2	40	2	29.2	40	2	29.2
Food Processing							200	0.5	36.5	200	0.5	36.5	200	0.5	36.5
Washing Machine							500	1	182.5	500	1	182.5	500	1	182.5
Refrigerator										300	6	657.0	300	6	657.0
Iron										1100	0.3	120.5	1100	0.3	120.5
Air Conditioner													1500	3	1642.5
Extended Appliances from Appendix 2															
Computer				*70*	*2*	51.1	*70*	*4*	102.2	*70*	*4*	102.2	*70*	*8*	204.4
Water Pump							500	0.2	36.5	500	0.2	36.5	500	0.2	36.5
Hair Dryer										1200	0.1	43.8	1200	0.1	43.8
Water Heating													3500	1	638.8

Table 11 uses the data in Table 9 to evaluate appliance rating and usage by MTF Tier level in the same format as Table 8. Some appliances are not considered for the MECS-CREST model for the reasons given below in Table 10:

Appliance	**Reason for dis-inclusion**

Printing	There is no information on time of use – for a household it is expected to be fairly low usage and that it would have a small impact on overall demand.
Rice Cooker	Cooking appliances will be considered separately
Air cooling	From the MTF report [1] it isn't clear what the difference is between *Air Cooling* and *Air Conditioning* except that *Air Conditioning* has significantly higher consumption. It was decided to use *Air Conditioning* and to dis-include *Air Cooling*
Electric Toaster	Cooking appliances will be considered separately
Microwave	Cooking appliances will be considered separately
Electric Stove (burner/hotplate only)	Cooking appliances will be considered separately
Room heaters	Excluded based on the fact that the current countries under consideration are all warm.

Table 10 Appliances not considered in the MECS-CREST model

Table 11 gives the full list of appliances from Table 8 and the extended appliance list from Table 9.

Appliance	Tier 1			Tier 2			Tier 3			Tier 4			Tier 5		
	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)	Watts	hours /day	Min. annual consumption (kWh)
Task Lighting	1	4	1.5	2	4	2.9	2	4	2.9	2	8	5.8	2	8	20
Phone Charging	2	2	1.5	2	4	2.9	2	4	2.9	2	4	2.9	2	4	2.9
Radio	2	2	1.5	4	4	5.8	4	4	5.8	4	4	5.8	4	4	5.8
General Lighting				12	4	17.5	12	4	17.5	12	8	35.0	12	12	52.5
Air Circulation				20	4	29.2	40	6	87.6	40	12	175.2	40	18	262.8
Television				20	2	14.6	40	2	29.2	40	2	29.2	40	2	29.2
Food Processing							200	0.5	36.5	200	0.5	36.5	200	0.5	36.5
Washing Machine							500	1	182.5	500	1	182.5	500	1	182.5
Refrigerator										300	6	657.0	300	6	657.0
Iron										1100	0.3	120.5	1100	0.3	120.5
Air Conditioner													1500	3	1642.5
Extended Appliances from Appendix 2															
Computer				*70*	*2*	51.1	*70*	*4*	102.2	*70*	*4*	102.2	*70*	*8*	204.4
Water Pump							500	0.2	36.5	500	0.2	36.5	500	0.2	36.5
Hair Dryer										1200	0.1	43.8	1200	0.1	43.8
Water Heating[4]													3500	1	638.8

Table 11 Full list (including the extended appliance list) of appliance rating and duration by MTF Tier level

[4] The figure for water heating (3.5kW for 1 hour) seems high. The calculation for this in Appendix 2 of [1] may be incorrect.

2.2.1 Household access to lighting and phone charging

Household access to lighting and phone charging is considered to be so important that it is treated separately. Tier 1 in the MTF is the threshold level for adequate basic lighting and phone charging, in other words a household with basic lighting and phone charging is at Tier 1 or greater. Tier 0 indicates no access to electricity, however there is a nuanced approach to measure progress between Tier 0 and Tier 1 access in [1, Ch. 7]. This considers access to lighting and communication including phone charging at a neighbour's house.

