A Techno-Economic Model to assess Optimal Distributed Energy Resource Investments in the Residential Sector

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Outline

- Background
- Goals
- Methods
- Results and Discussion
- Future Work
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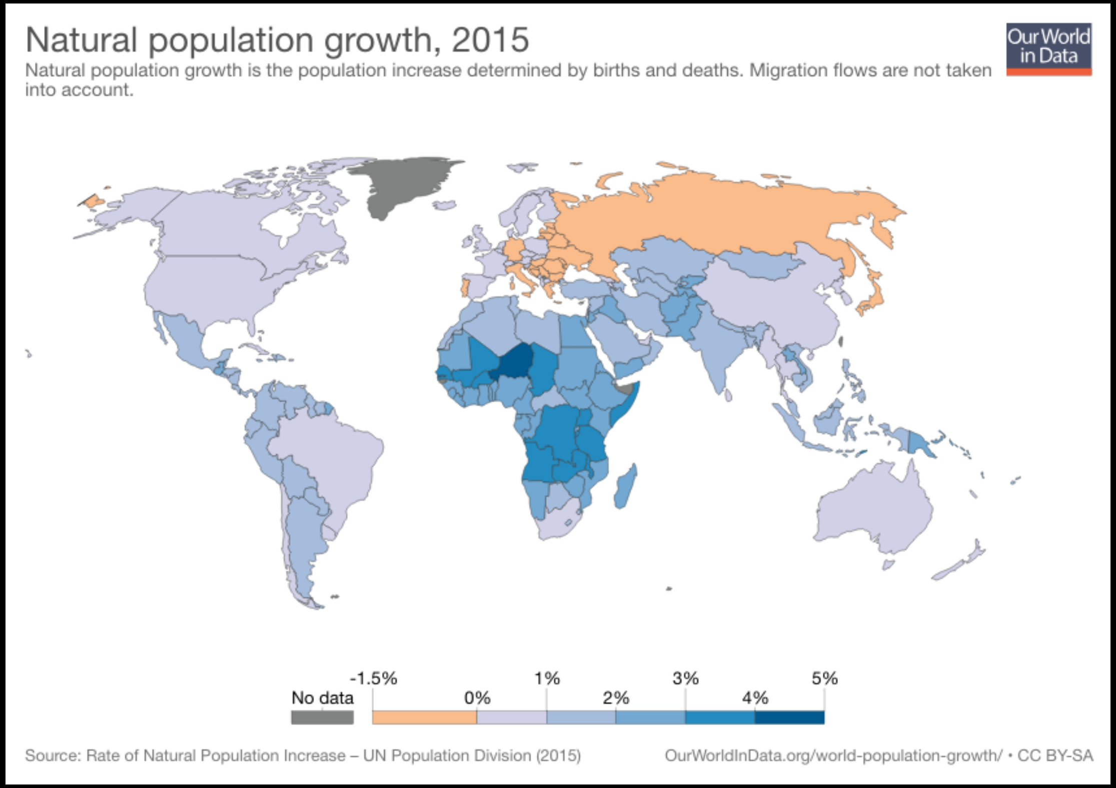
Population growth, climate change, and rising economic activities have increased overall electricity demand



The New York Times

U.S. Economy Grew by 2.3% in First Quarter, Easing Slightly

By PATRICIA COHEN APRIL 27, 2018

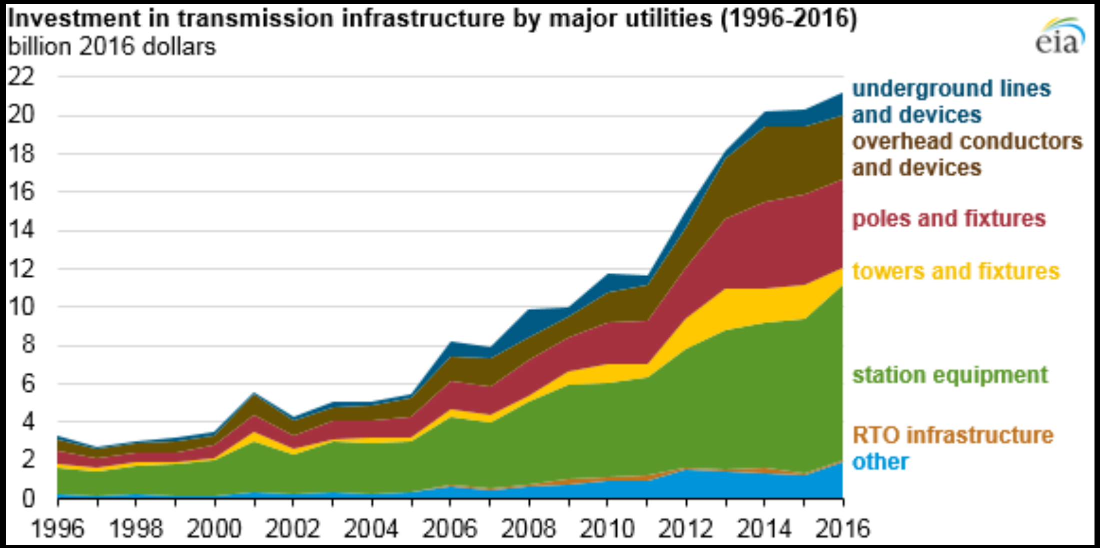
The Guardian

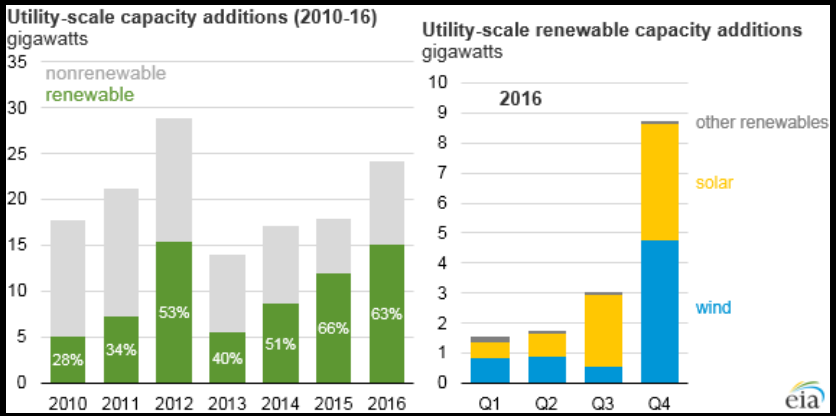
We're now breaking global temperature records once every three years

MAY 12, 2016

EIA projects 48% increase in world energy consumption by 2040

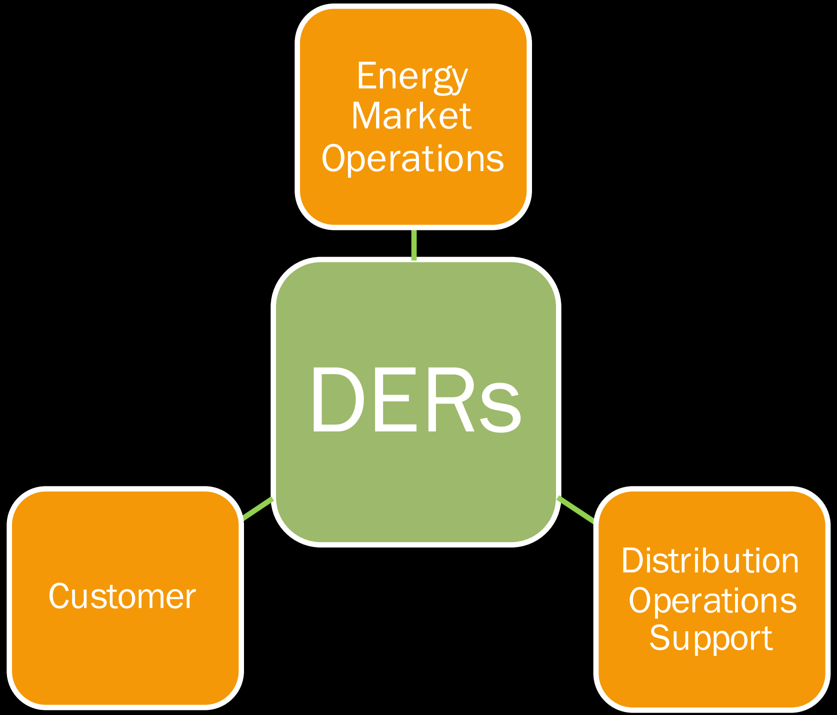
Maintaining the balance between supply and demand often necessitates the use of old inefficient generators and results in increased investment in generation, transmission, and distribution assets





Increased penetration of distributed energy resources (DERs), like solar and storage, can offset a portion of the load and additionally provide a variety of value streams

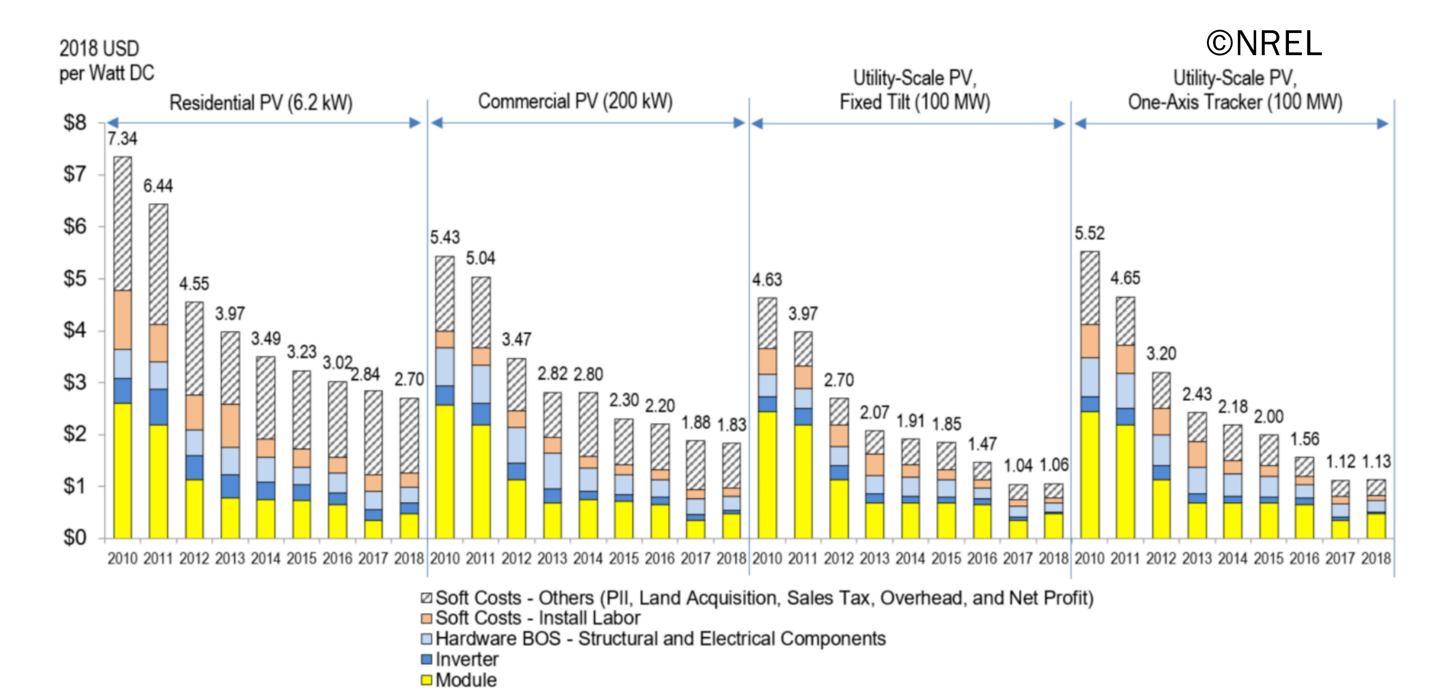
Peak Load Reduction (4-CP)
Energy Arbitrage
Real Time Price Dispatch



