Modelling of Isolated Solar PV Households with Battery Energy Storage

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Introduction

- Electrification of remote villages remains an important strategy in developing countries
- Solar panels and batteries are reducing in cost and competing with grid supplied energy in niche markets
  - May obviate network extension to remote areas generally
- Research Questions for solar/battery technology:
  - Optimal deployment to supply remote areas?
  - Clustering of buildings through microgrids?
    - Maximum distance for connecting small households could be interconnected?
- The focus is on Indonesia for the Australia Indonesia Centre

The Design Formulation - Demand

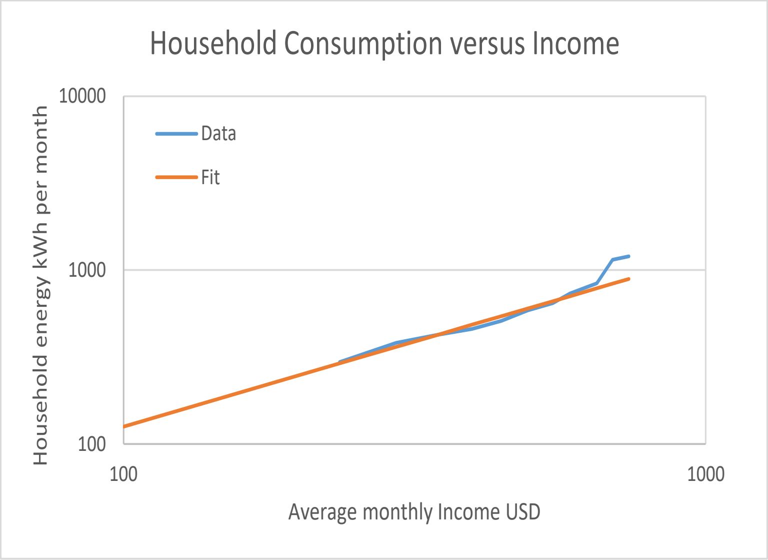
- Assume no metered demand for electricity
- Four components versus household income:
  - Household activity profile – randomised for each day
  - Appliance ownership
  - Appliance power characteristics (standby and maximum)
  - Energy consumption for various activities
- Link appliances to activities
- Stochastic demand model for each activity and appliances
- Some loads are deferrable for up to 8 hours if supply becomes available during this period
- Unserved energy and deferred energy valued:
  - US$5.00/kWh for unserved
  - US$2.50/kWh for deferred energy

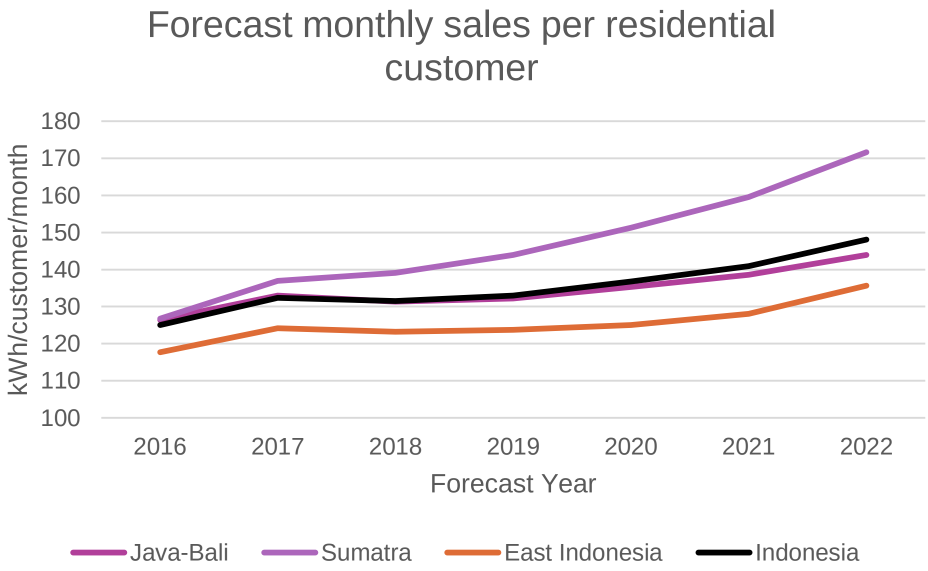
The Design Formulation - Supply

- Choose battery and solar panel options:
  - 320 W panels
  - Lead-carbon batteries
  - Separate infrastructure cost for space and electrical equipment
- Stochastic solar model based on random daily energy and half-hour sampling to allocate daily energy
- Simulation of alternative combinations of panels and batteries
  - optimise panels and batteries for each income level for a single household of each size
  - Include cost of unserved and deferred energy to optimise reliability
- Stochastic simulation of two connected households to assess value of interconnection
  - Savings in panels and batteries available due to interconnection

Electricity consumption versus income

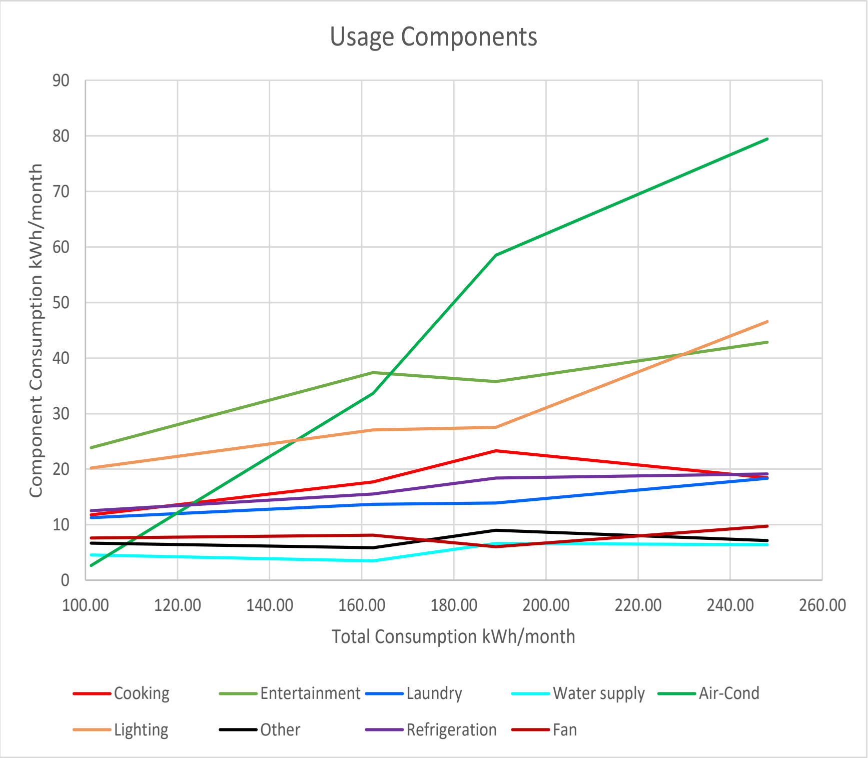
- Income and appliance ownership – key drivers of demand
- AS Permana, Sept 2008 showed a relationship between income and energy usage (including LPG)
- Average Indonesia usage about 130 kWh/month (PLN)
- Average energy demand also related to settlement size