2.3 Household cooking index in the Multi-Tier Framework (MTF)

The *Beyond Connections* report states that "*evidence shows that even when electricity is available, the poor rarely use it to meet their cooking needs*" [1]

The MTF for measuring access to energy for household cooking is different to the multi-tier framework for measuring cook stove performance that was proposed by the International Workshop Agreement (IWA) of
the International Organization for Standardization (ISO). In order to differentiate between the two, the cooking index in [1] uses the term "levels" since the IWA uses the term "tiers".

The MTF assesses access to household cooking under the categories:

- Indoor air quality (in terms of $PM_{2.5}$ and CO)
- Cookstove efficiency (provisional IWA tiers are used, but these are not described)
- Convenience (in terms of fuel collection time and stove preparation time)
- Safety (based on IWA tiers or accidents)
- Affordability (as a percentage of household income)
- Quality of fuel (in terms of heat rate that impacts the ease of cooking)
- Availability of primary fuel (as a percentage availability over a year)

The cooking index does not relate to appliance ratings and therefore is not useful for setting the MECS-CREST appliance data. However, this cooking index could be useful for assessing the impact of eCook devices considered in the MECS project on energy access tier levels.

TABLE ES.4
Multi-tier Matrix for Measuring Access to Cooking Solutions

ATTRIBUTES			LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
	1. Indoor Air Quality	$PM_{2.5}$ ($\mu g/m^3$)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
		CO (mg/m^3)					< 7 (WHO guideline)	
	2. Cookstove Efficiency (not to be applied if cooking solution is also used for space heating)			Primary solution meets Tier 1 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 2 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 3 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	Primary solution meets Tier 4 efficiency requirements [to be specified by a competent agency consistent with local cooking conditions]	
	3. Convenience: Fuel acquisition and preparation time (hrs/week)				< 7	< 3	< 1.5	< 0.5
	Stove preparation time (min/meal)				< 15	< 10	< 5	< 2
	4. Safety of Primary Cookstove	IWA safety tiers		Primary solution meets (provisional) IWA Tier 1 for Safety	Primary solution meets (provisional) IWA Tier 2	Primary solution meets (provisional) IWA Tier 3	Primary solution meets (provisional) IWA Tier 4	
		OR Past accidents (burns and unintended fires)					No accidents over the past year that required professional medical attention	
	5. Affordability						Levelized cost of cooking solution (inc. cookstove and fuel) < 5% of household income	
	6. Quality of Primary Fuel: variations in heat rate due to fuel quality that affects ease of cooking						No major effect	
	7. Availability of Primary Fuel						Primary fuel is readily available for at least 80% of the year	Primary fuel is readily available throughout the year

Table 12 Tiers for access to energy for cooking [1, Fig. 8.15]

2.4 Household heating index in the Multi-Tier Framework (MTF)

The section on the household heating index in the *Beyond Connections* report is fairly short. It states that the requirement for household heating is sometimes met with the same device as is used for cooking, but sometimes a separate device is used. The range of heating solutions includes: electric heating; fuel based centralised district heating system; fuel based stand-alone heating and direct solar heating. The need for heating can also be met with increased clothing or warm drinks. Space heating needs can be curtailed, although with increased discomfort and sometimes harm, through the use of other mechanisms. Unlike cooking is not usually a basic requirement for survival. The access factors for household heating are given in Table 13, it does not include ~~include~~ any appliance specific data.

Space heating is not considered in the MECS-CREST model as it is not required in the work being undertaken at this stage. The access to space heating does not include any appliance specific data.

TABLE ES.5
Multi-tier Matrix for Access to Space Heating

ATTRIBUTES		LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
1. Capacity			Personal space around individuals is heated	At least one room has heating		All rooms in the household have heating	
2. Duration					At least half the time when needed (> 50% of the time)	Most hours when needed (> 75% of the time)	Almost all hours when needed (> 95% of the time)
3. Quality					Comfortable temperature at least 50% of the time	Comfortable temperature at least 75% of the time	Comfortable temperature all the time
4. Convenience (fuel collection time in hrs/week)				<7	<3	<1.5	<0.5
5. Affordability					Cost ≤ 2 times the grid tariff		Cost ≤ the grid tariff
6. Reliability (number of disruptions/day)					<7	<3	<3 (total duration < 2 hours)
7. Indoor Air Quality	$PM_{2.5}$ (µg/m^3)		[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	[To be specified by a competent agency, such as WHO, based on health risks]	< 35 (WHO IT-1)	< 10 (WHO guideline)
	CO (mg/m^3)					< 7 (WHO guideline)	
8. Safety						No accidents (burns or unintended fires) over the past year that required professional medical attention	

