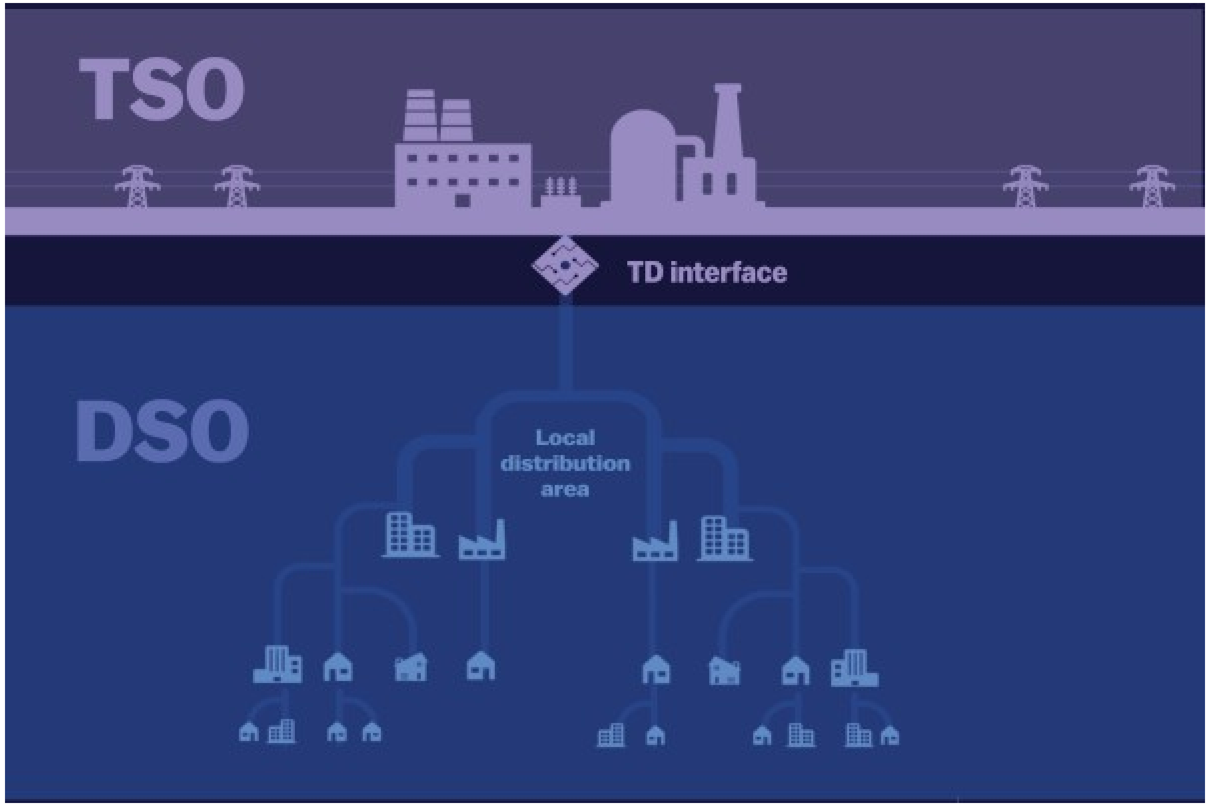
ELECTRICITY SYSTEM PLANNING MODELS IN THE AGE OF VARIABLE RENEWABLES

Cameron Wade

PIMS Workshop on Mathematical Sciences
and Clean Energy Applications
May 22, 2019

