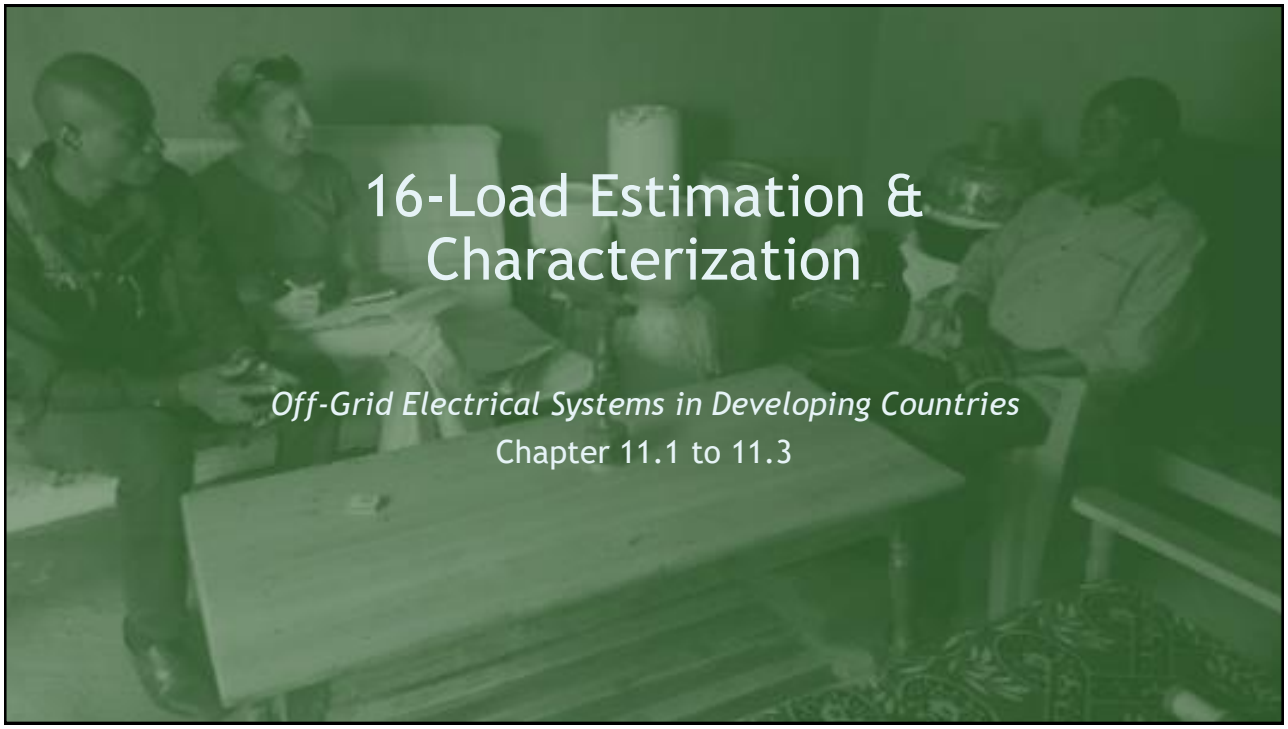

16-Load Estimation & Characterization

Off-Grid Electrical Systems in Developing Countries

Chapter 11.1 to 11.3

1

Learning Outcomes

At the end of this lecture, you will be able to:

- ✓describe the importance of load estimation in off-grid system design
- ✓articulate the characteristics of the load that are important to designing off-grid systems
- ✓calculate the average daily load, peak load, load factor, coincident factor of a group of users