Demand Charge Reduction

Congestion Management
Voltage Support

High capital and installation costs remain one of the major disadvantages associated with onsite solar and storage




12,810 views | Feb 18, 2018, 03:46pm

Energy Storage Is Coming, But Big Price Declines Still Needed

Joshua Rhodes Contributor
Energy

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DEEP DIVE

Not so fast: Battery prices will continue to decrease, but at a slower pace, GTM says

©Utility Dive

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This study creates a decision support tool for DER investments in the residential sector based on constant and time-varying electricity pricing structures

- Analysis of integrated residential system with various controllable loads and DERs
- Detailed thermodynamic models for controllable appliances
- Accounts for customer comfort
- Tool developed is not software-specific
- Results can easily be recreated by energy system modelers

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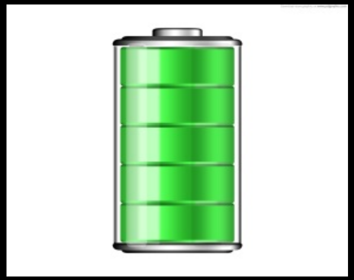
Three different scenarios are analyzed for the summer peak day of 2017:

1. Home with solar + energy storage system (ESS)
2. Home with solar but no ESS
3. Home with no solar and no ESS



A linear optimization model is developed in which the objective function consists of costs incurred by a residential customer

$$\underbrace{\sum_{t=1}^{T}\frac{P_{bought,t}\times\Delta t\times C_t}{100}}_{\text{Cost of electricity flowing from the grid to the home}} + \underbrace{\frac{C_t}{100}\times\sum_{t=1}^{T}P_{solar}(t)\times\Delta t}_{\text{Cost of remaining energy consumption}} - \underbrace{VOS\times\sum_{t=1}^{T}P_{solar}(t)\times\Delta t}_{\text{Incentive received for producing solar energy}} + \underbrace{\sum_{t=1}^{T}\frac{P_{grid,ESS}\times\Delta t\times C_t}{100}}_{\text{Cost of electricity bought from grid to charge the ESS}}$$

$$+\underbrace{(CC_{solar}+OM_{solar})\times Size_{solar}}_{\text{Cost of solar panels}} + \underbrace{(CC_{ESS}+OM_{ESS})\times Size_{ESS}}_{\text{Cost of energy storage system}} + \underbrace{CC_{controls}}_{\text{Cost of control infrastructure}} - \underbrace{Rebates}_{\text{Utility rebates}}$$

The objective function is minimized subject to the following constraints:

- Distribution system power transfer limits
- Energy conservation surrounding the home
- Energy conservation at the solar panels
- Energy capacity of the ESSs
- Charging and discharging rate of the ESSs

The objective function is minimized subject to the following constraints:

- Room temperature limits
- Hot water temperature limits
- Energy consumed by the electric vehicle and pool pump
- Temporal constraints for electric vehicle and pool pump

A flat residential rate is assumed for simplification purpose instead of the tiered residential pricing structure

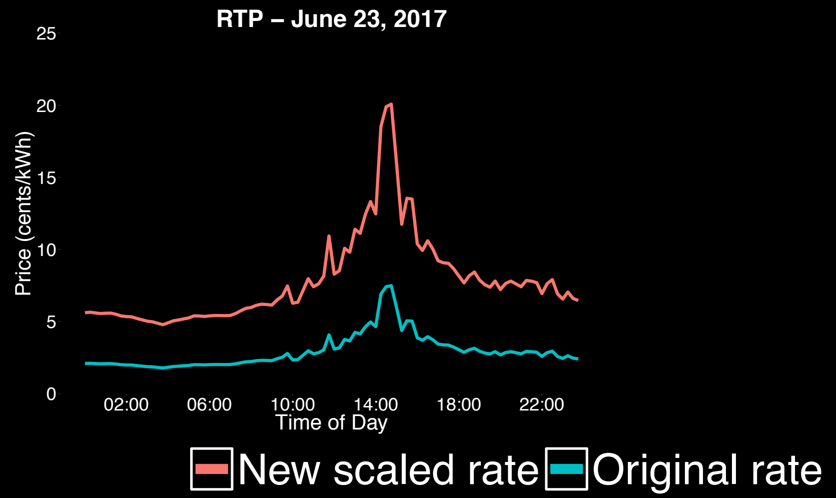
- 2.81 cents/kWh for 0-500 kWh
- 5.83 cents/kWh for 501-1000 kWh
- 7.81 cents/kWh for 1001-1500 kWh
- 9.31 cents/kWh for 1501-2500 kWh
- 10.81 cents/kWh for > 2500 kWh

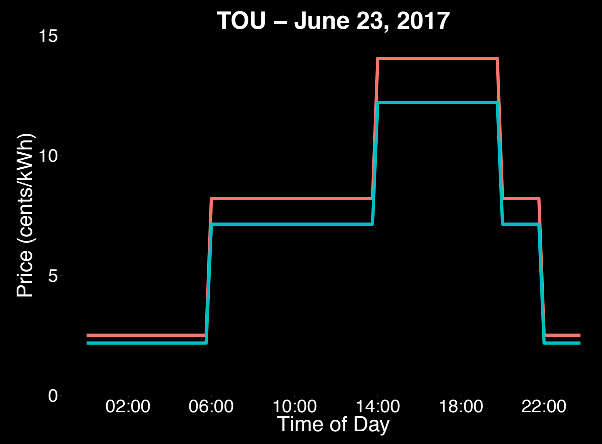
Assume C_t to be 7.81 cents/kWh

Note: Additional charges include community benefit charges, power supply adjustment charges, regulatory charges, etc.
Source: https://austinenergy.com/ae/residential/rates/residential-electric-rates-and-line-items

Sensitivity analysis is performed on the results using real-time price (RTP) structures and time-of-use (TOU rates)

- RTP – 15-min interval 2017 historical prices from Austin Energy
- TOU rates inspired by rates from Austin Energy residential pilot program





Note: Additional charges include community benefit charges, power supply adjustment charges, regulatory charges, etc.

