Navigating the Design Space of Trajectories Towards Low/Zero Carbon Energy Systems in California

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Outline

• Introduction and Context
  o Motivation
  o Major Questions

• Example 1 – Large-Scale Electrification of Transportation
  o Grid Integration and Achievable GHG Emissions

• Example 2 – Large Scale Deployment of Energy Storage
  o Scale of Energy Storage Deployment Needed
  o Net Environmental Benefits of Energy Storage Deployment

• Conclusions
Motivation

• Environmental Sustainability
  
  ○ Greater attention is being given to the detrimental environmental impacts of the current configuration of our energy and water sectors:
    
    ✓ Climate Change
    
    ✓ Air / Water / Land pollution

• Resource Security
  
  ○ Historical events have highlighted the vulnerability of the supply of resources traditionally used to provide energy and water services
    
    ✓ Geopolitical instability
    
    ✓ Sustained drought
    
    ✓ Infrastructure Vulnerabilities
Motivation

• California Policies and Goals
  o Senate Bill 100 (2018) - Law
    ✓ At least 60% renewable by 2045 and 100% zero-carbon by 2045

  o Executive Order S-3-05 – Goal
    ✓ Economy-wide reduction in greenhouse gas emissions to 80% below year 1990 levels by 2050

  o California Zero-Net Energy (ZNE) Mandates
    ✓ All new residential homes must be ZNE by 2020
    ✓ All new commercial buildings must be ZNE by 2030
    ✓ 50% of existing commercial buildings must be ZNE by 2030
Major Questions

How do we choose between different technological pathways of achieving these outcomes?

What are the obstacles and unintended consequences we may encounter when deploying new technologies to meet these outcomes?

What are some of the solutions we can employ to avoid or mitigate any undesirable consequences?
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Example 1 – Electrification of Transportation

Example 1: Large Scale Electrification of Transportation

Questions
What are the impacts of large-scale deployment of alternative powertrain vehicles on the energy system?

What needs to be done to actually realize the potential benefits of these technologies for meeting environmental outcomes?

Content Sources:
• UCI APEP WTW GHG Study, 2014
• UCI Spatially and Environmentally Resolved Energy and Environment Tool, 2014
• Zhang et al., *J. Power Sources*, 2013
Example 1 – Electrification of Transportation

• Renewable Utilization and Greenhouse Gas Emissions
  o Usage of electric vehicles can provide significant reductions in greenhouse gas emissions, even including life cycle processes.
  o With advances in decarbonization of manufacturing, these reductions can be even higher

Source: UCI APEP
• Renewable Utilization and Greenhouse Gas Emissions
  
  o Realizing potential greenhouse gas benefits from EVs has other considerations, however.

  o Recall that to utilize renewables, electric loads have to match renewable generation profiles or one must be shifted such that this occurs!
Example 1 – Electrification of Transportation

• Renewable Utilization and Greenhouse Gas Emissions

  o **Unintended Consequence:** Without charging management or energy storage, consumer travel patterns limit the potential greenhouse gas reductions that can be obtained from using electric vehicles!
Example 1 – Electrification of Transportation

- Renewable Utilization and Greenhouse Gas Emissions
  - Smart Charging
    - Consumers schedule their travel plans into the electric grid.
    - Grid operators dispatch the charging profile to benefit the grid.
    - Ensures that the consumer has enough charge to meet their next scheduled trip.

### Example 1 – Electrification of Transportation

#### Year 2050: 325 GW Renewables + 90% Alternative Vehicle Fleet Penetration

<table>
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<th>Reference</th>
<th>Year 2010 Actual</th>
<th>Year 2050 Renewables w/Adv. Gasoline ICV</th>
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<td>BEV 200 mi Total</td>
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<tr>
<td>Combined GHG Emissions [MMg/yr]</td>
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Renewable Utilization and Greenhouse Gas Emissions

- Potential issues with smart charging:
  - Smart Charging may interfere with consumer convenience and may pose privacy issues.
  - Grid operator control of battery charging may degrade battery.
  - Does not leave as much room for unscheduled travel.

- If we can't get consumers to smart charge, we will need energy storage.

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Example 2: Large Scale Deployment of Energy Storage

Questions

How much energy storage do we need to meet California’s energy and environmental goals?

What is the net benefit – including life cycle impacts and use-phase benefits – of deploying energy storage systems to scale?

Content Sources:
• Tarroja et al, Energy, 2018
• Forrest and Tarroja et al., J. Power Sources, 2016
• In preparation
Example 2 – Large Scale Energy Storage Deployment

• Energy storage has been identified as a key component for enabling renewable resource integration.
  ○ Wind and solar are the leading forms of renewables that are accessible to many areas of the world, and energy storage is needed to effectively harness these sources.

• How much energy storage is needed?
  ○ Depends on the composition of the rest of your system.
    ✓ How much of your generation portfolio is flexible and dispatchable to meet loads?
    ✓ How much of your loads are flexible enough to shift to align with low carbon generation?
Example 2 – Large Scale Energy Storage Deployment

• How much energy storage is needed?
  
  o **Extreme Case:** 100% RE using wind, solar and storage only.
    