Table 13 p11 Beyond Connections (same table on126 Table 8.16)

3 Application of the MTF to appliance ownership model

Zambia is one of the countries for which there is a comprehensive MTF survey. This is reported in [4]. The data was collected between September 2017 and March 2018. A total of 3,612 households were surveyed in 260 *evaluation areas*, 130 of which were urban and 130 were rural. In the survey none of the sampled households used mini-grid as their main source of electricity. The survey found a large gap in access between urban and rural areas as shown in Figure 2 Zambia MTF tier distribution comparison of rural and urban areas from [4], with three in four urban households having access to electricity but only one in ten rural households having access. There is also wide differences in access across the provinces.

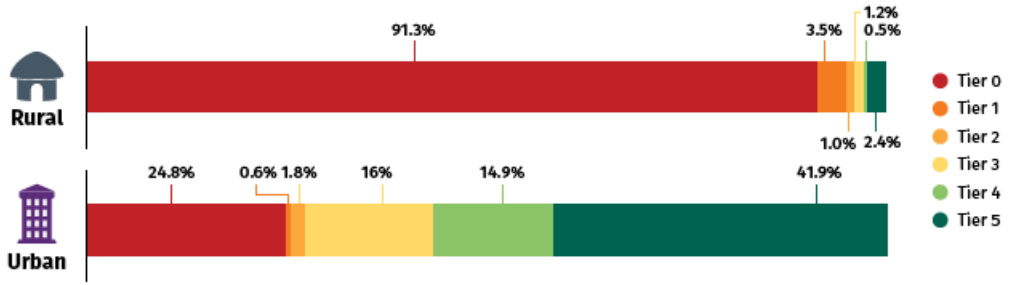

Figure 2 Zambia MTF tier distribution comparison of rural and urban areas from [4]

Table 14 shows the proportion of population within each tier of the MTF for Zambia, categorised by National, Urban and Rural. These figures are used to assign appliances to a group of modelled households in a rural or urban area of Zambia, based on the mapping of appliances and their usage to the MTF tier levels in Table 8 and Table 9. This data is a spreadsheet titled *Appliance Data and Multi-Tier Framework _data_table_v*p*.xlsx*

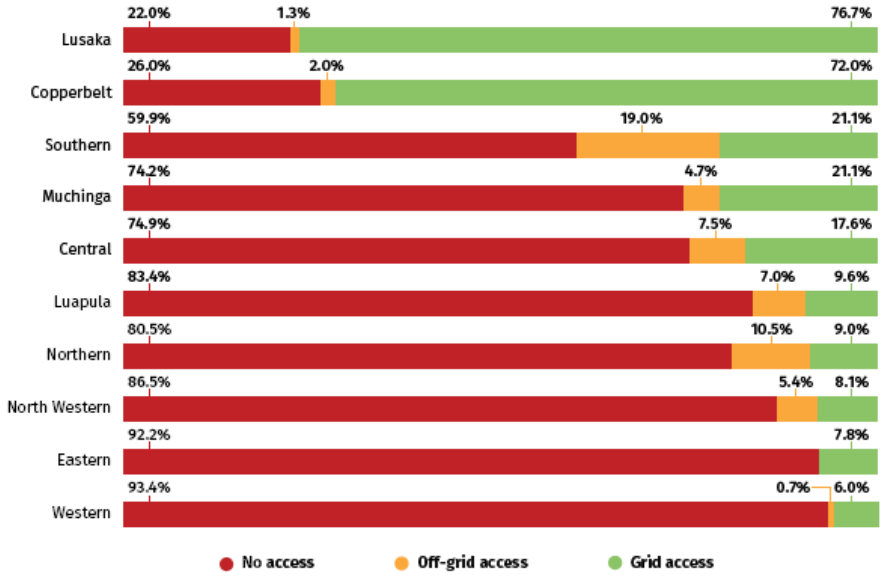

Figure 3 Zambia MTF Tier distribution by province [4]