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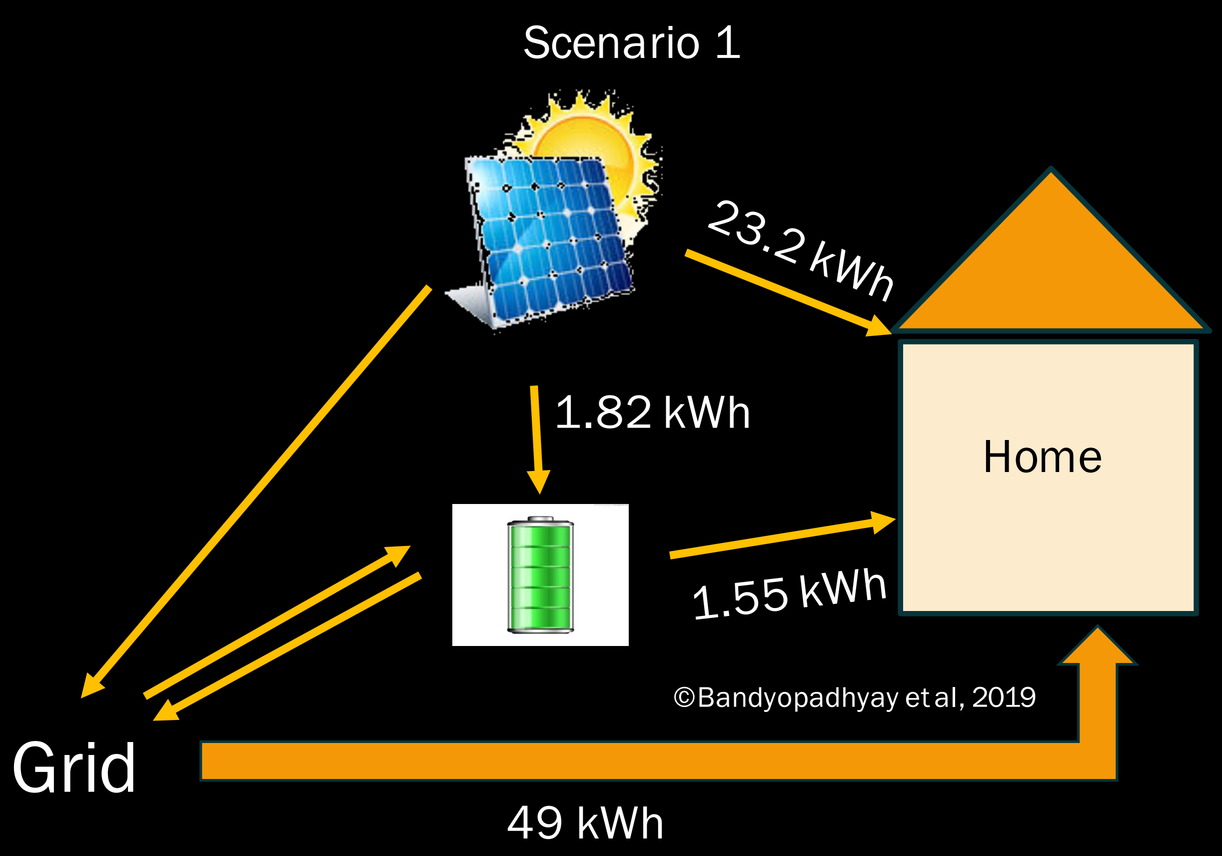
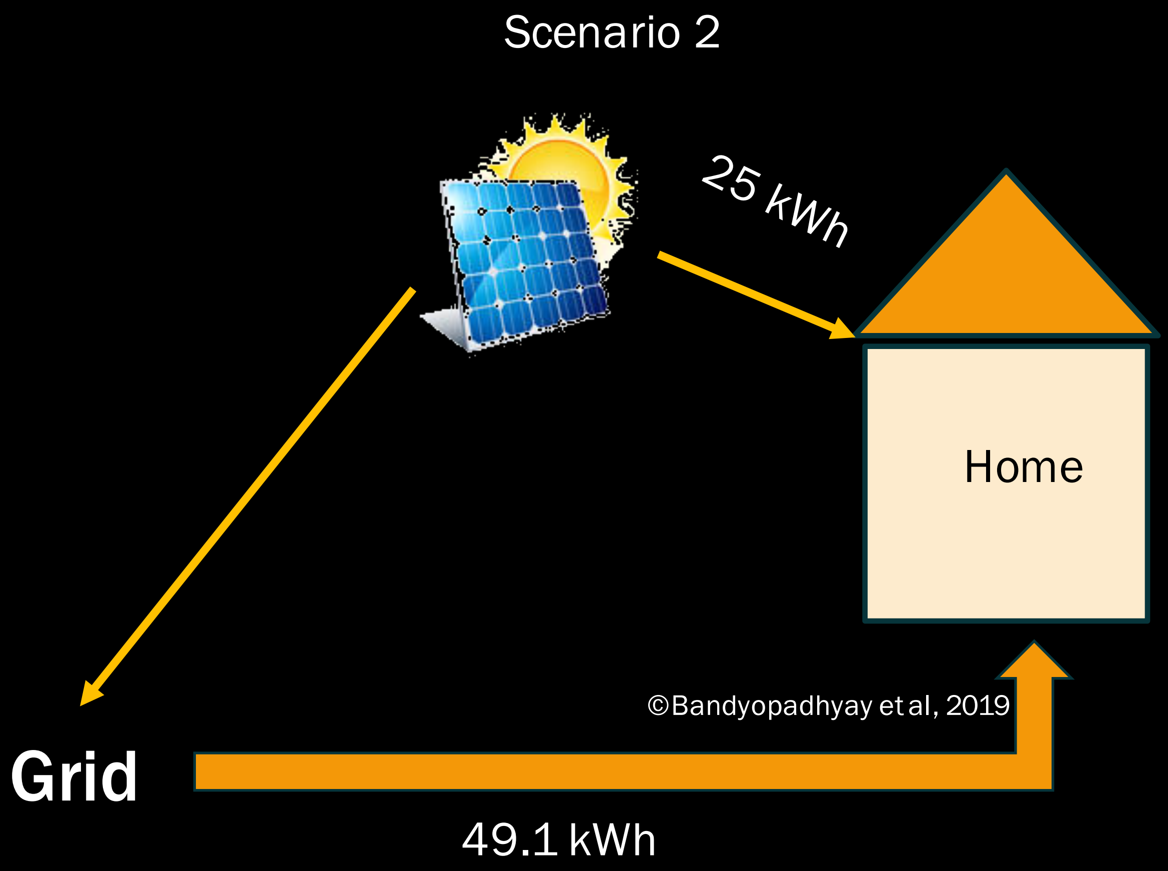
Economic costs to the customer are compared for the three scenarios, assuming three electricity pricing schemes

	Constant rates	Real-time pricing	Time-of-use rates
Lowest daily energy cost ($)	Home with solar + ESS	Home with solar + ESS	Home with solar + ESS
Lowest daily expenditure including amortized ESS, DER & controls costs ($)	Home with solar + no ESS	Home with no solar + no ESS	Home with no solar + no ESS

Power flows for the constant electricity rate scenarios are shown



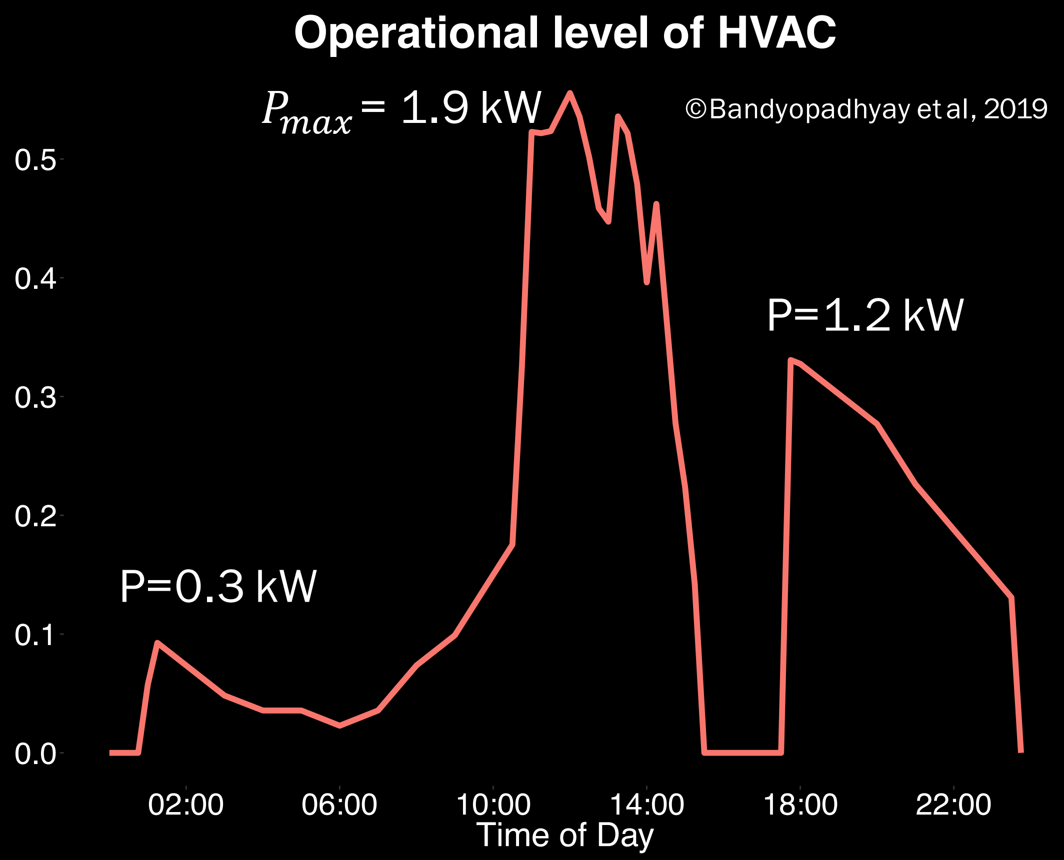


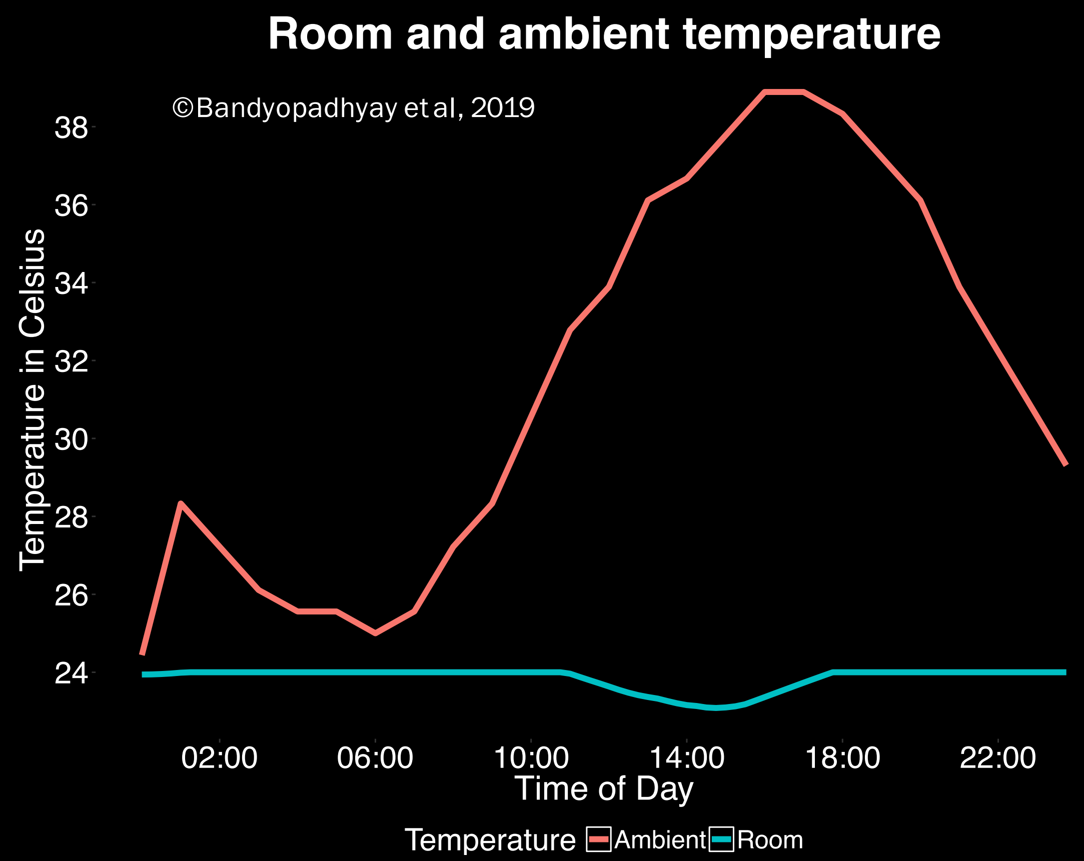
Note: 73.4 kWh is bought from the grid for Scenario 3 with no solar and no ESS

