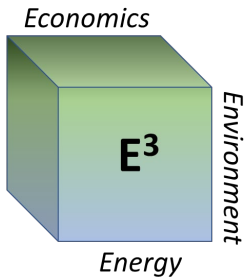

Closing Thoughts: Power Systems Perspective

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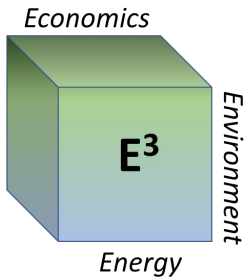
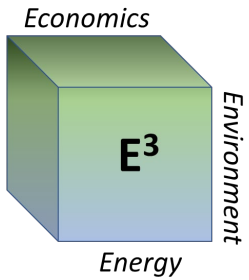


Power System Operation and Control Fundamentals Regardless of Weather and Uncertainties

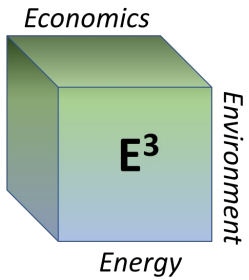
- Maintain energy balance (supply equals demand plus losses).
- Maintain frequency response and regulation (to ensure energy balance).
- Still need to maintain contingency reserves (guard against losing energy balance with the loss of a large generator).
- Still need to maintain reactive power to support voltage (facilitate transfers of energy across the transmission system).
- Still need to maintain transmission security (observe thermal, voltage, and transient stability limits).
- Still need to acknowledge other operational constraints on generation and load (start and notification times, min run times, min run levels, etc.)

- ***These all must happen regardless of energy market design! Still must happen with large penetration of variable and intermittent resources.***



We must embrace and understand risk and uncertainty

- Weather
  - Impacts on load forecast
  - Impacts on wind and solar output
  - Impacts on storage discharge and charging especially with short duration storage
  - Impacts on dispatchable generator availability
- Other load forecast uncertainty
- Planned and maintenance generator and transmission outages
- Fuel market dynamics (especially natural gas)



Law of Conservation of Risk-Part 1

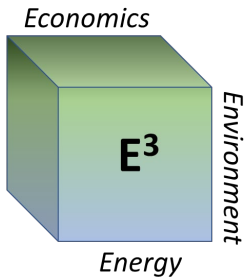
1) Risk can neither be created or destroyed. It is ubiquitous and all around us.

2) Risk can be transformed from “event risk” to “monetary risk” or monetary values.

- This is key in thinking about power system operations…do we take actions that cost money (committing resources) or risk involuntary load shed or worse

3) Risk can be known or unknown. Just because it is unknown, does not mean it is not present. The above in the “Rumsfeldian” sense is that there are “known unknowns, and unknown unknowns”

- Winter storm Uri…I would argue it could have been known, but we have short memories

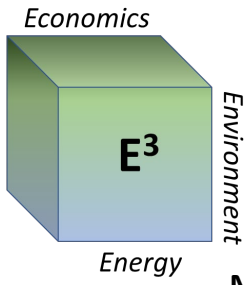


Law of Conservation of Risk-Part 2

4) Risk can be transferred from one party to another knowingly or unknowingly.

- Often this is unknowingly….if we fail to account for risks in operations, we are in effect transferring those risks to generators and loads in the form of even and monetary risk
- We need to make transparent how these risks are being transferred and get these into the market prices to allow generators and load to make decisions

This is where the melding of weather and power systems modeling come into play



Power Systems Operation and Planning Timelines

Make decisions based
On uncertainty and risk
From Ops Planning

Day-ahead
Unit Commitment

Ranges of weather forecasts
Refine outage schedules

Operations Planning
2 weeks – 3months out

Long-term Planning

Real-time
Operations

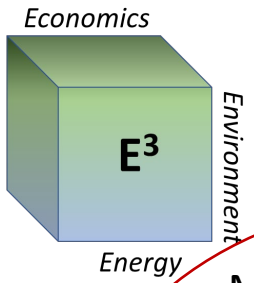
Realization of
Risk and uncertainty

Operations Planning
2 days -2 weeks out

Ranges of weather forecasts
Informs wind and solar output,
Generator outages, load forecast
errors

Operations Planning
3months – 1 year out

Use long term weather
Forecasts and start managing
Planned and maintenance outages



Power Systems Operation and Planning Timelines

Make decisions based
On uncertainty and risk
From Ops Planning

Day-ahead
Unit Commitment

Ranges of weather forecasts
Refine outage schedules

Operations Planning
2 weeks – 3months out

Need to transfer from ops planning to Markets. Not there yet!

Long-term Planning

Real-time
Operations

Realization of
Risk and uncertainty

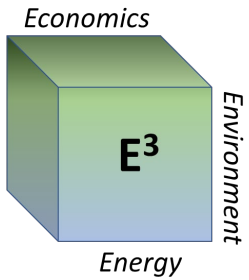
Operations Planning
2 days -2 weeks out

Ranges of weather forecasts
Informs wind and solar output,
Generator outages, load forecast errors

Operations Planning
3months – 1 year out

Use long term weather
Forecasts and start managing
Planned and maintenance outages

We have just arrived here



Challenges Going Forward

- Change is hard and people and institutions resist change
  - How do we overcome these fears of change?
  - If we cannot embrace change, we cannot adapt, and it will not end well

- We are working in silos (aka “cylinders of excellence”) and that prevents us from seeing the big picture
  - We need to talk and work with each other more
  - We need to show how all the pieces fit together (even though those pieces may seem disparate…they are related and we must see and find those linkages)

- Aside from the technical work, we need to do the “adaptive work” to break out of old habits and “the way we have always done things”