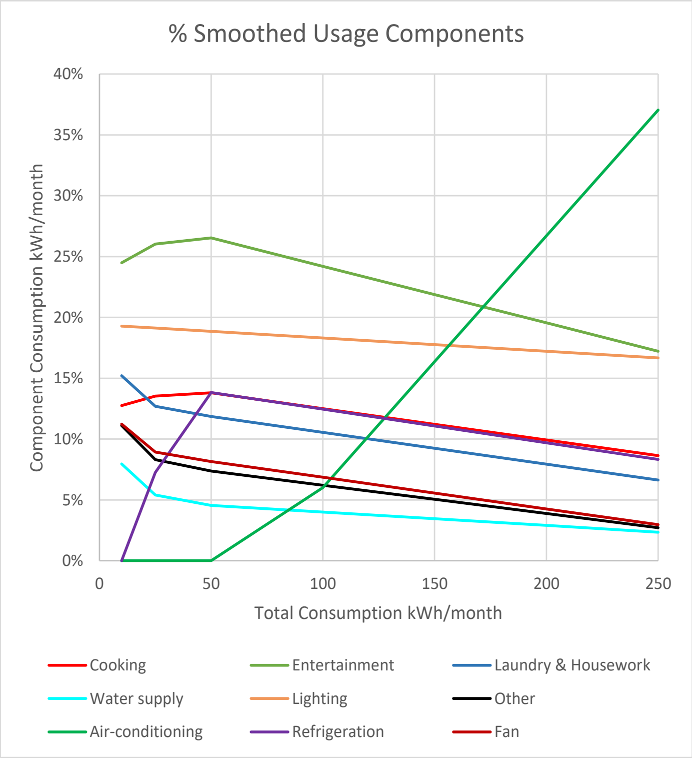




Energy use for applications

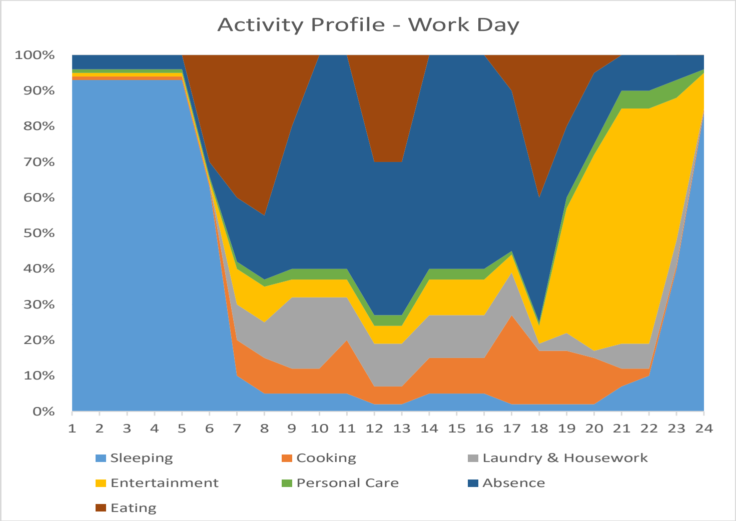
- Sorapipatana 2016 showed energy use by household activities at four different consumption levels
  - Interpolate and extrapolate to range 10 – 200 kWh/month

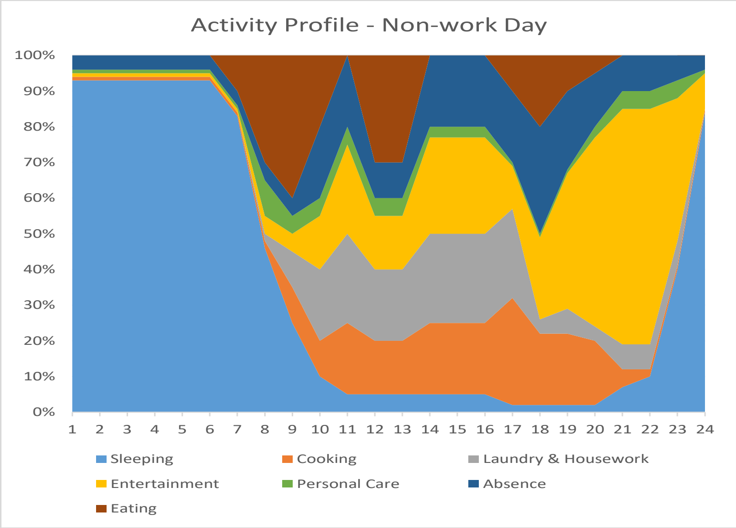




Activity Modelling

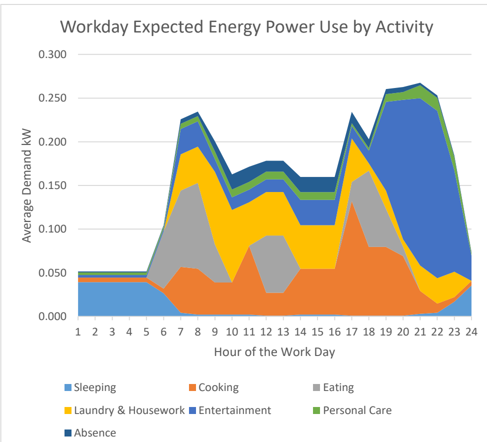
- Created seven activities for individuals and households
  - Sleeping
  - Cooking
  - Eating
  - Personal Care
  - Laundry and housework
  - Entertainment
  - Absence
- Allow one core activity for the household
  - individuals not considered
- Model household activity as a random activity with different probabilities over the day for
  - Work days
  - Non-work days
- Based on modelling by (Wilke 2013)