Constant electricity rate

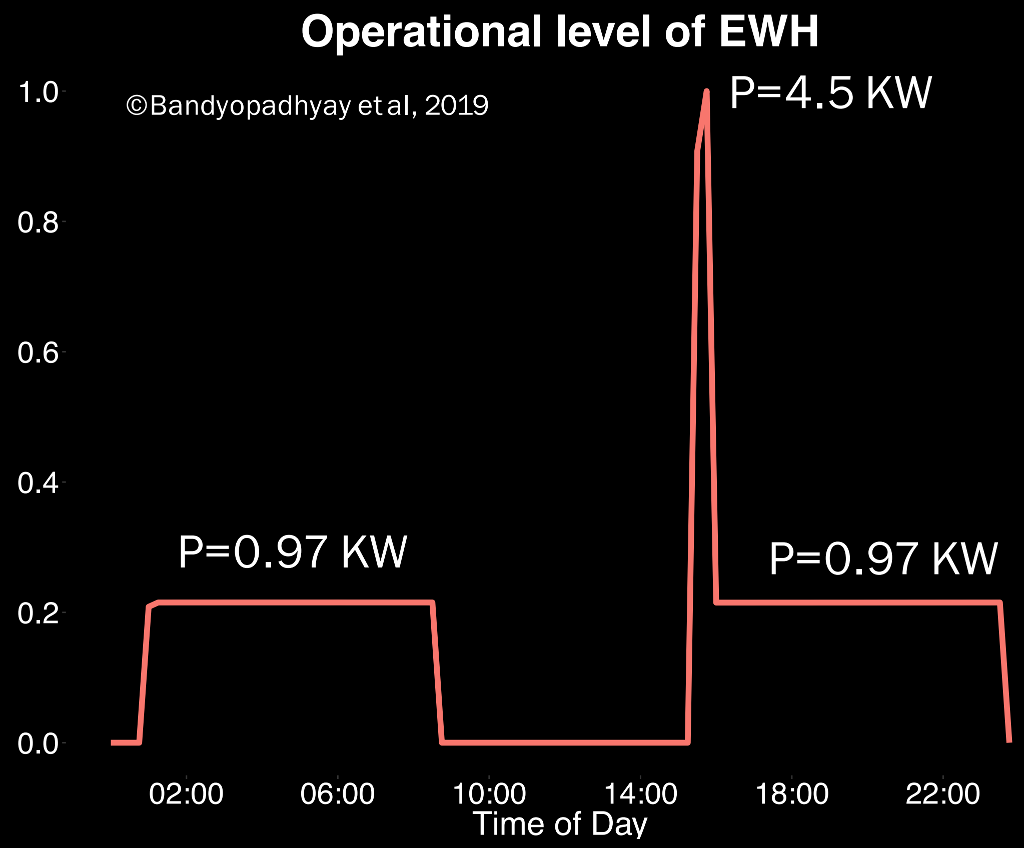
Power flows for Scenario 1: Home with solar + ESS

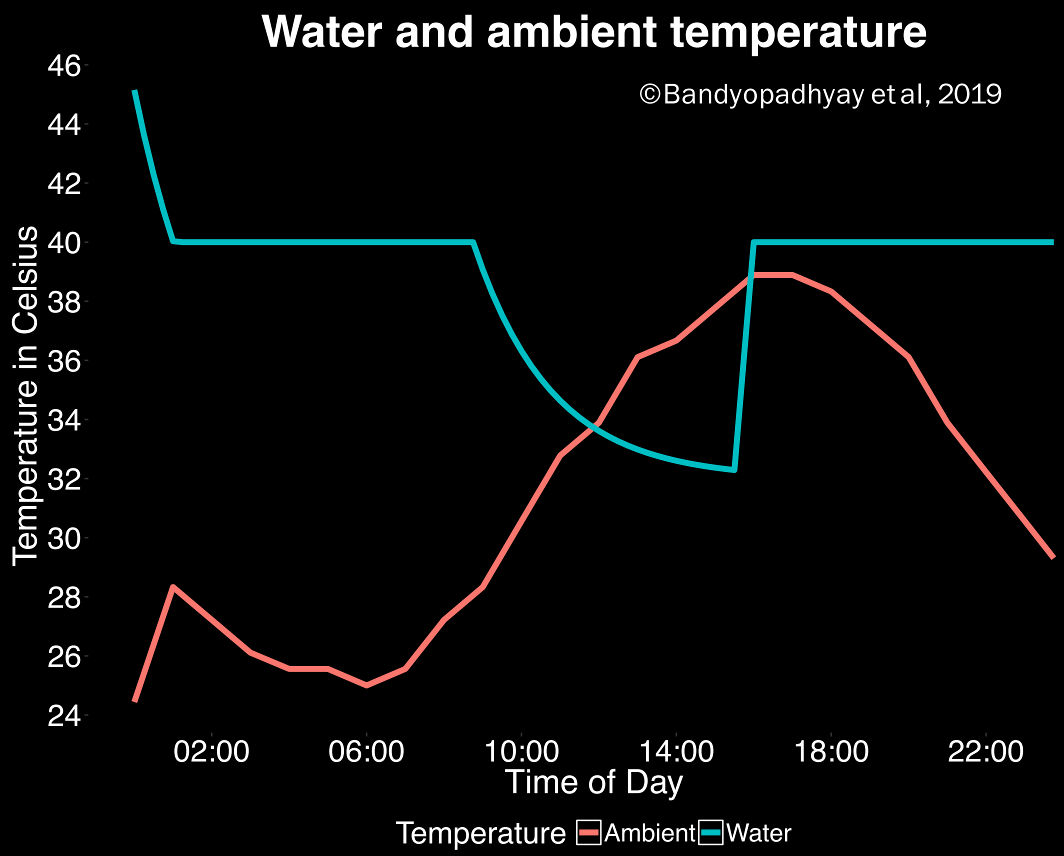
The HVAC maintains the room between 21ºC (~70ºF) and 24ºC (~75ºF) all day although ambient temperature rises to 39ºC (~102ºF) around 4 p.m.



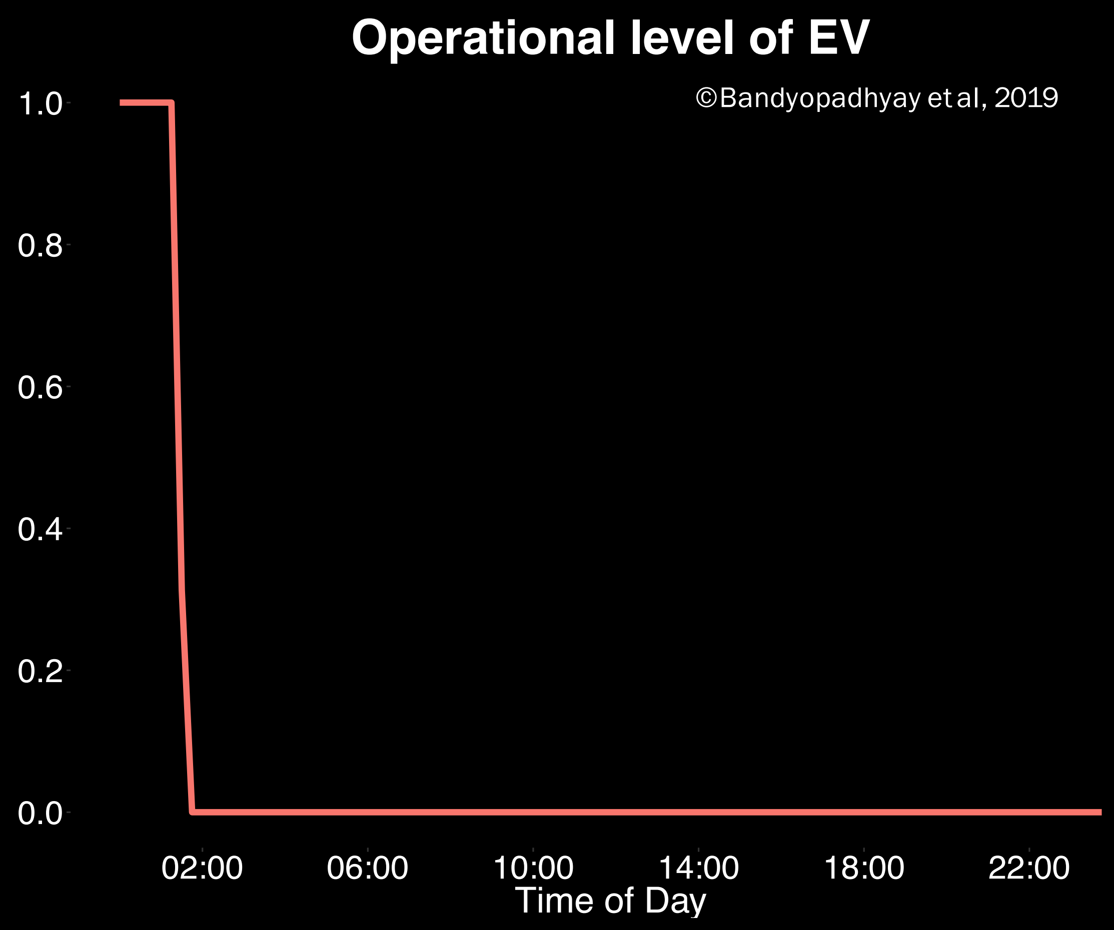


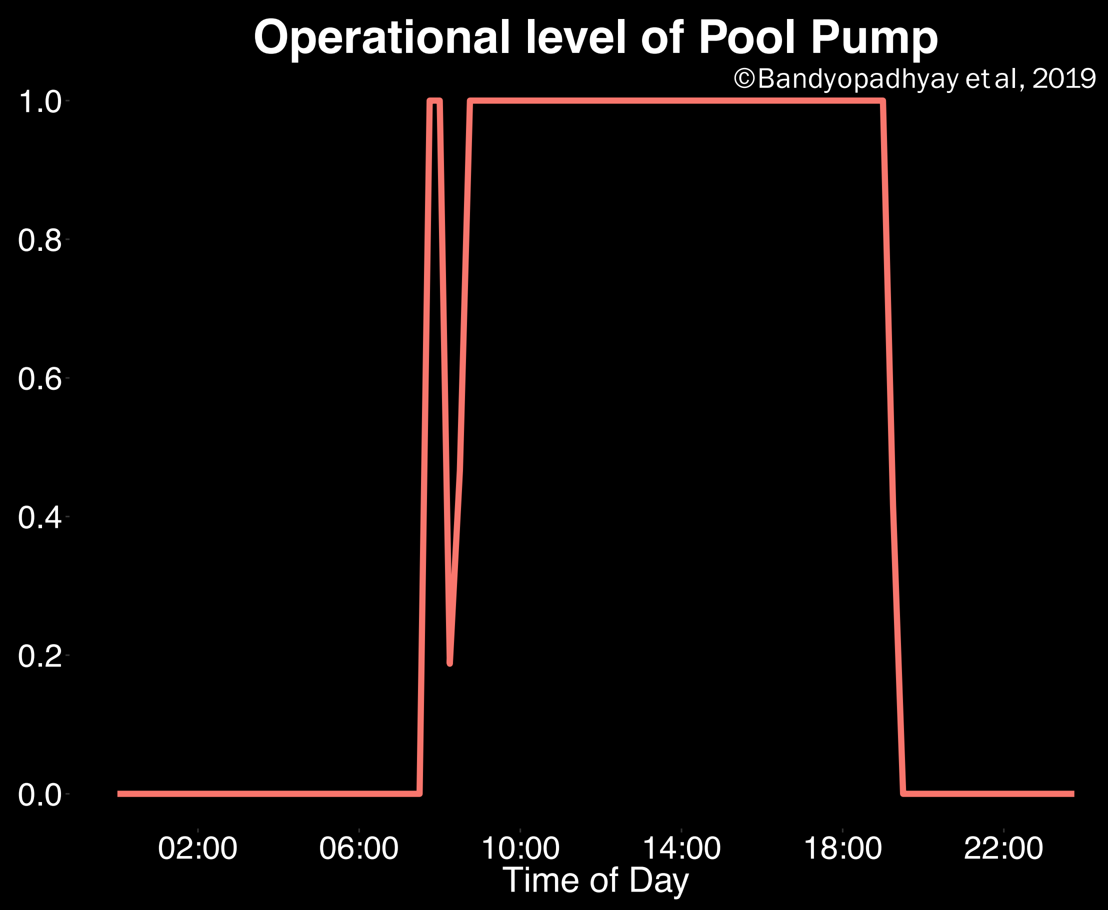
The EWH maintains the water between 40ºC (~104ºF) and 45ºC (~113ºF) before 9 a.m. and after 4 p.m.