    Can require between 5660 GWh and 17000 GWh of storage for CA alone!
    
    ✓ Each 1.0% is equivalent to ~ 338 million Tesla Powerwall batteries or 4561 GWh!!
    
    o Compare to Tesla gigafactory = 50 GWh production per year.
Example 2 – Large Scale Energy Storage Deployment

• How much energy storage is needed?
  o Using a mix of generation sources and dispatchable loads to meet an 80% renewable goal in 2050.

  o Assess how much energy storage is needed as we increase the intelligence of battery electric vehicle charging:
    ✓ Immediate (Uncoordinated) charging
      – Plug-in upon arrival, full charging power until battery is filled.

    ✓ Smart charging
      – Maximize charging when renewables are generating.

    ✓ Vehicle-to-grid (V2G)
      – Maximize charging when renewables are generating + discharge energy back to the grid if battery has a surplus.
Example 2 – Large Scale Energy Storage Deployment

• **Immediate Charging**

- Requires relatively large capacity of stationary energy storage to reach 80% RE.

- Misalignment of loads and generation requires significant shifting capabilities.

- Most of the energy passes

○ **Unintended Consequence:** If we don’t manage how electric vehicles are charged on the electric grid, we will require a significant amount of energy storage in order to meet renewable energy utilization goals.
Example 2 – Large Scale Energy Storage Deployment

• Smart Charging

- Reduced capacity of stationary energy storage to reach 80% RE.
- Better alignment of EV load with renewable generation reduces shifting capability requirement.
- Energy storage system can better focus on discharging to meet the stationary load in addition to the mobile load.
Vehicle-to-Grid (V2G)

*IF* all EVs do V2G, can potentially eliminate the needs for stationary energy storage (for meeting 80% RE).

Higher effective storage efficiency allows achievement of higher renewable penetrations.

Many practical considerations that need to be discussed, however.
Example 2 – Large Scale Energy Storage Deployment

- Aggregated Results

- Increased charging intelligence reduces the required capacity of stationary energy storage.
- V2G can (theoretically) eliminate energy storage needs!
Example 2 – Large Scale Energy Storage Deployment

• All energy storage technologies can provide environmental and health benefits through enabling use of excess renewable generation.

• These technologies, however, also have their own environmental and health impacts which are not well understood on a common, comparable basis.

• Additionally, technology advances and new chemistries introduce new unknowns regarding the environmental and health impacts of these systems relative to their benefit.
Example 2 – Large Scale Energy Storage Deployment

- Example: Environmental benefits vs impacts: GHG Emissions
  - Using Vanadium Flow Batteries as an example
    - Emissions reductions from energy storage deployment are high for the first units of energy storage capacity.
      - Reduces natural gas usage on the electric grid.
    - As more energy storage is deployed, benefit increases at a slower rate until an asymptotic value.
    - Manufacturing & materials extraction emissions increase linearly with capacity.
    - **Capacity Threshold**: \( \sim 1840 \text{ GWh} \)
      - Installing more storage after this point actually increases GHG emissions!

Source: In preparation
Example 2 – Large Scale Energy Storage Deployment

- Example: Environmental benefits vs impacts: Particulate Matter
  - Using Vanadium Flow Batteries as an example

  - Unlike GHG emissions, energy storage provides limited benefit for reducing PM emissions from the electric grid.
  - Natural gas power plants already have low PM emissions, therefore offsetting with renewables does not reduce PM emissions significantly.
  - PM emissions from manufacturing + materials extraction increase linearly with capacity.
  - Capacity Threshold: ~780 GWh
    - Installing more storage after this point actually increases PM emissions!

Source: In preparation
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Overall Conclusions

• Unintended Consequences:
  o Deploying plug-in electric vehicles may **not necessarily provide large GHG emissions reductions** if charging loads are not intelligently managed.
  
  o Lack of flexibility in large electric loads can require **significantly more capacity of energy storage** to meet the same renewable penetration goal.
  
  o Without accounting for the materials and manufacturing contributions to environmental impacts of energy storage systems, capacity may be **deployed to a level that cancels the environmental benefits** of these systems.

• Potential Solutions:
  o **Incentivize load flexibility** through meaningful compensation for consumers such as BEV drivers to charge when renewable generation is abundant.
  
  o **Include life cycle impacts of energy storage** in capacity sizing optimization analyses and **incentivize more environmentally benign supply chains**.
Overall Conclusions

• There are many ways by which we can transform the technology portfolio of our energy and water sectors to meet sustainability-oriented outcomes.

• Certain pathways, however, can have unintended consequences which can make them less effective at progressing towards intended outcomes.

• Predictive modeling to identify and avoid these consequences can better inform large-scale planning to increase the probability of meeting environmental outcomes.
Questions?

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