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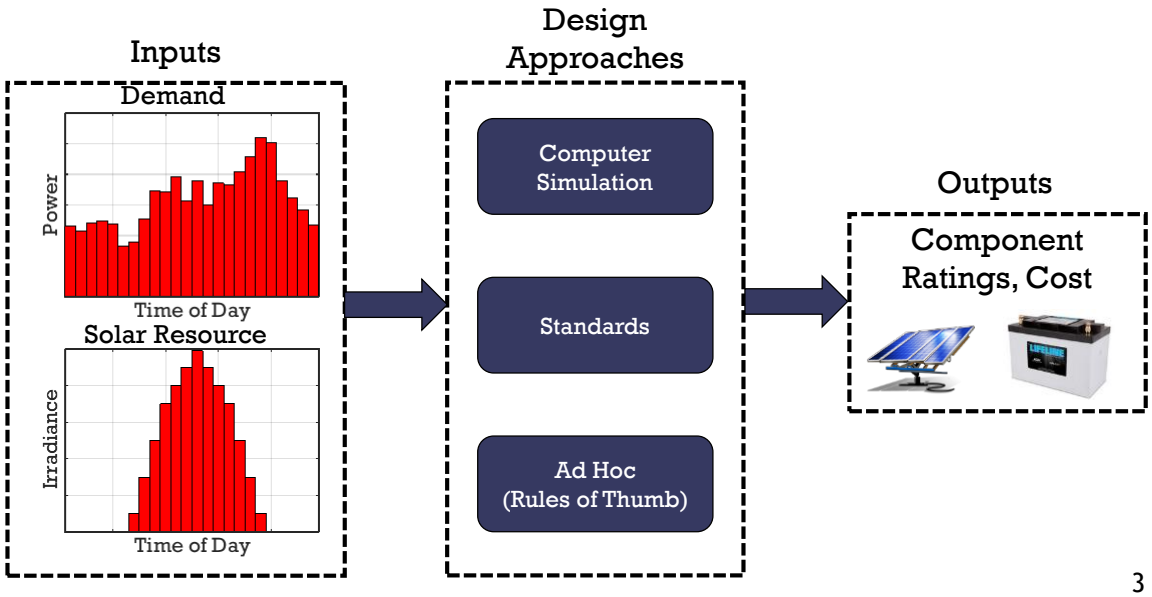

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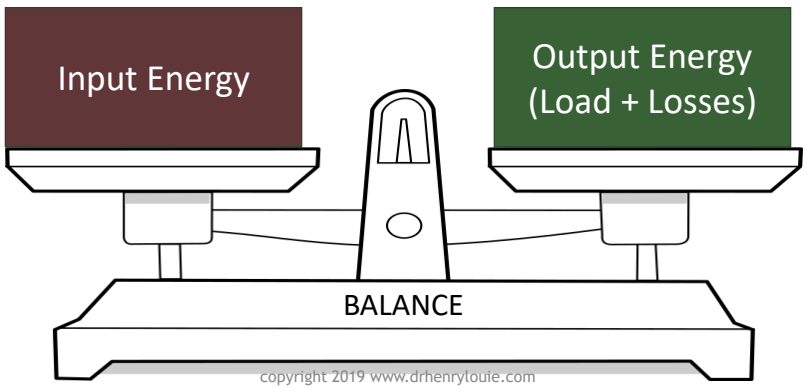
A technically-appropriate design is one that…

strikes a reasonable balance between the cost of implementing and operating the system with the ability of the system to reliably and safely meet the needs of its users



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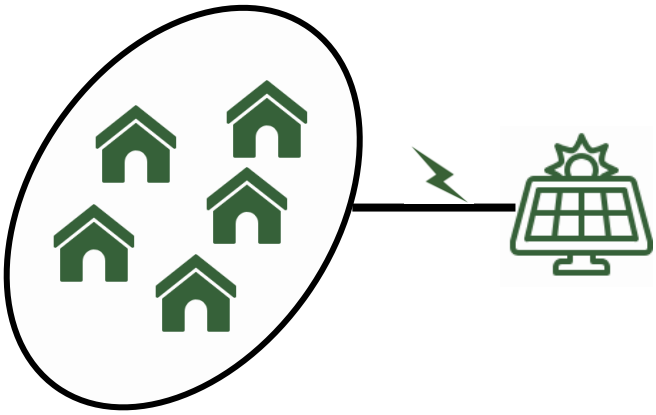
Load Characteristics



What do we need to know about the load to design our system?