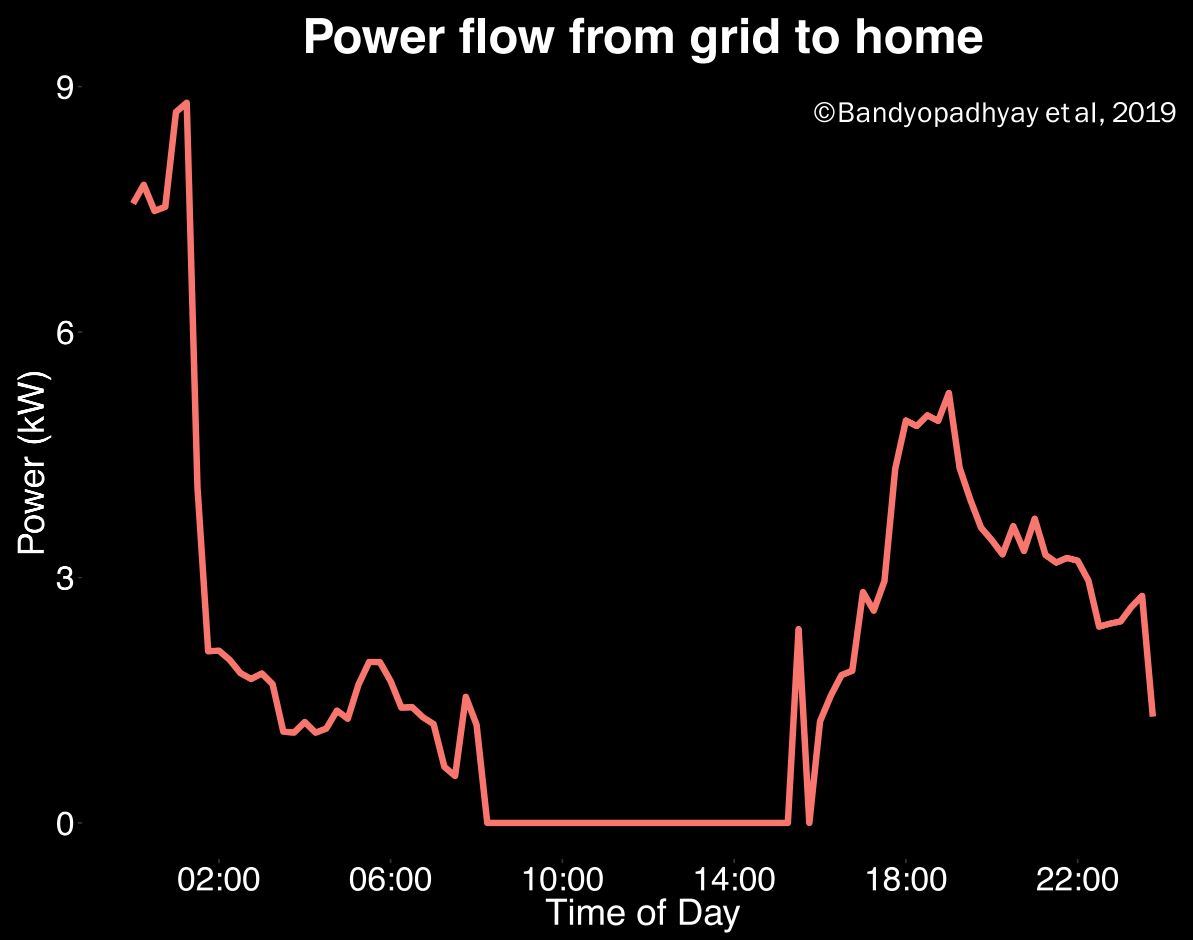


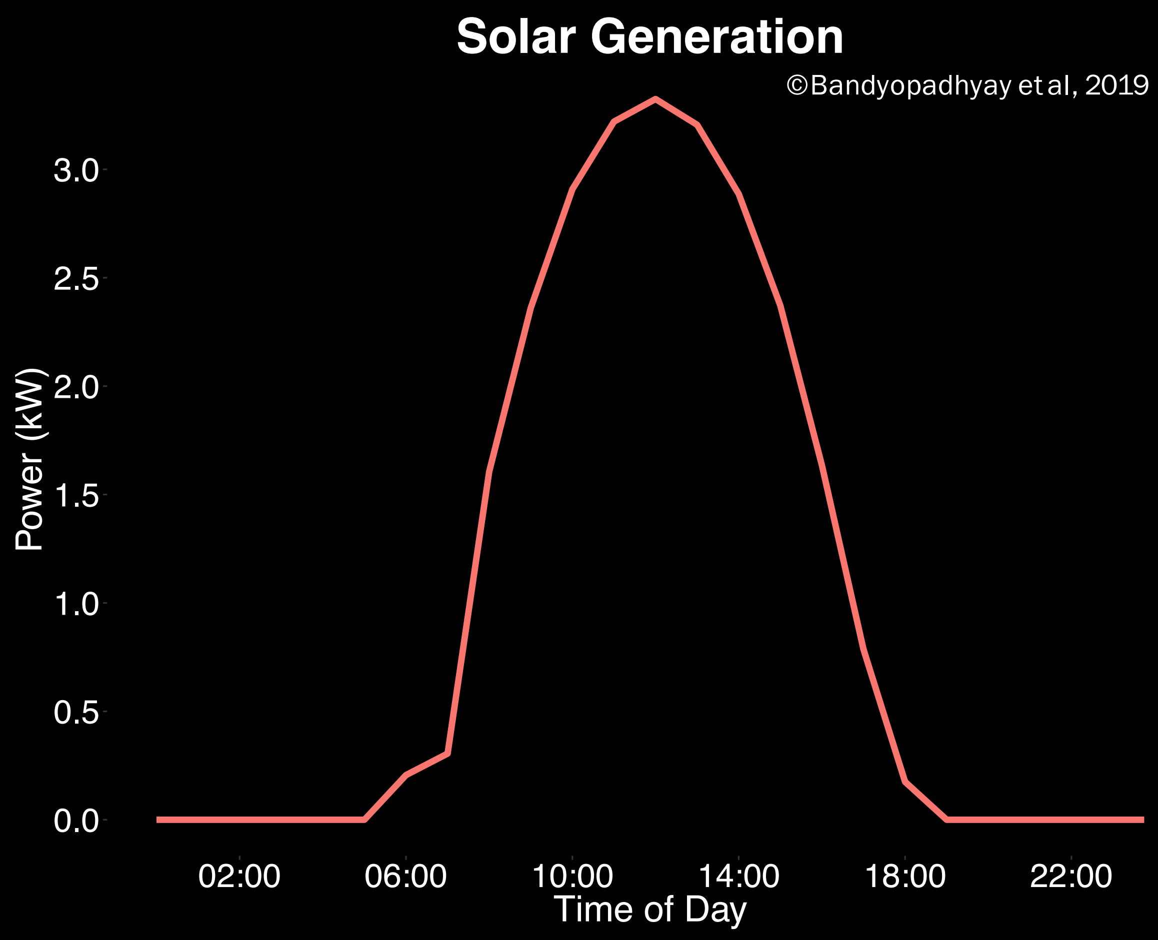
The EV is charged right after midnight and the pool pump runs between 8 a.m. and 10 p.m.