2060 Project



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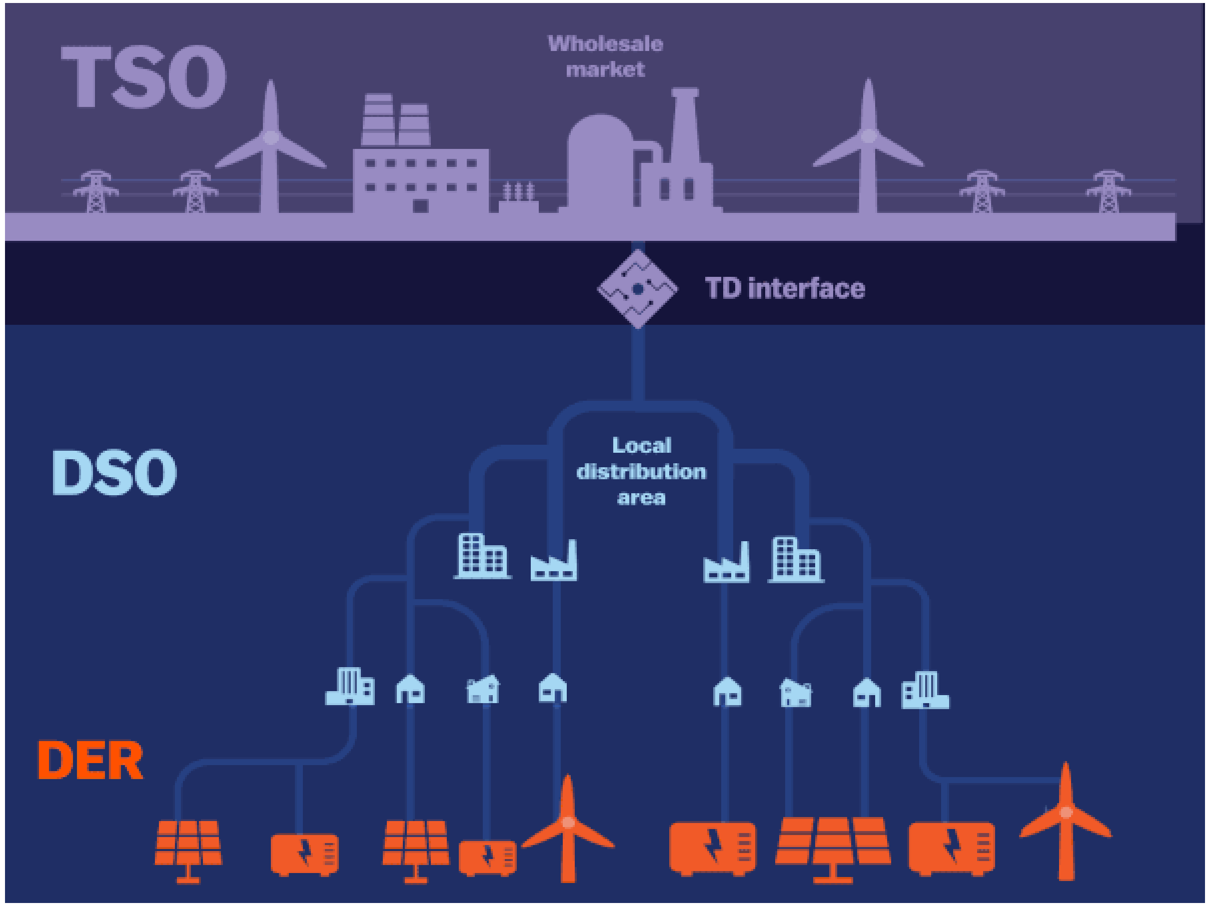

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Outline

- Overview of energy & power system models
- Overview of power system planning models
- Challenges imposed by variable generation
- Deep dive into the temporal dimension