✓How much load (average daily load and peak)

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Average Daily Load

- Energy consumption (watthours/day)
- Depends on user type: household, commercial, industrial
- Distribution of average daily load has a "long tail"
  - Most users use little energy, but a few use a lot
- Important for sizing energy production system and batteries

Representative Data

User Class	Avg. Daily Load (Wh)	Percent of Users (%)	Percent of Total Load (%)
Household (low)	35	75	15.5
Household (high)	250	20	29.6
Commercial (low)	1500	4.5	40.0
Commercial (high)	5000	0.5	14.8

Serving high-consumption users is critical to financial viability of off-grid systems

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Average Daily Load

$$\bar{E} = \frac{\text{total energy consumed over } D \text{ days}}{D}$$

$\bar{E}$: Average daily load (kWh/day)
D: number of days

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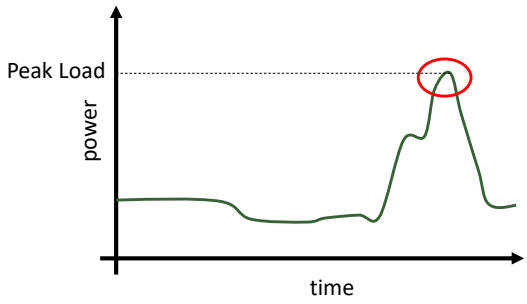
Peak Load

- Power consumption (watts)
- Maximum power consumed
- Important for sizing inverters, generators, transformers, fuses, etc.



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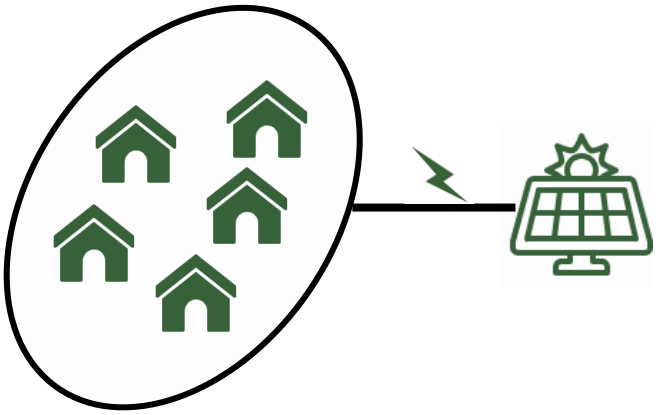
Load Characteristics



What do we need to know about the load to design our system?

- ✓How much load (average daily load and peak)
- ✓When it is consumed (daily load profile)

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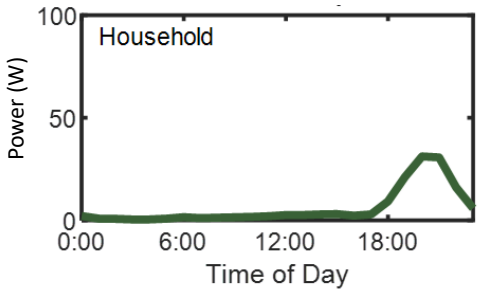
Load Profile

- Load Profile: *average load over the course of the day*
- Total area under the Load Profile equals average daily consumption
- Timing of consumption is important
  - Load co-incident with generation is desirable
  - Night-peaking load profiles are a poor fit for solar-powered systems