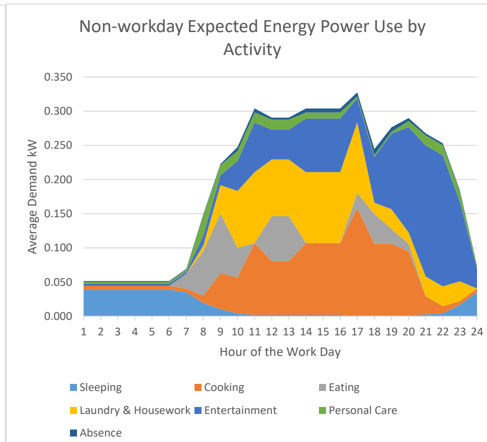




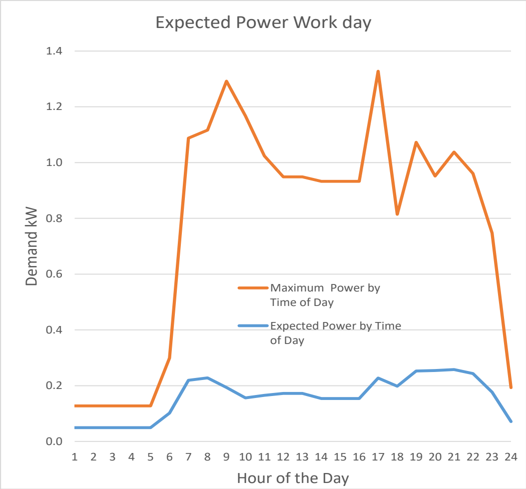
Random sampling of energy use

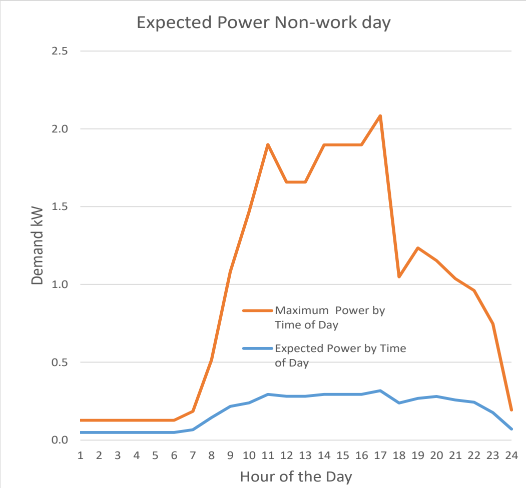
- Derive activities and energy use profiles as random processes





- 126 kWh/month



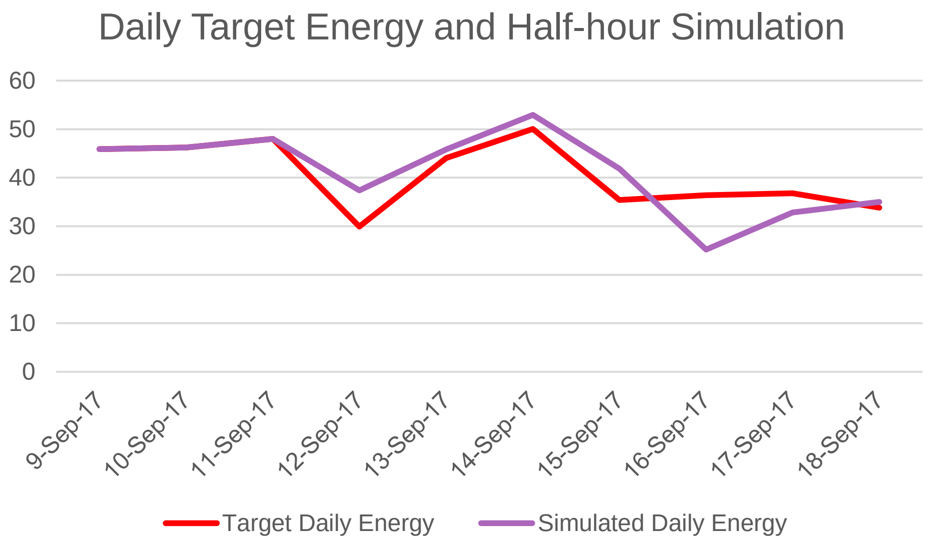


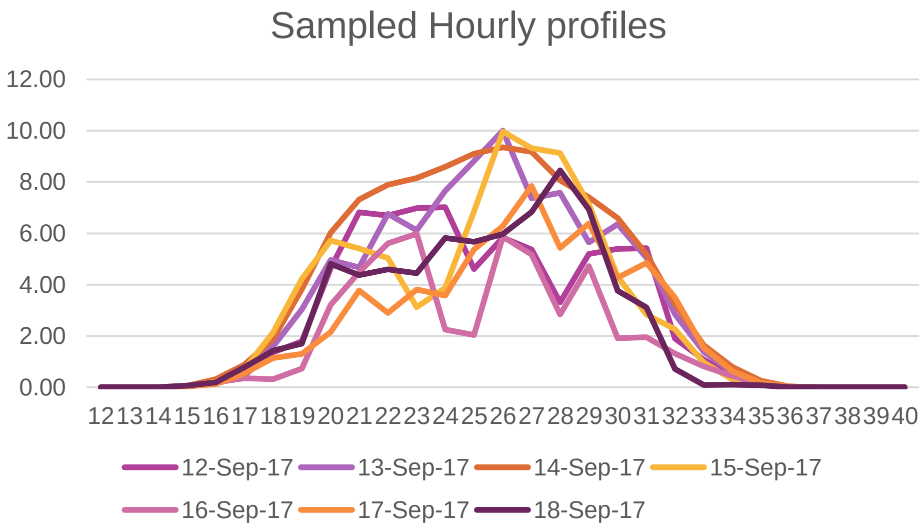
Solar Energy

- Solar energy is based upon a solar insolation model which takes account of
  - Latitude and longitude of the location
  - Orientation of the panels
  - Rating of the panels
  - Allowance for shading at start and end of day
  - Allowance for direct and diffuse insolation
- Initial model based on public data from an 11 kW Jakarta Installation from pvoutput.org
  - Fitted the model parameters to match the part-year daily energy data

Modelling of solar energy

- Model daily energy as an auto-regressive model (data fitted)
- Model half-hour energy as an auto-correlated profile (50%) to match the sampled daily energy within maximum and minimum daily profile by time of the year