Energy System Models

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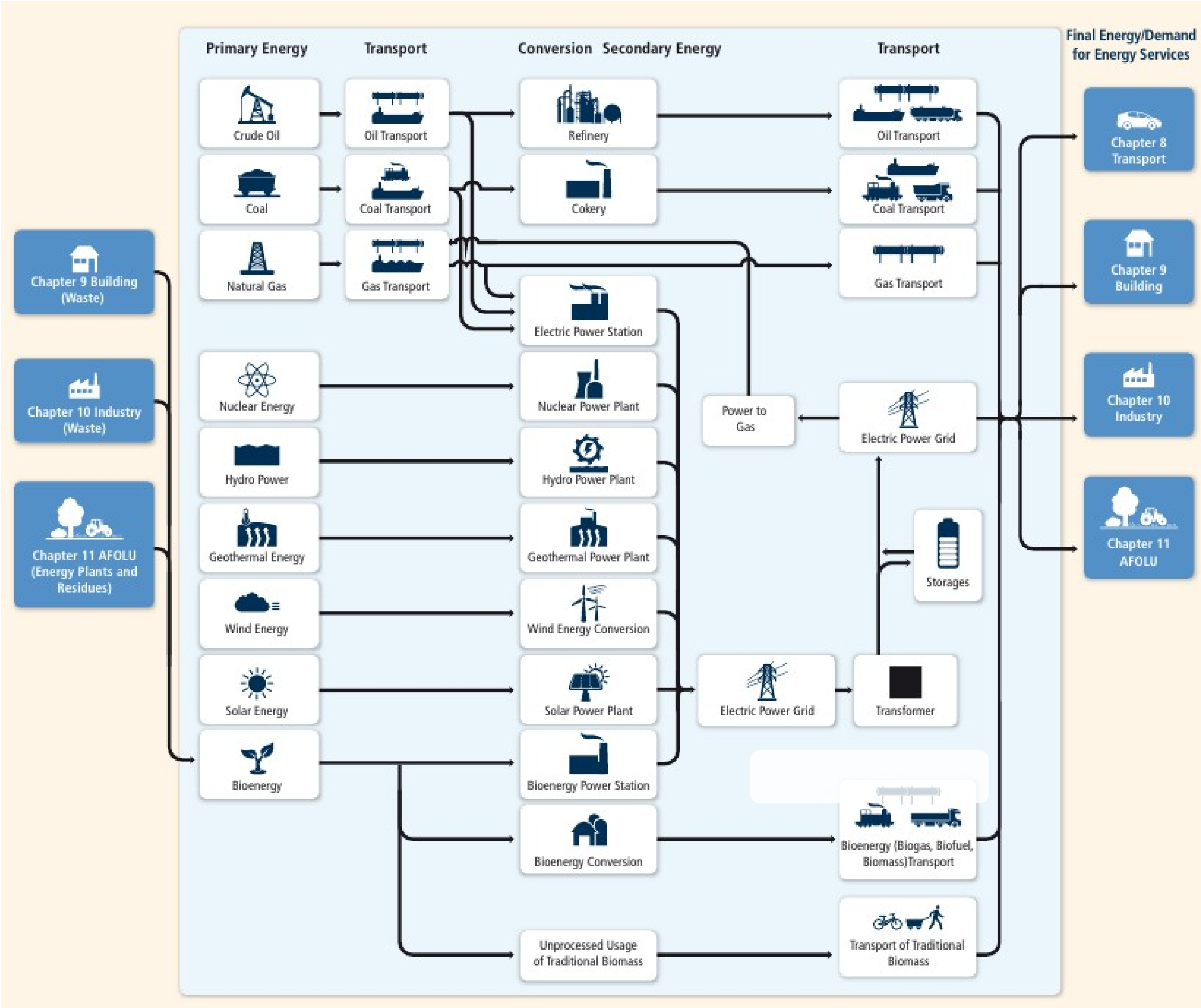
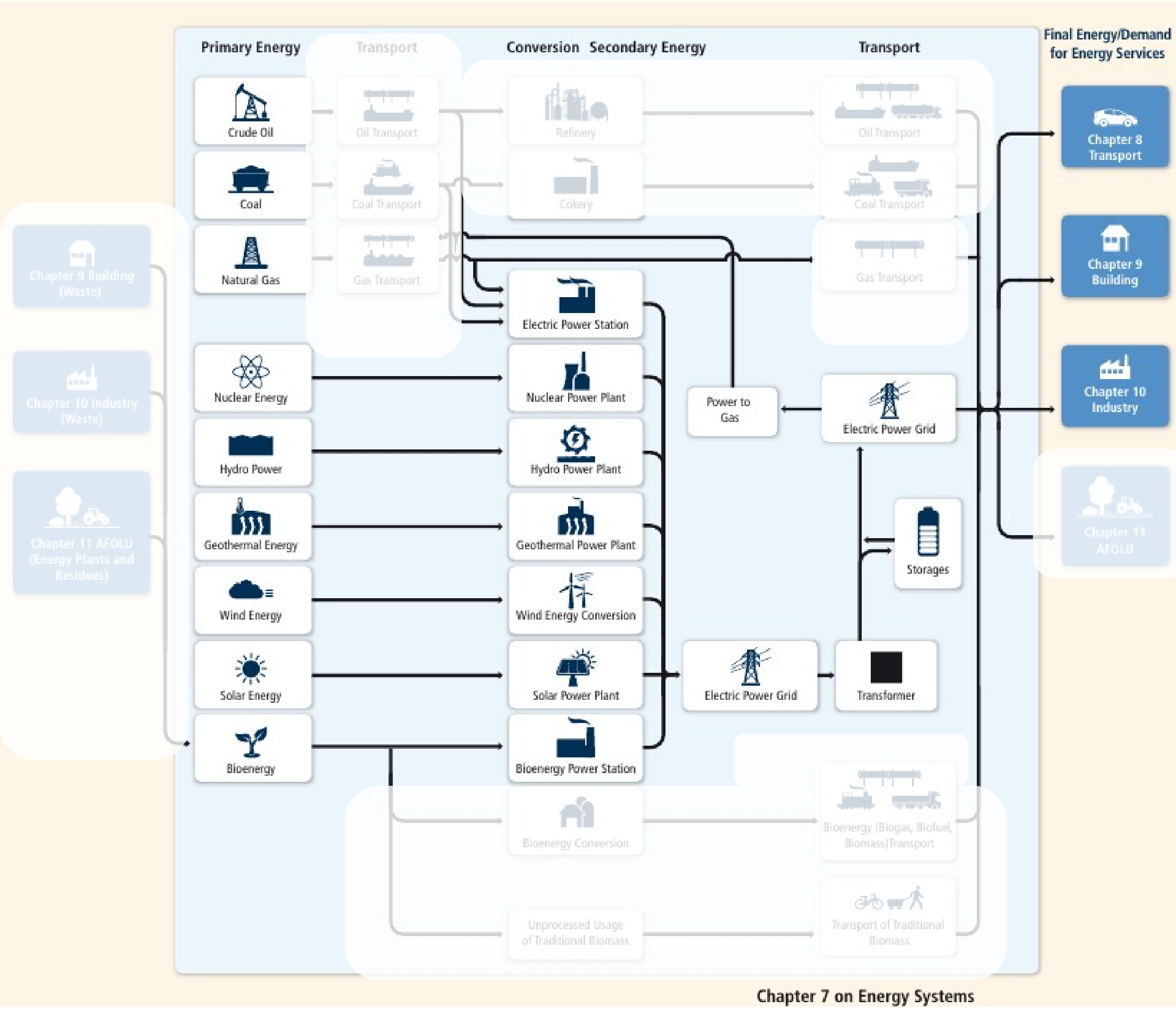