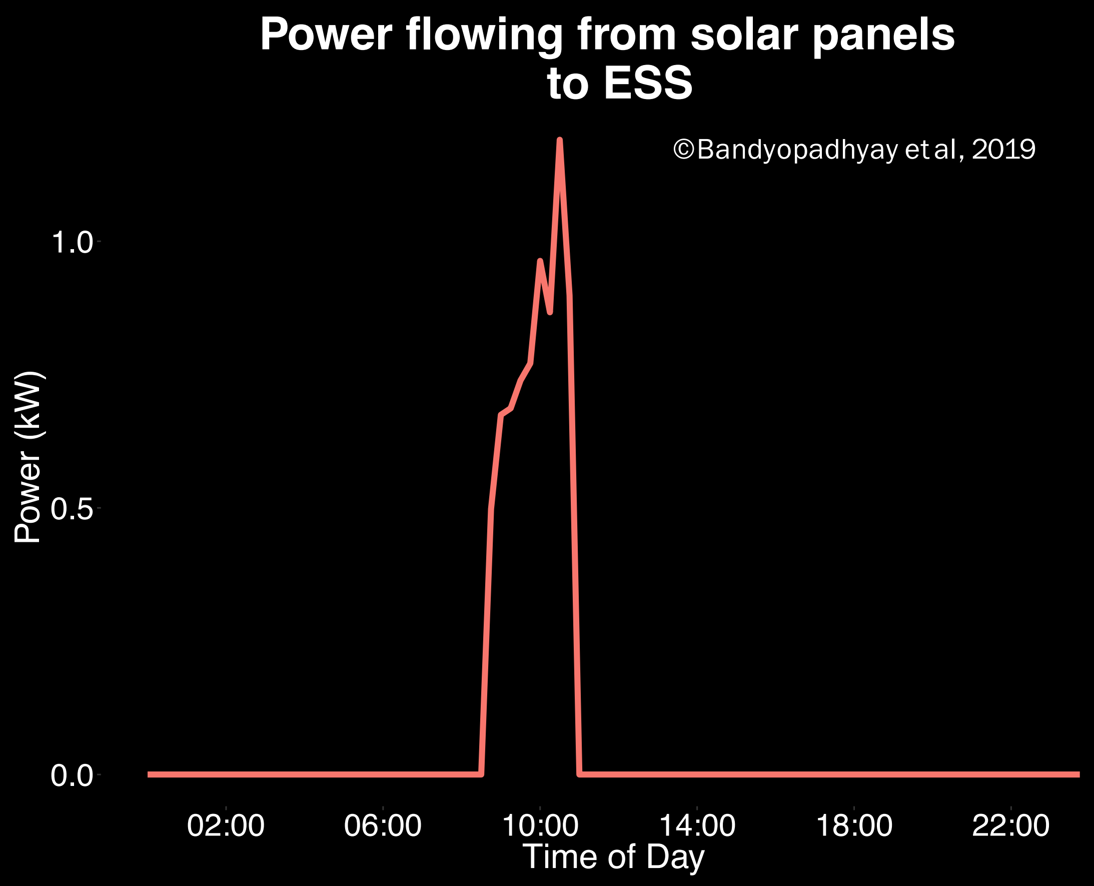


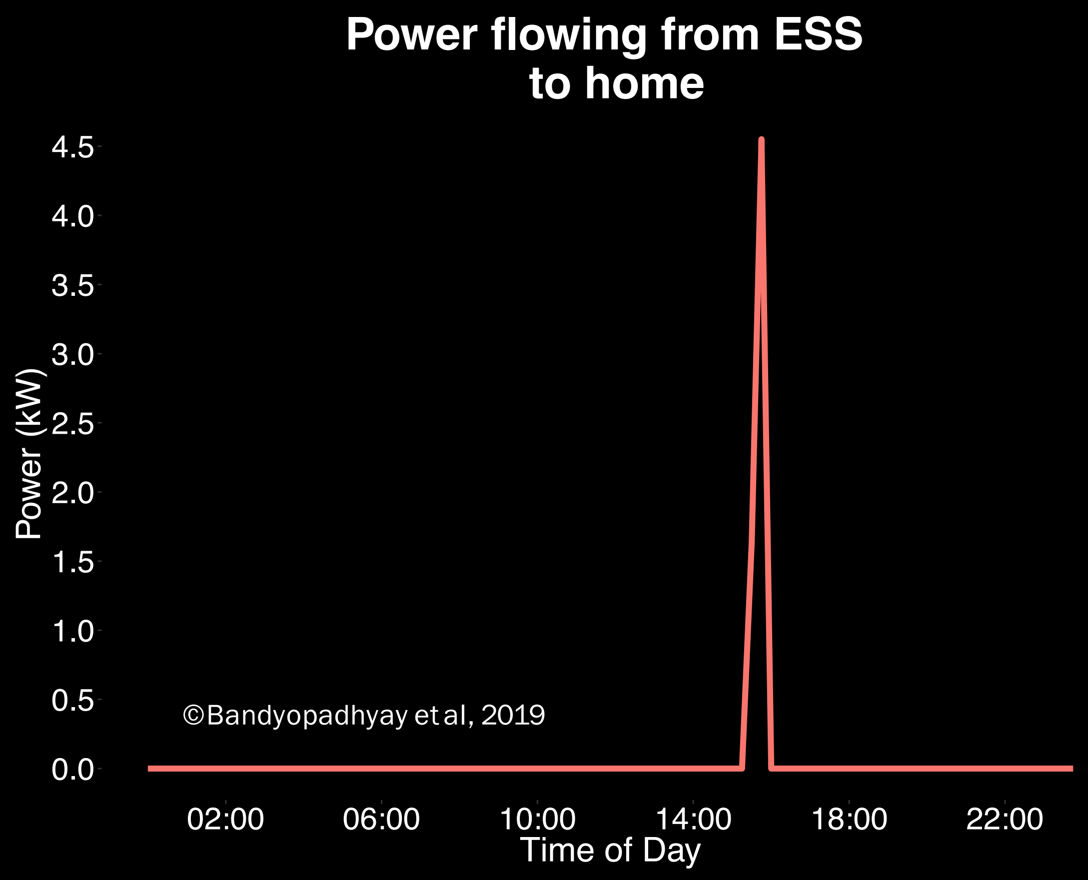
Power flows from the grid to the home when solar PV generation is low or not available





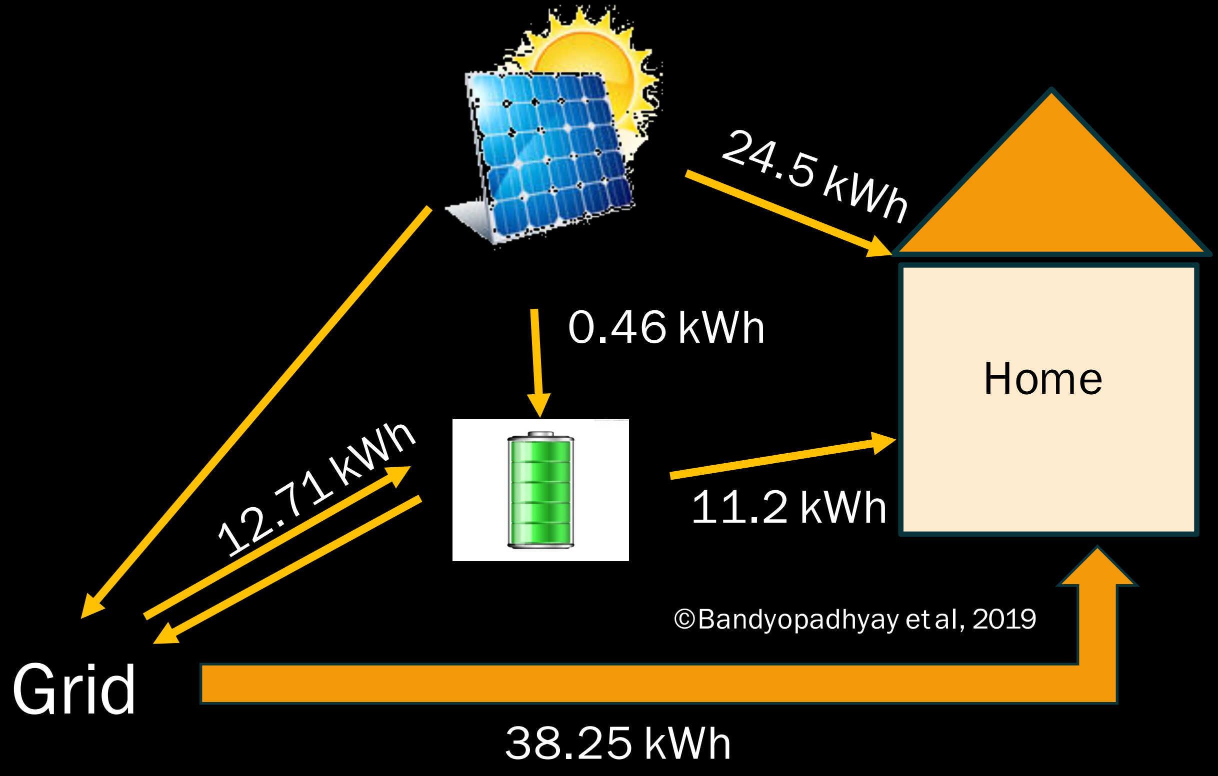
The ESS is charged from the solar panels in the morning and discharges in the afternoon