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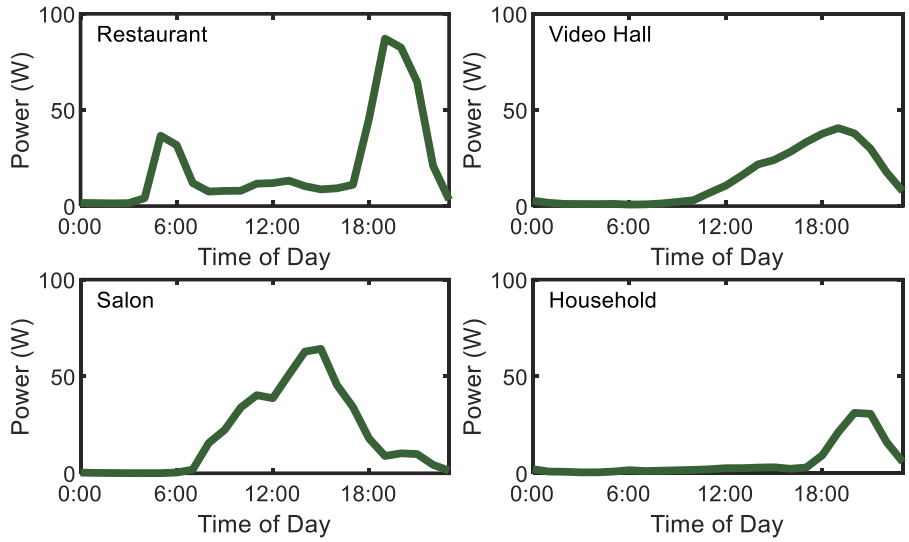
Load Profiles



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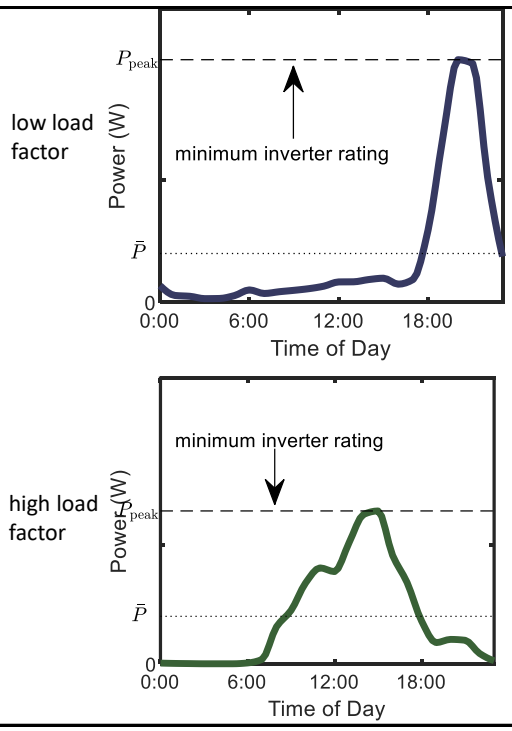
Load Factor (LF)

- Load Factor: *ratio of average power $\bar{P}$ and peak load P_{peak}*
- Higher load factors are desirable
  - lower equipment power ratings needed

$$LF = \frac{\bar{P}}{P_{peak}} = \frac{\bar{E}}{24 \times P_{peak}}$$



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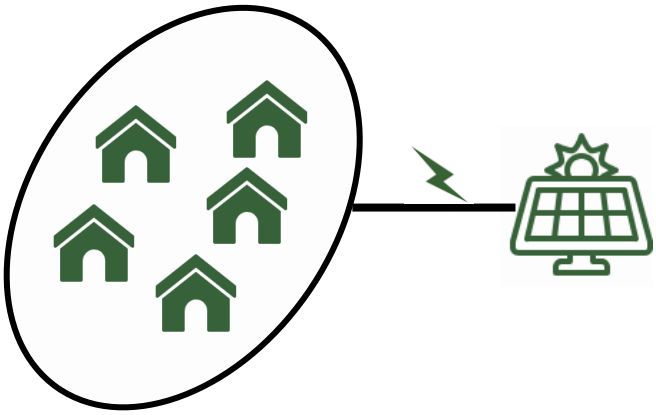
Load Characteristics



What do we need to know about the load to design our system?