Chapter 7 on Energy Systems

Bruckner, Thomas, et al. "Energy systems." (2014).

Electric Power System Models



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Electric Power System Models

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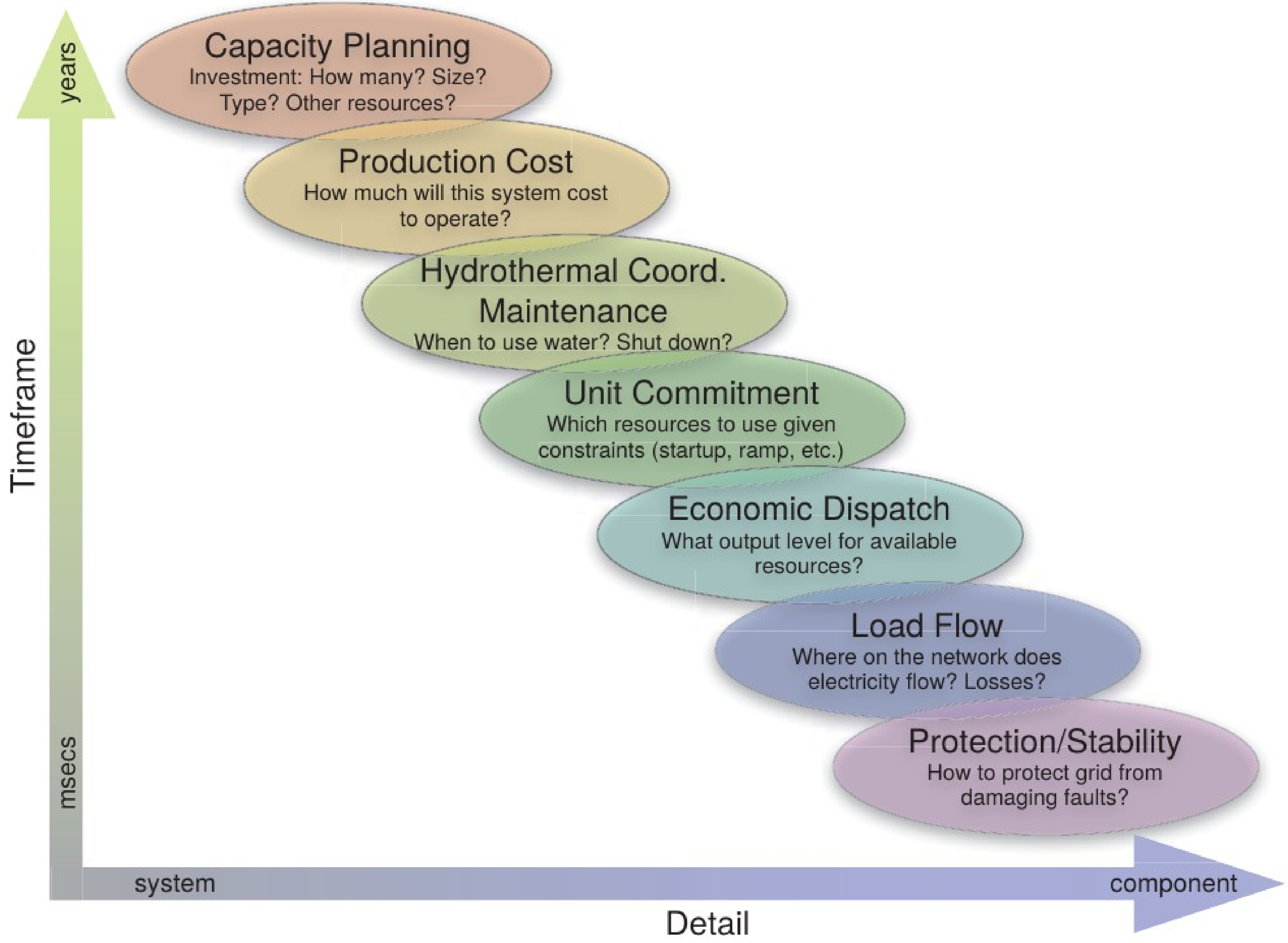