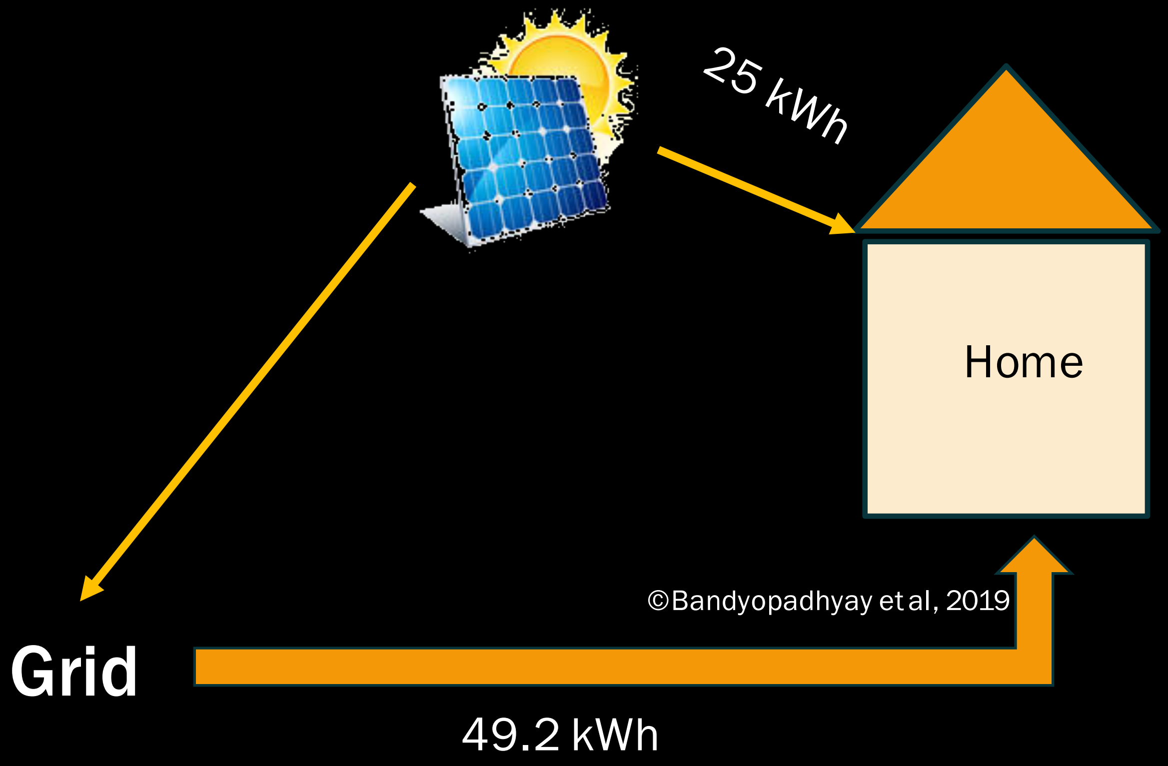


Power flows for the RTP scenarios are shown

Scenario 1



Scenario 2

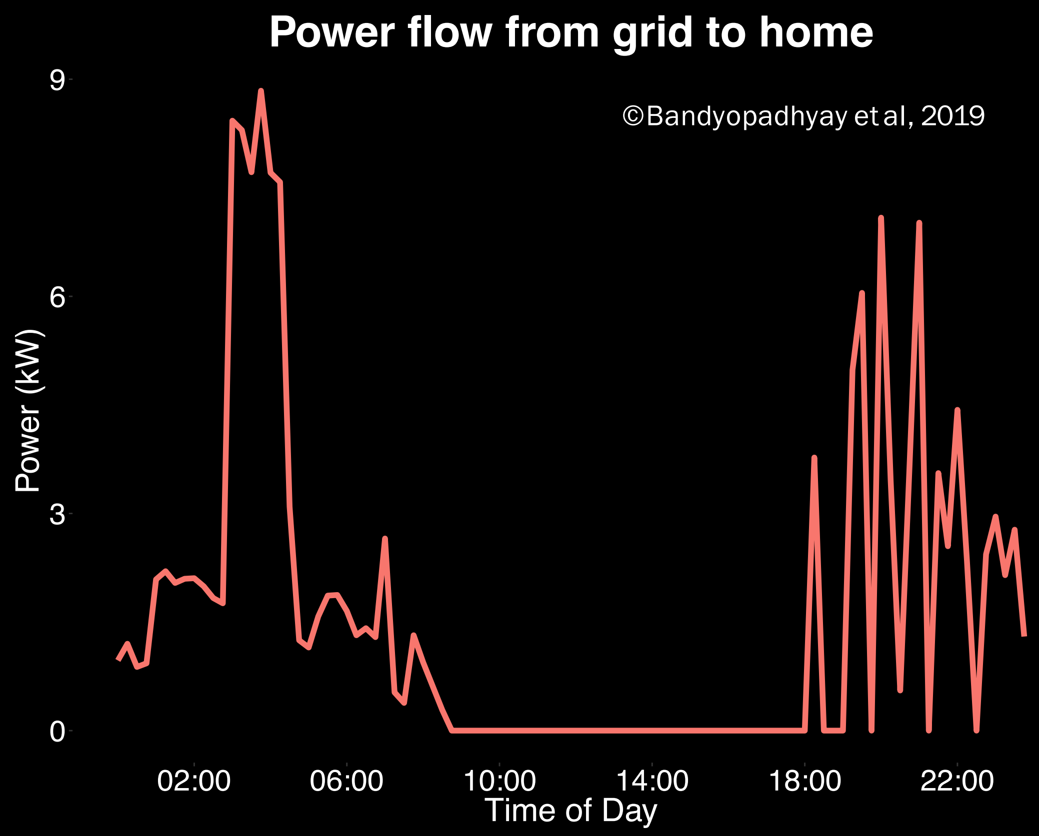


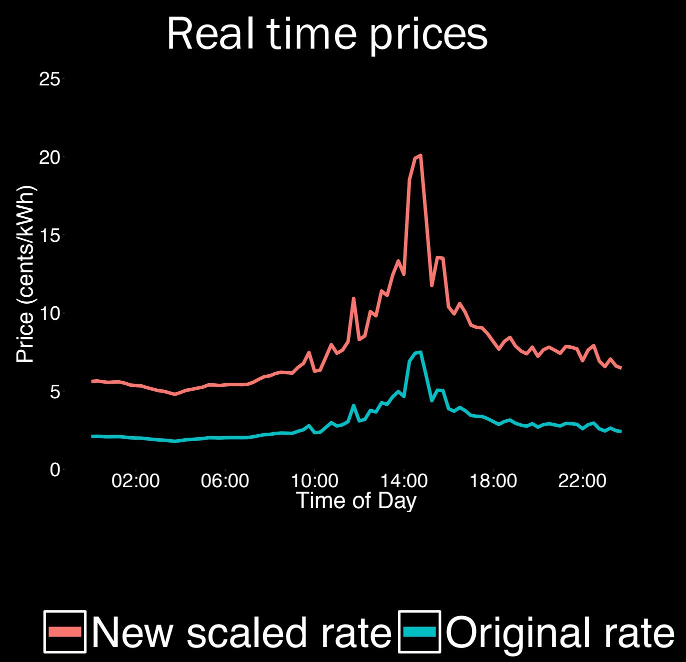
Note: 74.9 kWh is bought from the grid for Scenario 3 with no solar and no ESS

Real-time pricing

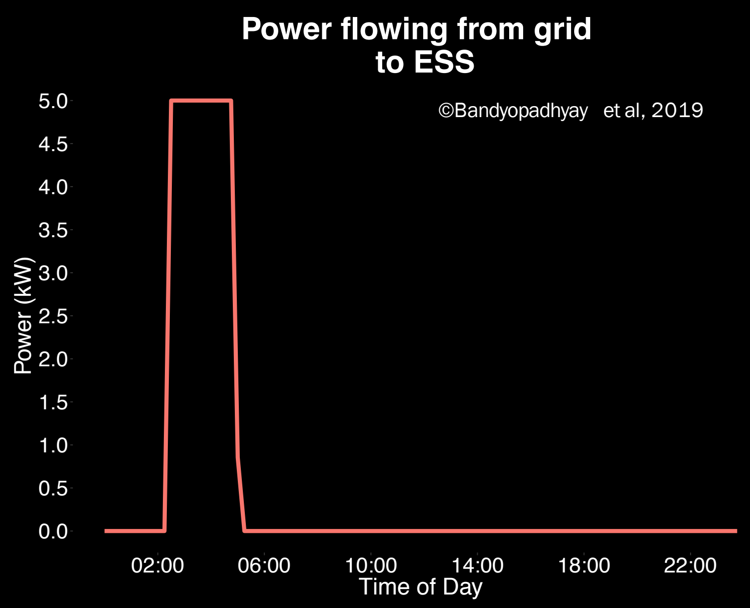
Power flows for Scenario 1: Home with solar + ESS

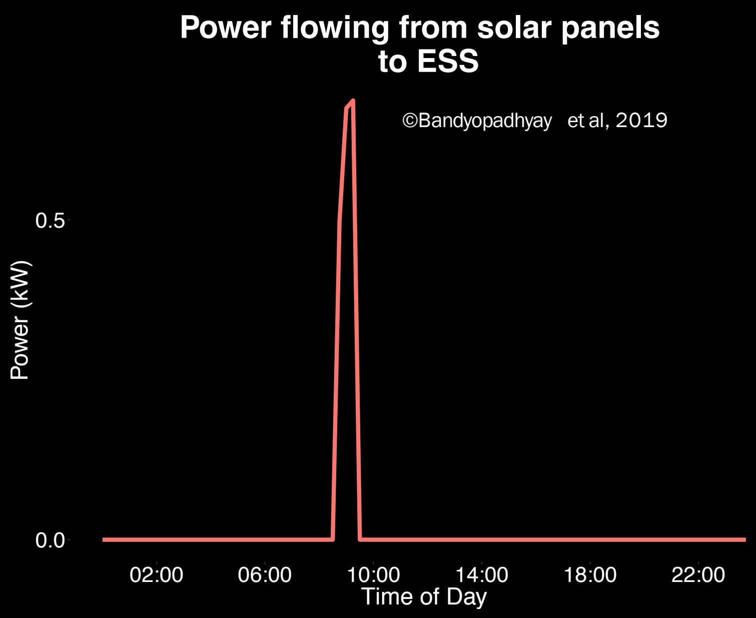
Power flow from the grid to the home is greatest when prices are lowest

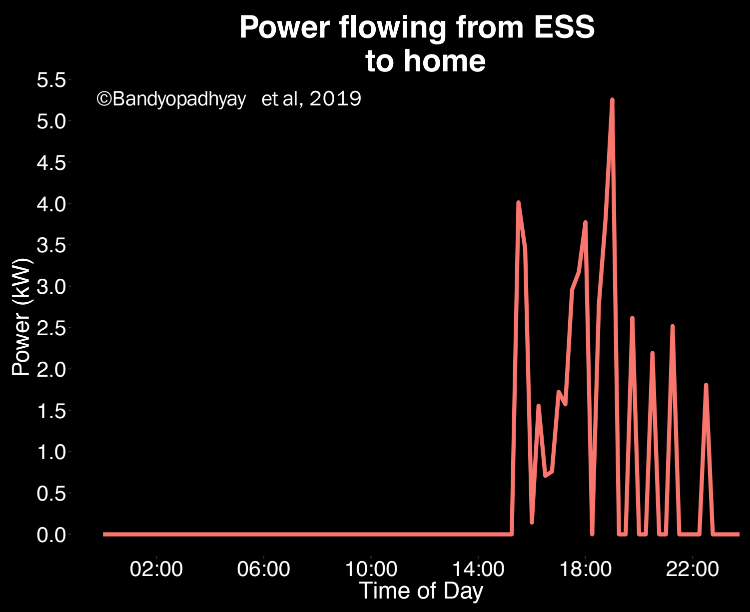




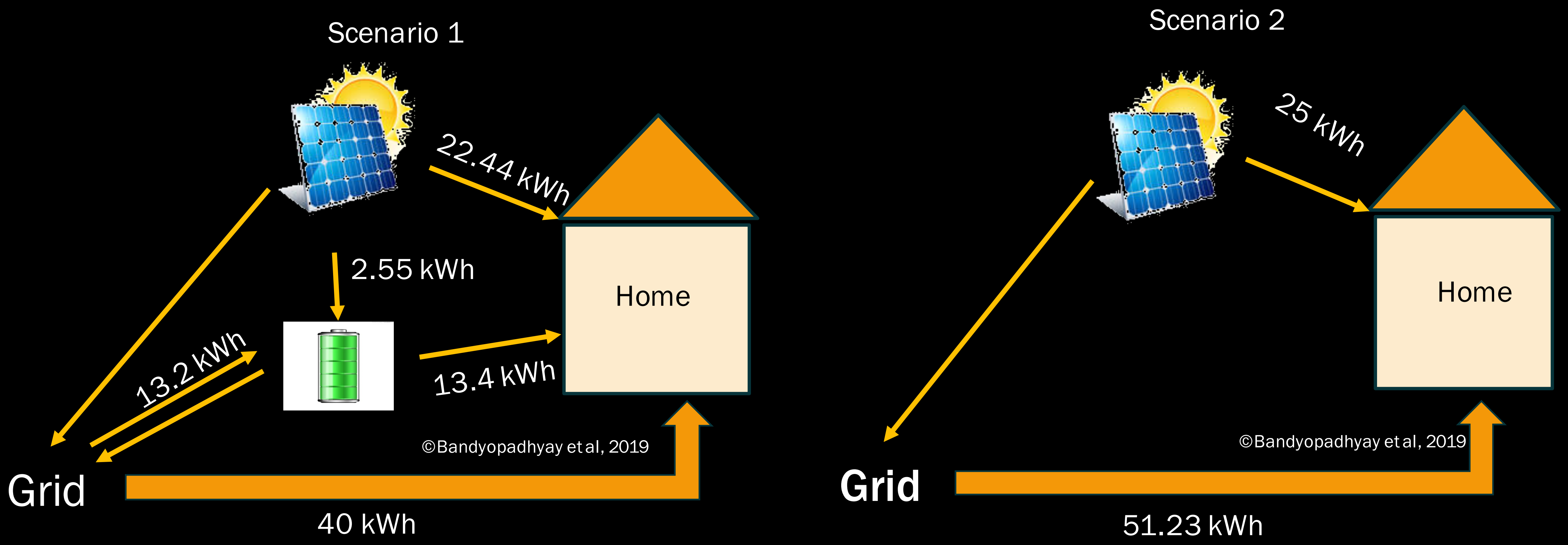
The ESS is charged from the grid and solar panels in the morning hours and discharges in the evening hours