- ✓How much load (average daily load and peak)
- ✓When it is consumed (daily load profile)
- ✓How load varies over time (day-to-day and

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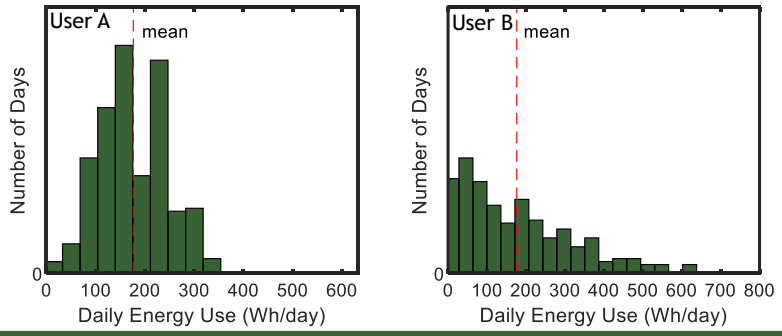
Day-to-Day Variation

Reliability is dictated by extreme conditions, which is not captured by the average daily load



User A and B have same average daily consumption, but User B's consumption is more variable and requires a more expensive system to reliably serve

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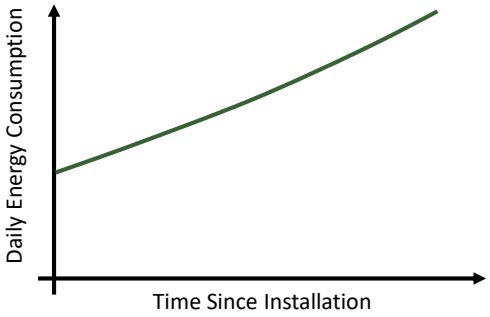
Year-to-Year Variation

- Consumption usually increases over time
  - 5-10% per year
- Load growth not consistent nor guaranteed
- Access to appliances a barrier
  - Appliance finance/leasing programs



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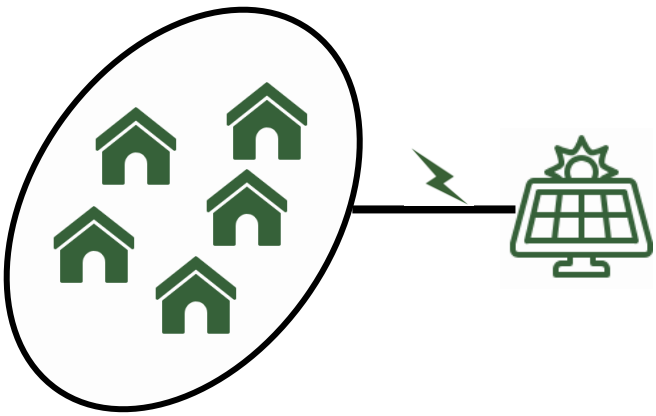
Load Characteristics



What do we need to know about the load to design our system?

- ✓How much load (average daily load and peak)
- ✓When it is consumed (daily load profile)
- ✓How load varies over time (day-to-day and year-to-year)
- ✓How load is coincident between users

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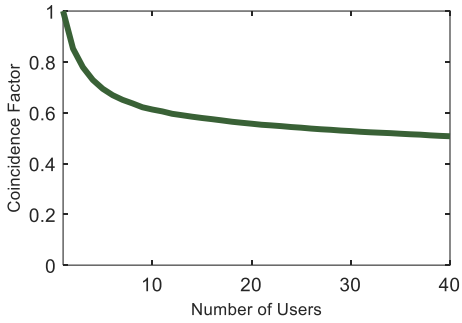
Coincidence Factor (CF)

- Coincidence Factor: *ratio of the peak aggregate load to the sum of the individual peak loads*
- Less coincidence is desirable
- Households tend to exhibit high coincidence
- Inverse of CF is known as the *diversity factor*