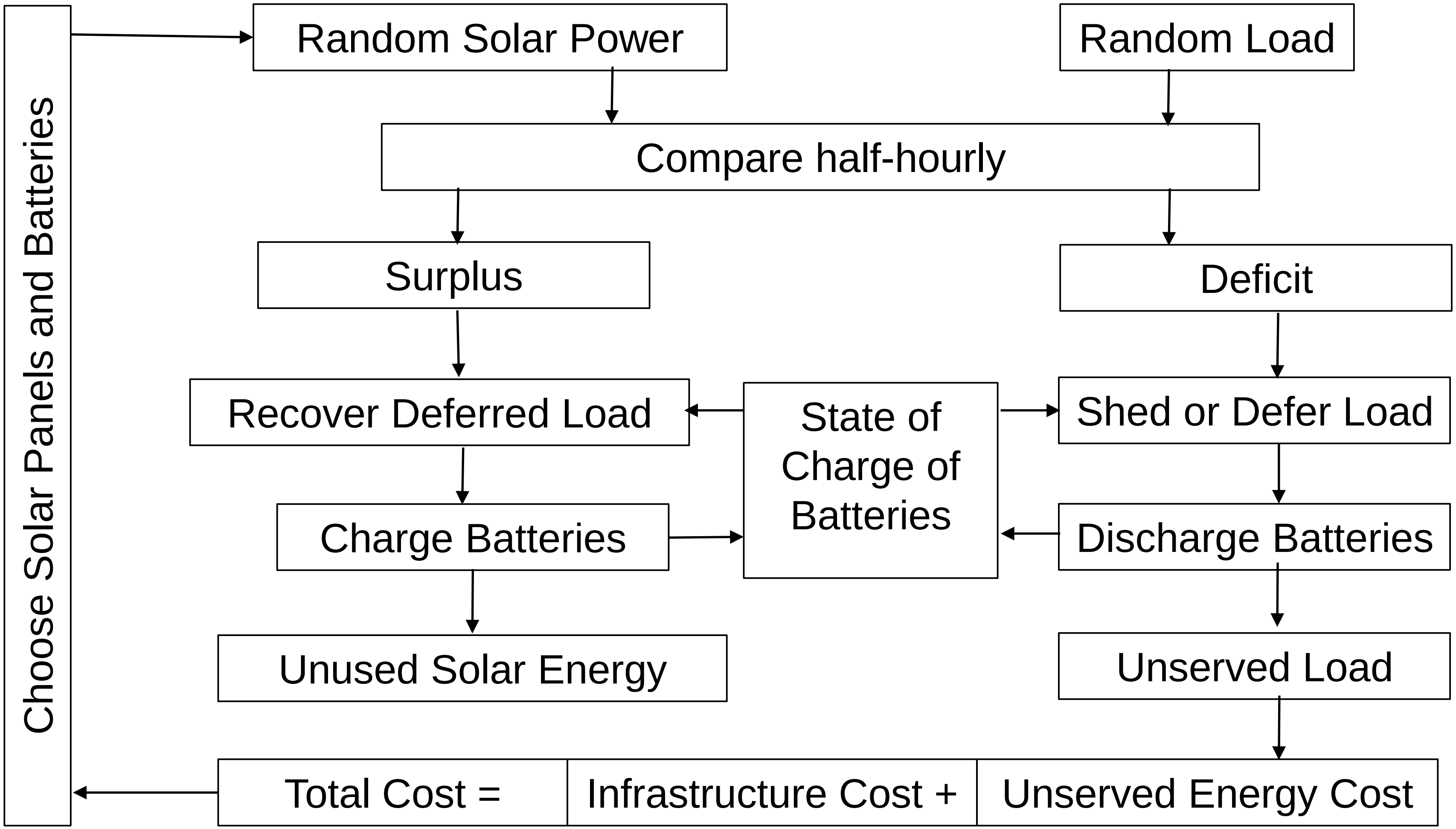


Batteries

- Initial model based on Narada lead-carbon batteries
- Three sizes were selected based on data provided by PT Solar Power Indonesia

	Units	Small	Medium	Large
Gross Capacity	kWh	1.44	3.6	7.2
Usable Capacity	kWh	0.96	2.4	4.8
Maximum Power	kW	0.36	0.9	1.8
Cycle efficiency	%	90.99%	91.98%	92.95%
Unit Cost	$/kW	$775	$620	$620
Infrastructure Cost	$	$922	$1,126	$1,283
Technical Life	Years	10	10	10
Annual capacity degradation	%	3.3%	3.3%	3.3%