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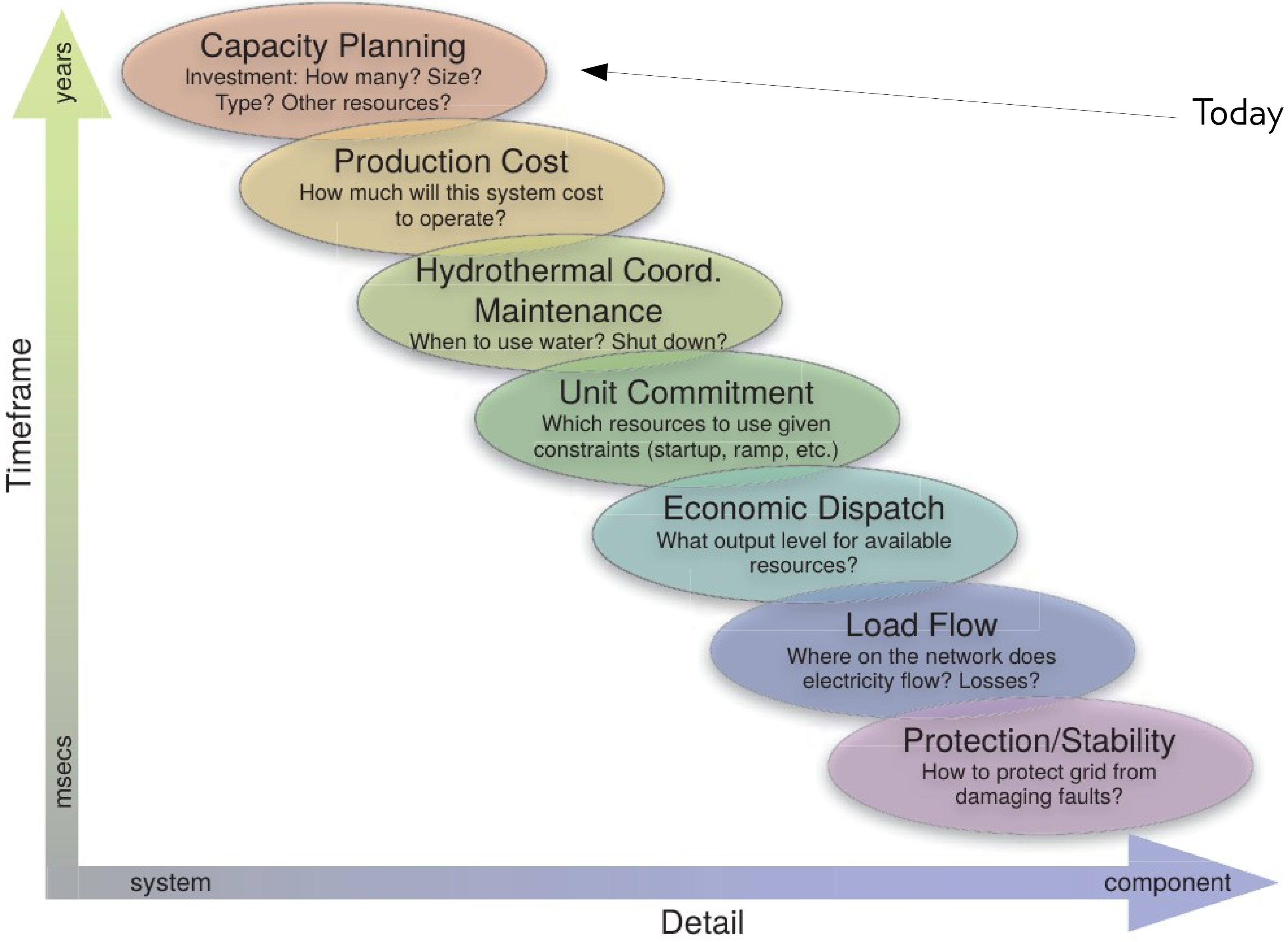
Electric Power System Models