Power flows for the TOU scenarios are shown

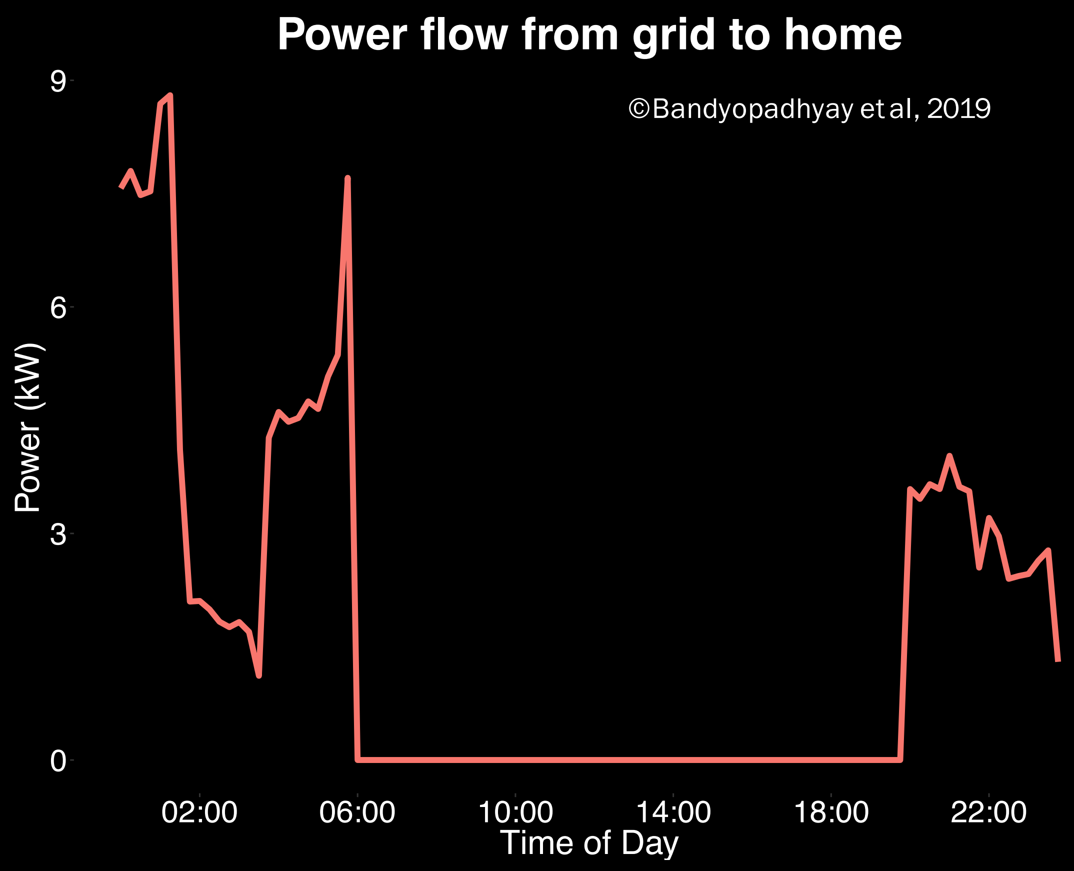


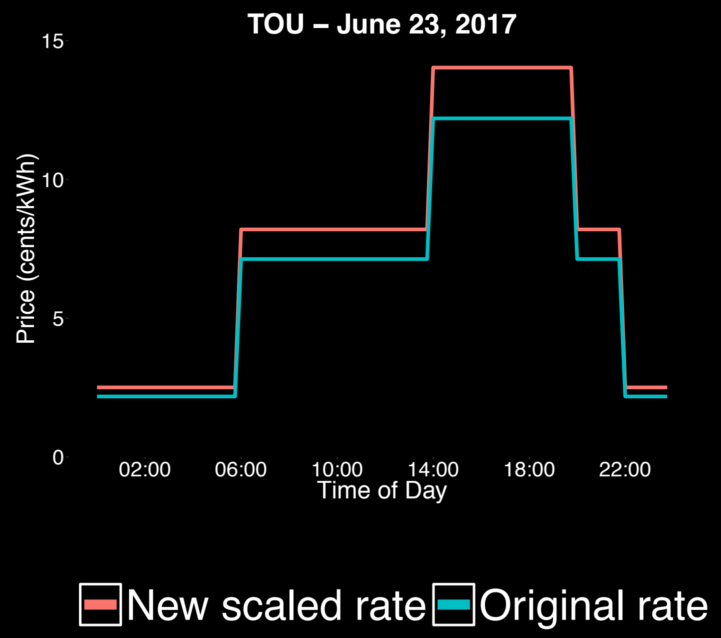
Note: 76 kWh is bought from the grid for Scenario 3 with no solar and no ESS

Time-of-use rate

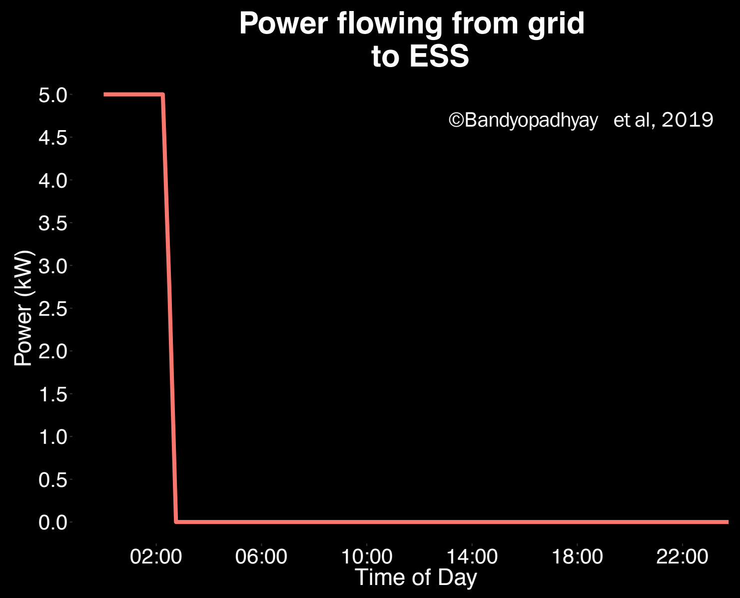
Power flows for Scenario 1: Home with solar + ESS

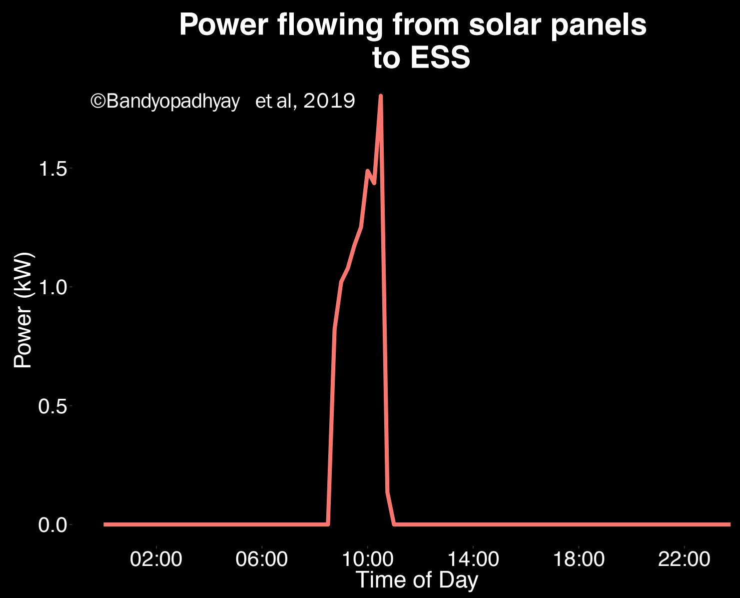
Power flows from the grid to the home mostly during the off-peak period

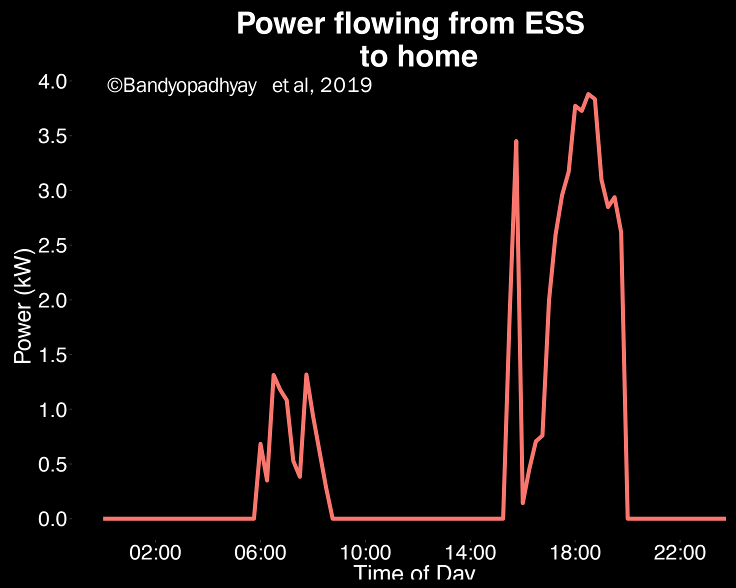




The ESS is charged from the grid in the early morning hours (off-peak period) and from the solar panels during late morning. The ESS discharges to the home in the morning as mid-peak hours start and during the on-peak and mid-peak hours in the evening







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Several avenues for further research exist

- Sensitivity analyses
  - DER rebates from other electric utilities
  - DER ownership frameworks
  - DER control methodologies
- Modelling customer willingness for demand response
  - ‘Rational behavior’ vs. ‘cost’ of time, attention, effort for demand response

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This study establishes a tool for residential customers to decide whether or not to invest in DERs based on various utility electricity pricing structures

- Cost of electricity bought from the grid is lowest for customers with solar and storage for all pricing scenarios
- Capital costs for DERs need to decrease further to keep the overall customer expenditure low
- ESS rebates are needed in addition to solar rebates

Acknowledgments

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