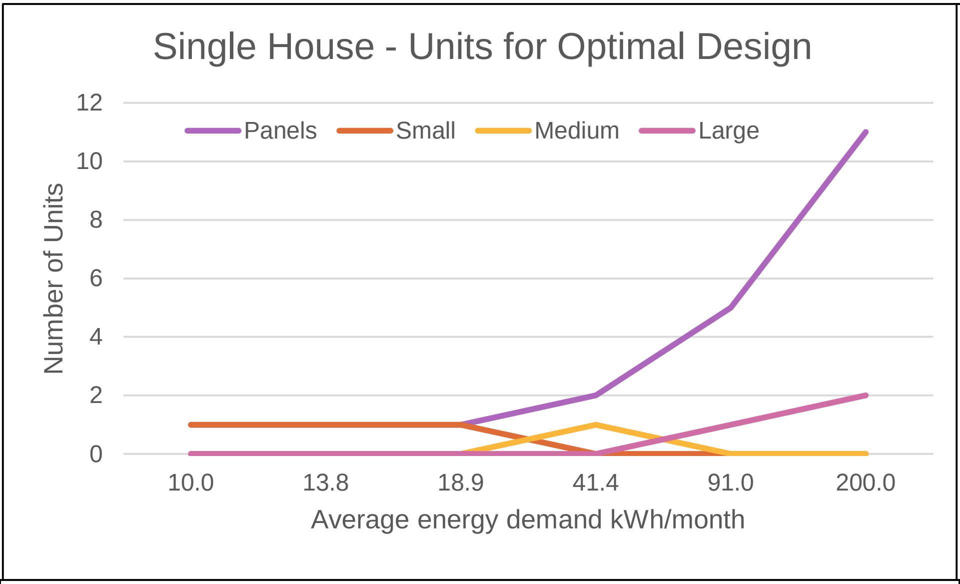
Single House Dispatch Method

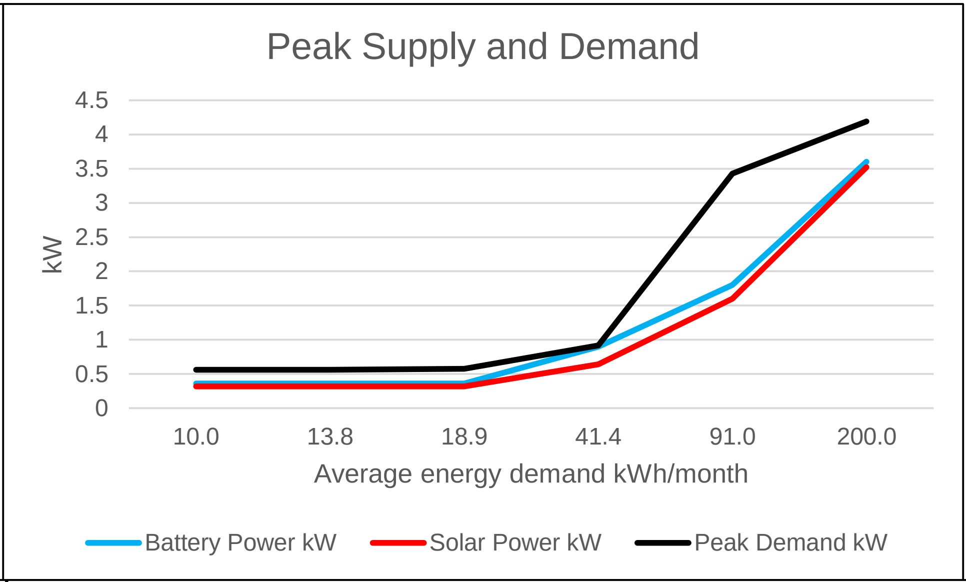


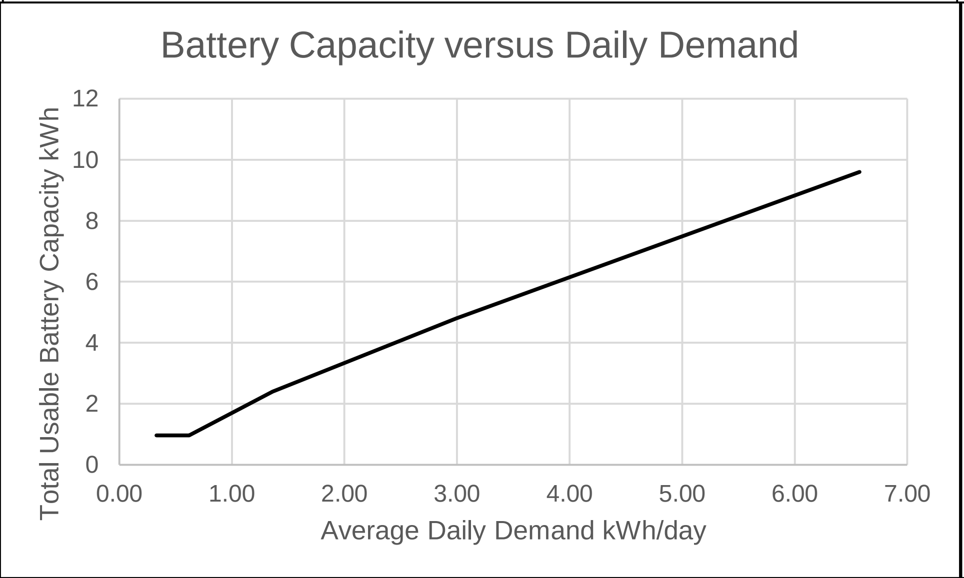
Observations from Single House Analysis

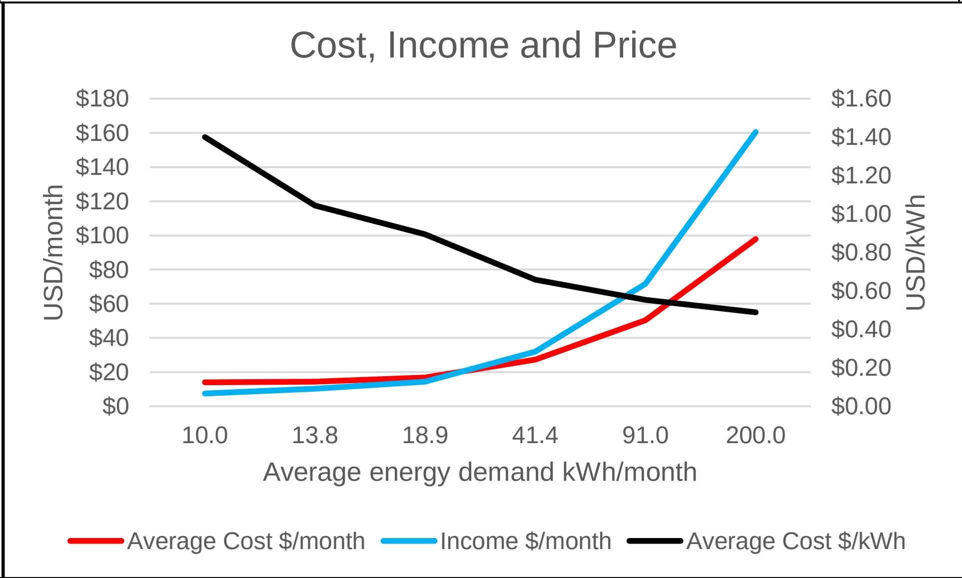
- Economic issues
  - Costs exceed income below 20 kWh/month
  - Costs are about 63% of income at average national consumption of 130 kWh/month
    - Marked costs reductions needed to support complete remote electrification unless electricity can promote increase of income (cost and utility to be considered)
- Technical guide:
  - Battery power and solar power capacity are closely aligned
  - Battery storage capacity is 1.5 to 2 times the average daily energy demand
  - Battery unit size increases with demand level over the range