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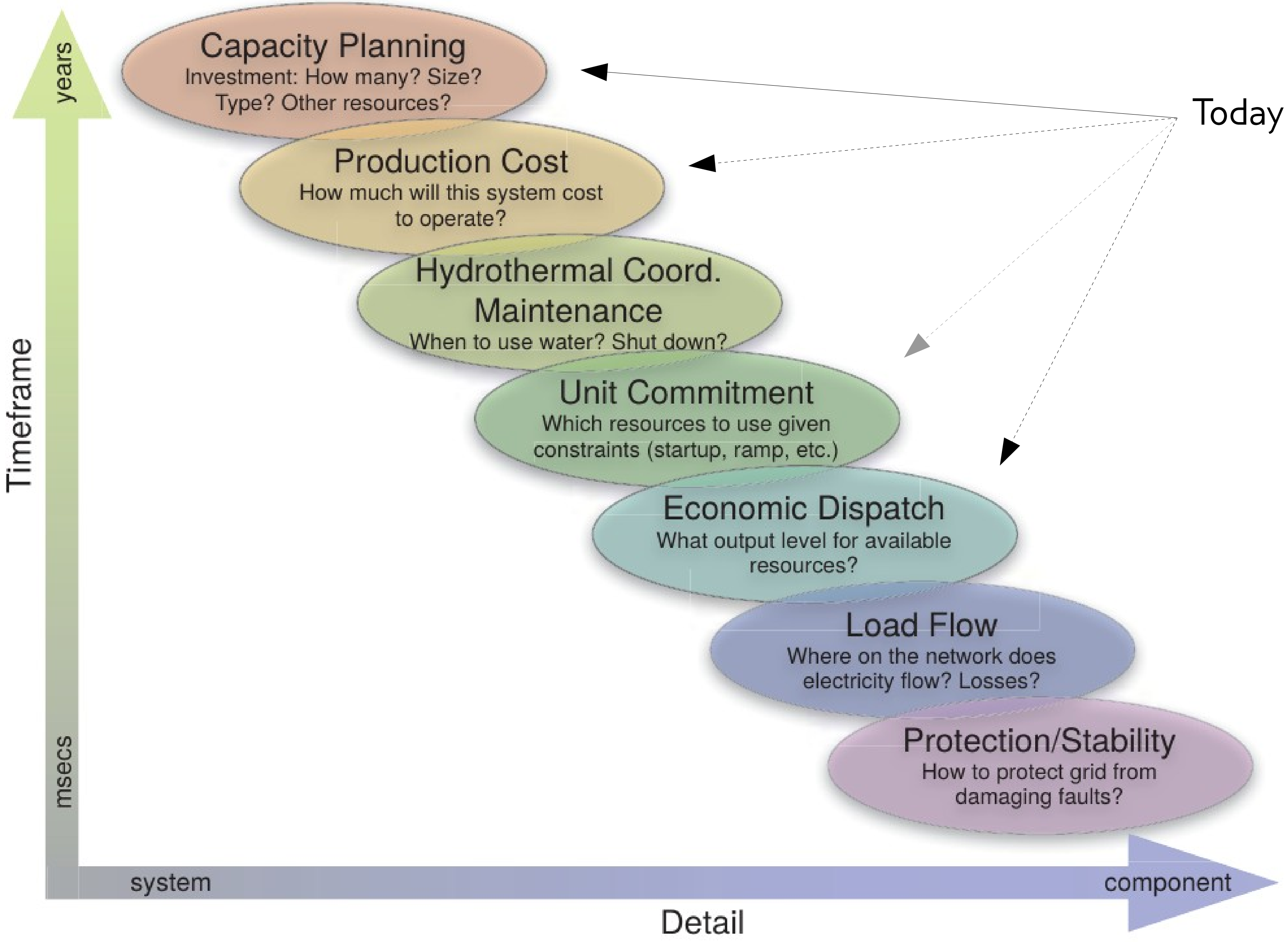