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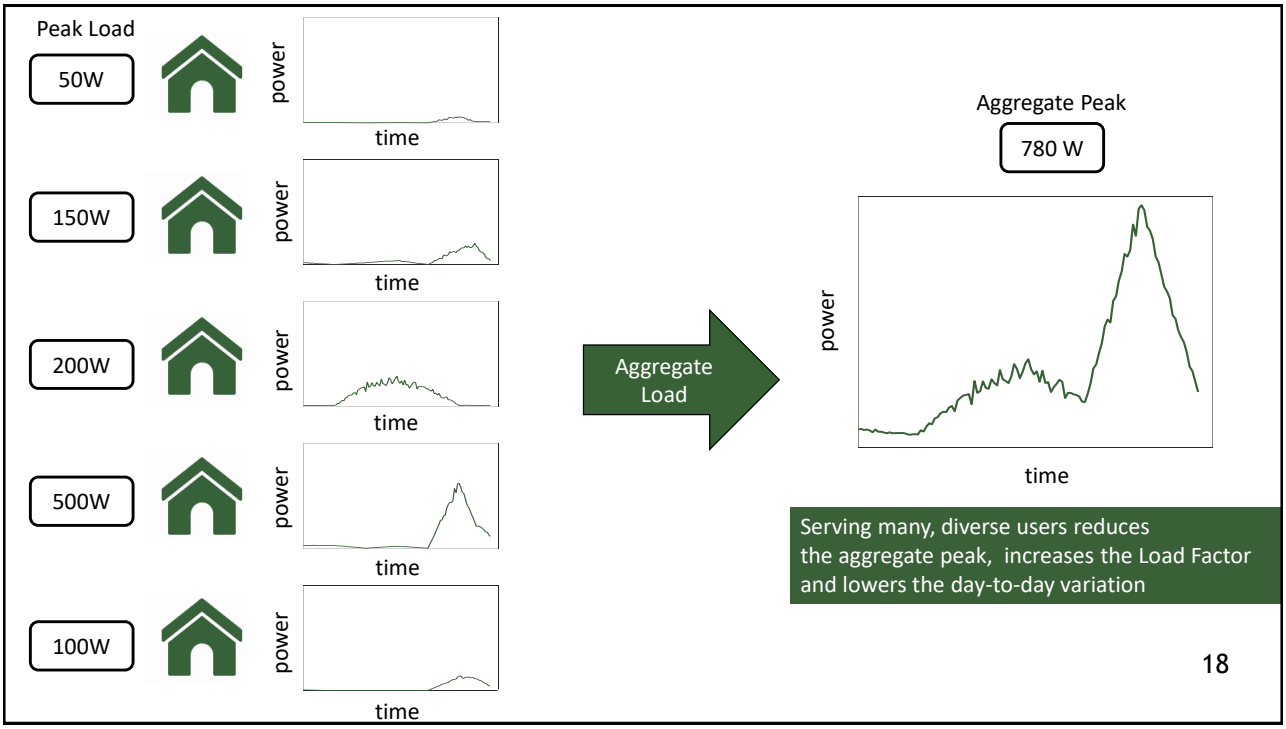

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Coincidence Factor

$$CF = \frac{P_{\text{peak,agg}}}{\sum_{n=1}^{N} P_{\text{peak},n}}$$

$P_{\text{peak,agg}}$: peak of the aggregate load (W)
$P_{\text{peak},n}$: peak of the nth user

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Preferable Load Characteristics

- ✓High average daily load
- ✓Load profile that is co-incident with production
- ✓Load Factor near 1.0 (not peaked)
- ✓Low day-to-day variation
- ✓Predictable long-term growth
- ✓Low Coincidence Factor

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Load Estimation Approaches

- Bottom-up
- Survey
- Regression
- Data-driven

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Bottom-Up Estimation

- Requires knowledge of appliances and load profile
- Only realistic in certain scenarios (e.g. lighting only, or when usage is controllable)
- Energy estimation of user *n*

$$\hat{E}_n = \sum_{a=1}^{A} p_a \times \frac{K_a}{100} \times T_a$$

P_a: rated power of appliance a,(W)
T: average hours of use per day of appliance a, (h)
K_a: loading percentage appliance a, (%)
A: total number of appliances