Single House Solutions

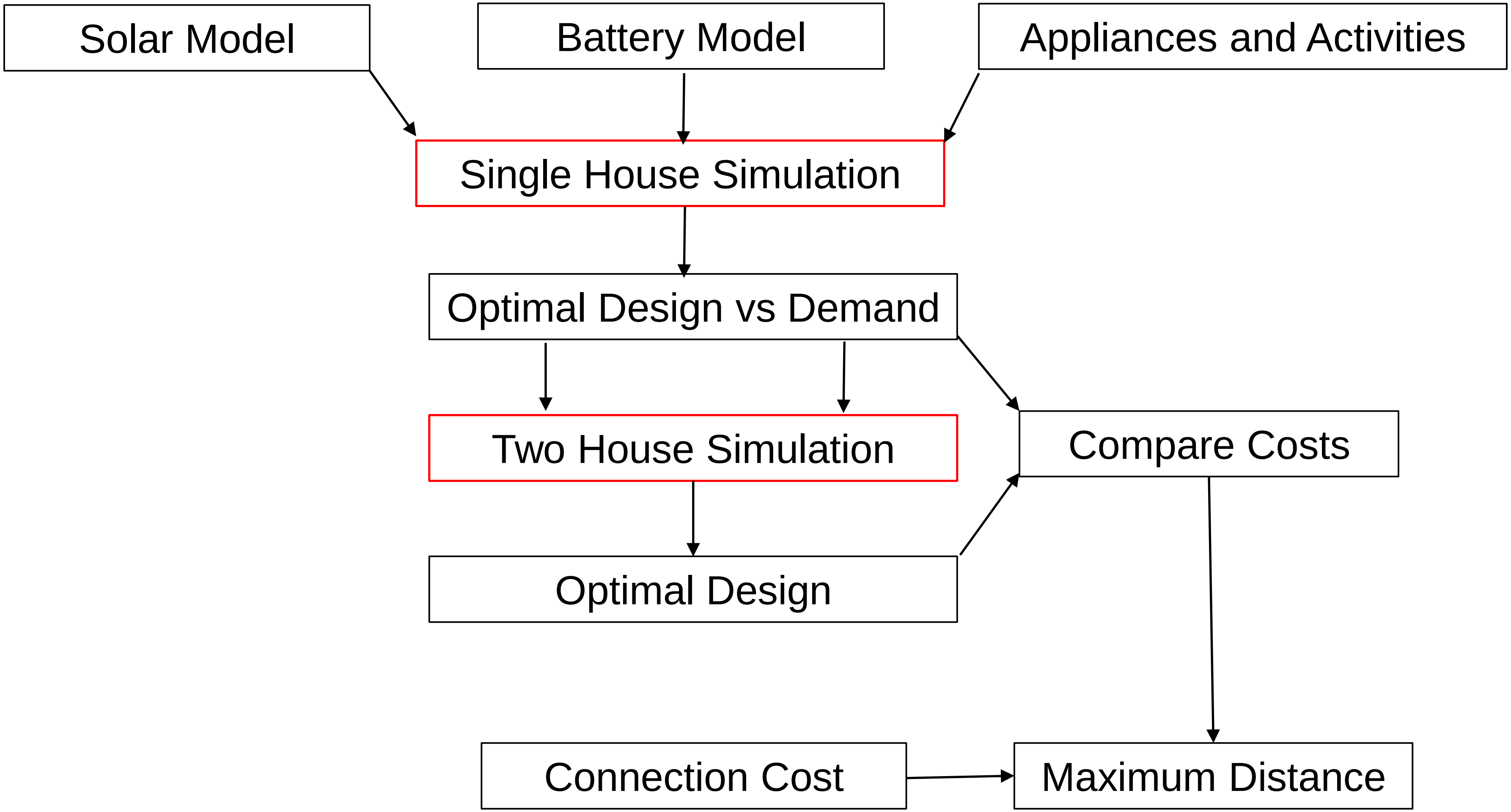




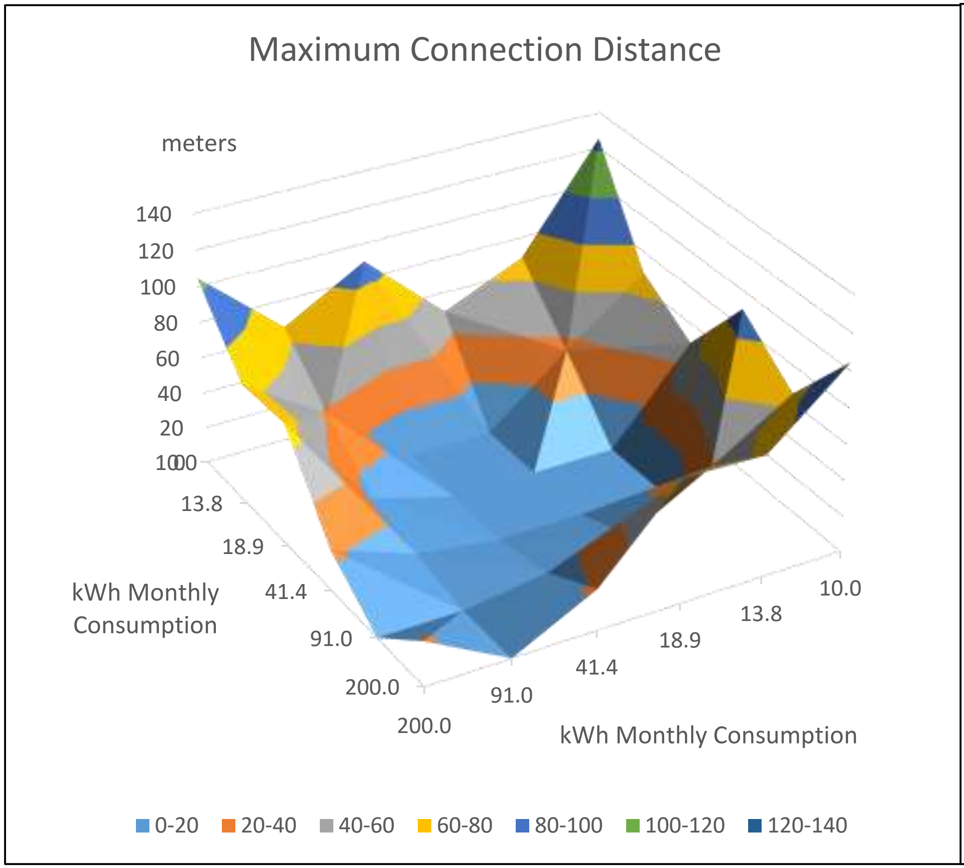


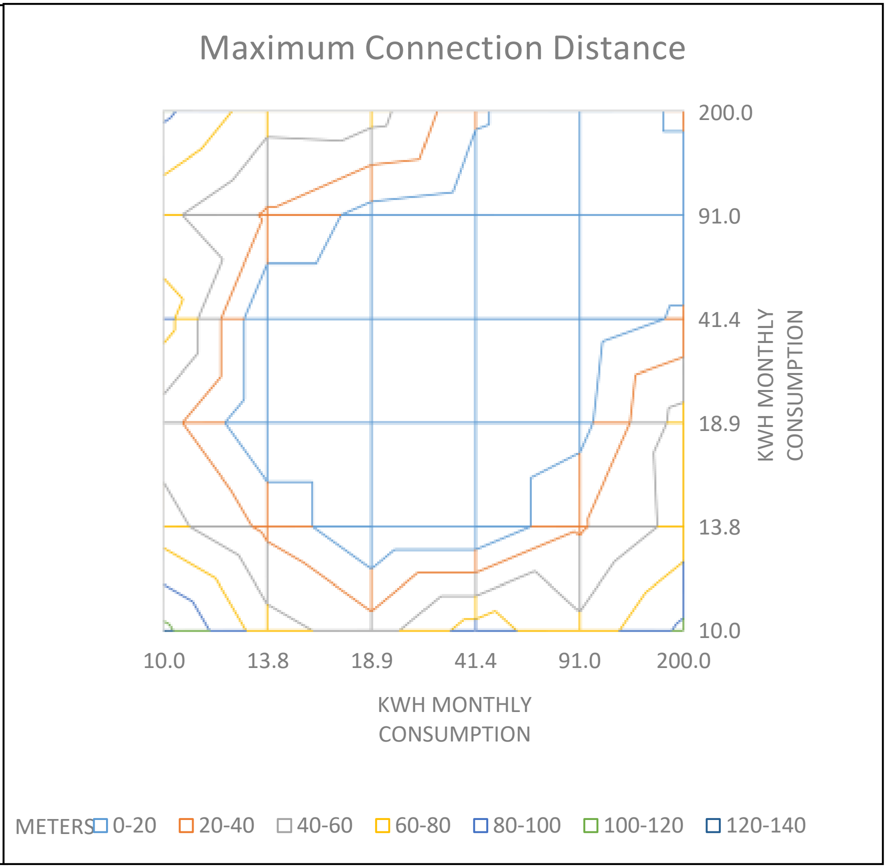


Two- House Interconnection Value

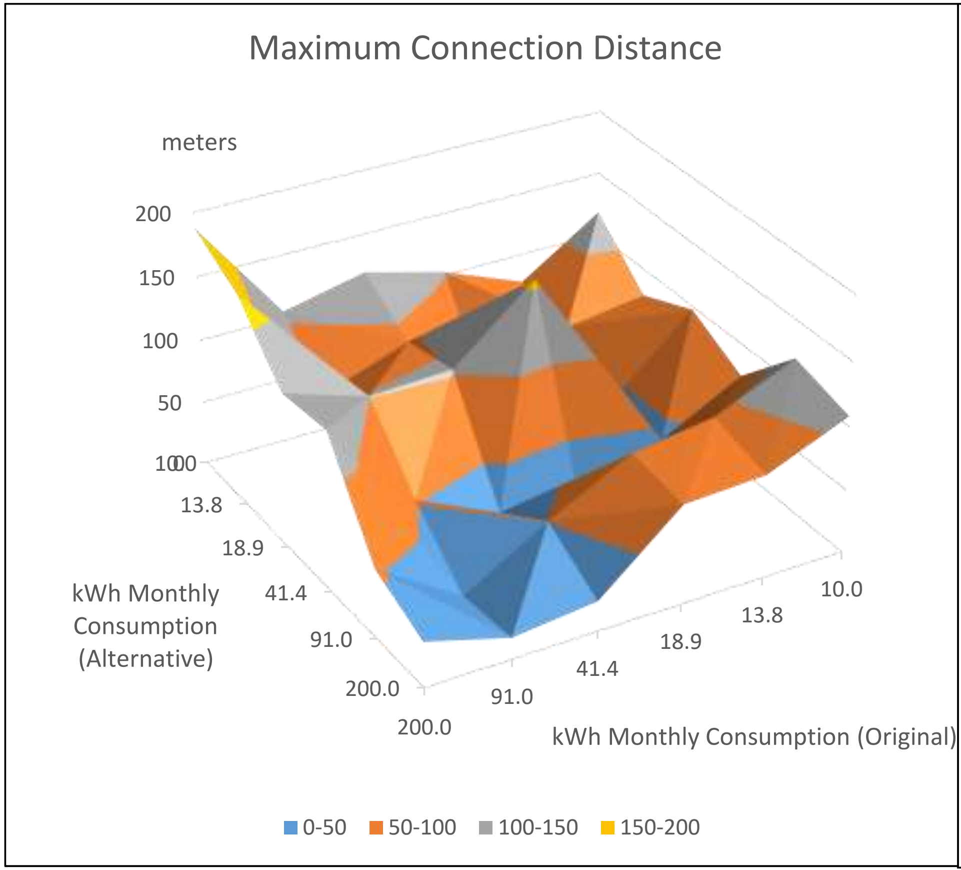


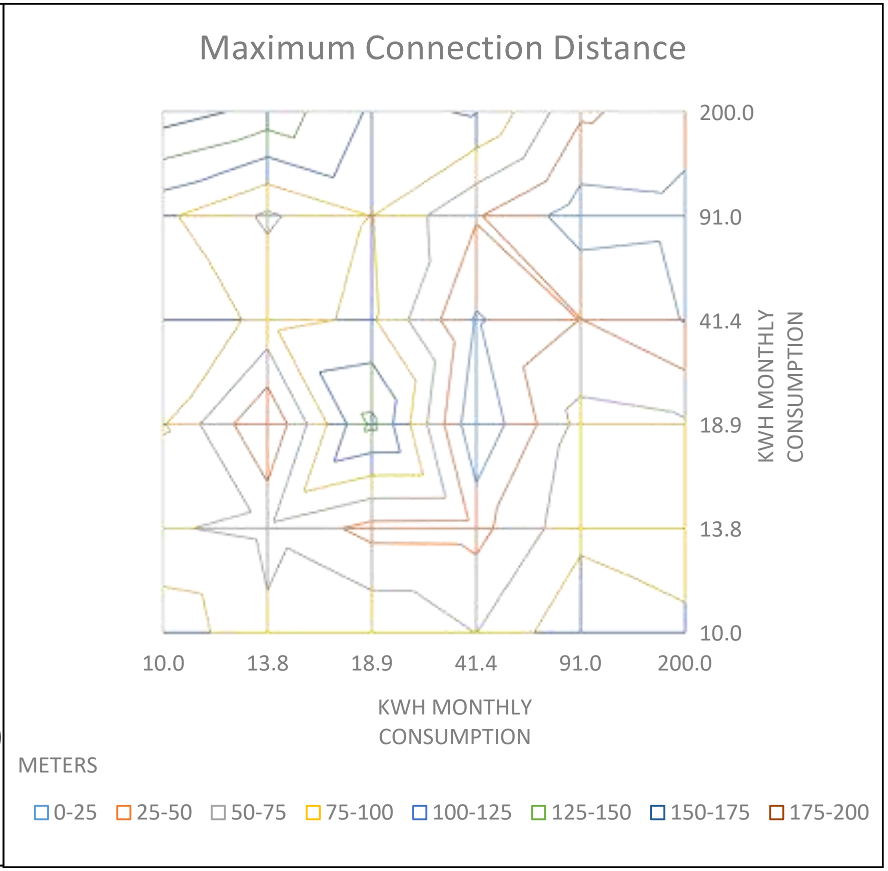
Maximum Distance – to 120 meters





Different solar panel orientation – 190m meters





Maximum Distance

- Based on these results: houses are worth interconnecting up to 120 m distant...
  - If the patterns of demand are disparate in volume and timing
  - If the consumption is below the efficient scale of the available solar panels and batteries