Zambia		Tier 0 (% of total)	Tier 1 (% of total)	Tier 2 (% of total)	Tier 3 (% of total)	Tier 4 (% of total)	Tier 5 (% of total)
Capacity	National	59.3	2.2	0.7	-	-	37.7
	Urban	24.2[5]	0.6	0.4	-	-	74.8
	Rural	91.2	3.7	1.0	0.1	-	4.1

Table 14

[5] This incorrectly states 59.3 in the document

Zambia					
Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
	Task Lighting	Task Lighting	Task Lighting	Task Lighting	Task Lighting
	Phone Charging	Phone Charging	Phone Charging	Phone Charging	Phone Charging
	Radio	Radio	Radio	Radio	Radio
		General Lighting	General Lighting	General Lighting	General Lighting
		Air Circulation	Air Circulation	Air Circulation	Air Circulation
		Television	Television	Television	Television
			Food Processing	Food Processing	Food Processing
			Washing Machine	Washing Machine	Washing Machine
				Refrigerator	Refrigerator
				Iron	Iron
					Air Conditioner
		Computer	*Computer*	*Computer*	*Computer*
			Water Pump	*Water Pump*	*Water Pump*
				Rice Cooker	*Rice Cooker*
				Electric Toaster	*Electric Toaster*
				Microwave	*Microwave*
				Electric Stove (burner/hotplate only)	*Electric Stove (burner/hotplate only)*
				Hair Dryer	*Hair Dryer*
				Air cooling	*Air cooling*
					Water Heating

Use data from this paper for appliance ToU *C:\Users\b3046420\OneDrive - Newcastle University\Reading\MECSComp of load profs in mGrid - assess perf metrics using meas and interview data_Hartvigsson_2018.pdf*

Table 1
Appliances identified in the interviews, their occurrence and verified rated power. The "-" sign indicate no verification of rated power or calculation of confidence measure was possible. For power, the assumed power is therefore noted in brackets. An "*" sign indicates cases when only one interviewee had the appliance and thus no confidence value could be calculated.

Appliance type	Mean number of appliances per customer	Average rated power (W) (that was verified by inspection)	Usage			
			Start time (average)	Standard deviation (hours:min)	Stop time (average)	Standard deviation (hours:min)
Households						
TV	0.81	88	16:00	5:00	22:00	0:45
DVD	0.6	14.3	17:30	2:15	21:30	1:00
Stereo	0.5	100	19:00	8:30	21:30	1:15
Lights	8.6	29.5	18:00	4:45	21:00	4:00
Iron	0.4	1000	7:15	2:30	10:15	1:00
SMEs						
Lights	1	27	14:30	5:30	20:30	1:15
Stereo	0.4	75	9:30	3:45	20:45	1:30
DVD	0.2	- (14.3)	10:45	5:00	21:30	1:45
TV	0.3	60	10:30	4:30	21:15	1:30
Computer	0.16	Intel Pentium 4[a]	8:00	1:30	19:30	0:45
Trimmer	0.21	- (15 W)	8:00	1:30	21:30	2:00
Hairdryer	0.16	65	14:00	*	16:00	*

[a] An Intel Pentium 4 computer is assumed to use 150 W of continuous power. The computers were also fitted with TFT screens (15–19 in.) with an assumed continuous power consumption of 20 W.

4 References

[1] M. Bhatia and N. Angelou, *Beyond connections: energy access redefined*. World Bank, 2015.

[2] N. Angelou *et al.*, “Global tracking framework,” The World Bank, 2013.
[3] “Countries | Multi Tier Framework.” https://mtfenergyaccess.esmap.org/countries (accessed Sep. 24, 2020).
[4] L. Luzi, Y. Lin, B. B. Koo, D. Rysankova, and E. Portale, “Zambia–Beyond Connections: Energy Access Diagnostic Report Based on the Multi-Tier Framework,” World Bank, 2019.