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Bottom-Up Estimation

	Quantity	x	Rating (W)	x	Duration of Use/Day	x	Loading Percent	=	Energy Use/Day
	5	x	11W	x	4hrs	x	100/100	=	220 Wh
	1	x	200W	x	24hrs	x	10/100	=	480 Wh
									700 Wh

Surveys

- Common method
- Estimate future energy use through surveys (door-to-door)
- Typical questions
  - What appliances do you expect to own?
  - What hours will you use them?
- Use bottom-up approach based on results
- Should be used with caution, as it is error-prone

Sources of Error

- ✓Appliance ownership is mostly speculative
  - Appliance cost can delay ownership
  - Appliances can be acquired over time
- ✓Appliance usage is also speculative
  - How much use can they afford?
  - Intermittent use is hard to estimate
- ✓Inaccuracy of power ratings and load percent
  - Many appliances do not consume constant power
  - How should stand-by power be accounted for?

Surveyor bias!

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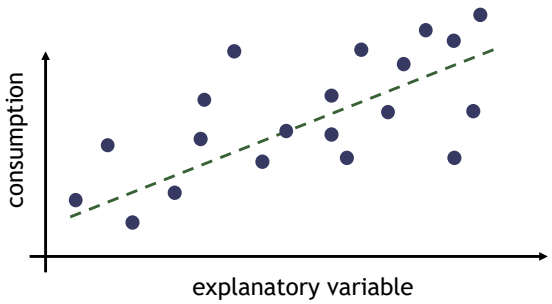
Regression

- Use mathematical model based on demographic/census data to estimate usage
- Several explanatory variables proposed [4,5]
  - Number of people living in house
  - Income
  - Distance to grid
  - Presence of a flushing toilet



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Data-Driven

- Use historical consumption data from similar mini-grids to predict consumption of new mini-grids
- Requires access to historical data from many mini-grids
- Requires a framework for determining which mini-grid projects are similar

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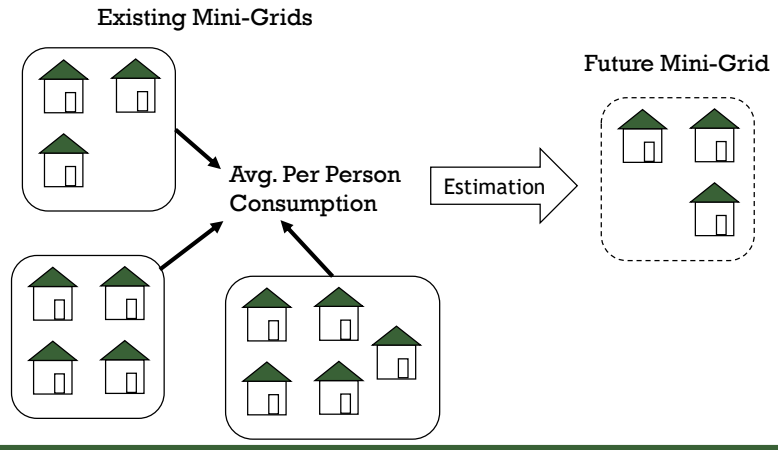
Data-Driven Prediction



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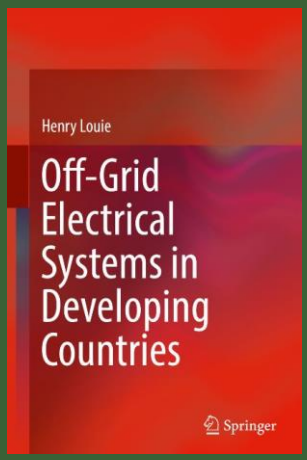

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