  - If no constraints on solar panel installation and same roof orientation
- If roof orientation is dissimilar, then maximum interconnection distance may be up to 190 m
  - Design optimisation is more complex to match solar panel location to patterns of prospective demand

Other issues

- Further considerations not studied…
  - Limited roof space constraining solar capacity
  - Limited space for security of battery facility
  - Lower cost connection at DC voltage for shorter distances?
  - Connection of residential and community buildings
  - Economies of scale with centralised solar installation supplying many houses

Next Steps

- Seek a software platform to enable more complicated networks with multiple buildings to be solved
  - PLEXOS
  - Minizinc
  - Bespoke programming
- Access survey data on household activities, buildings and energy consumption for a prospective village project and test whether these conclusions are robust.
- Formulate a microgrid planning method that can quickly assess
  - Interconnectness among premises
  - Aggregate costs for regional economic planning
  - Value for micro-economic development
  - Value for future interconnection with main grid

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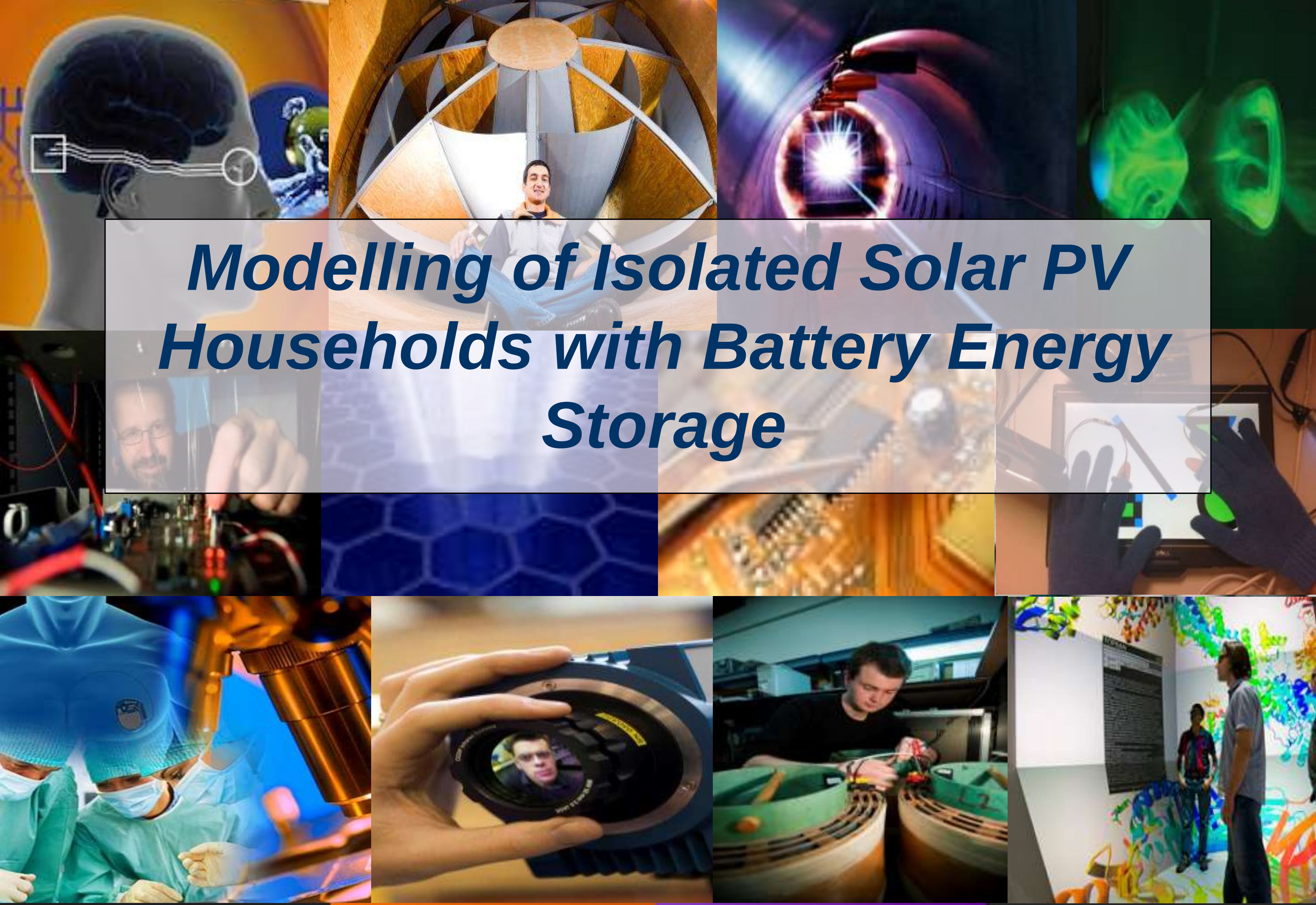

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