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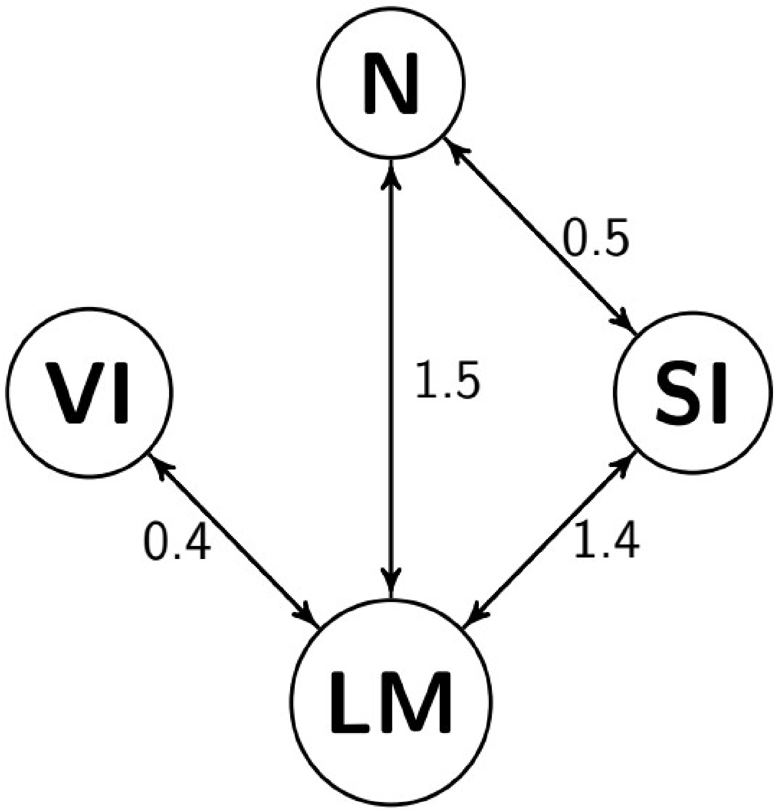
Electricity System Planning Models

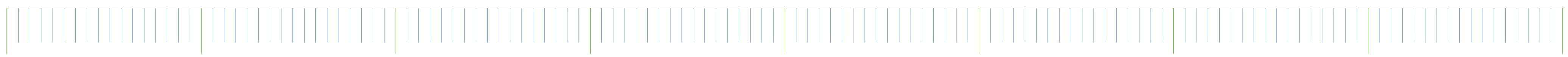
1. Choose + Discretize Space

2. Choose + Discretize Time

3. Optimize:

- What to build.
- Where to build it.
- When to build it.
- How to operate it.





Electricity System Planning Models

1. Choose + Discretize Space
2. Choose + Discretize Time
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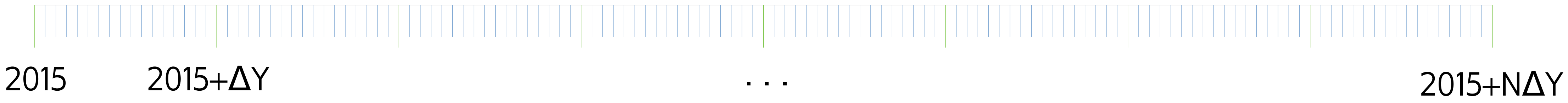
   - How to operate it.

- Used by central planners (e.g. BC Hydro)
- In market context, used as a means of indicative planning by ISO and/or regulators.
  - Inform design of incentives and/or new markets
- Public officials to assess prospective policy



Planning Models: Before VRE

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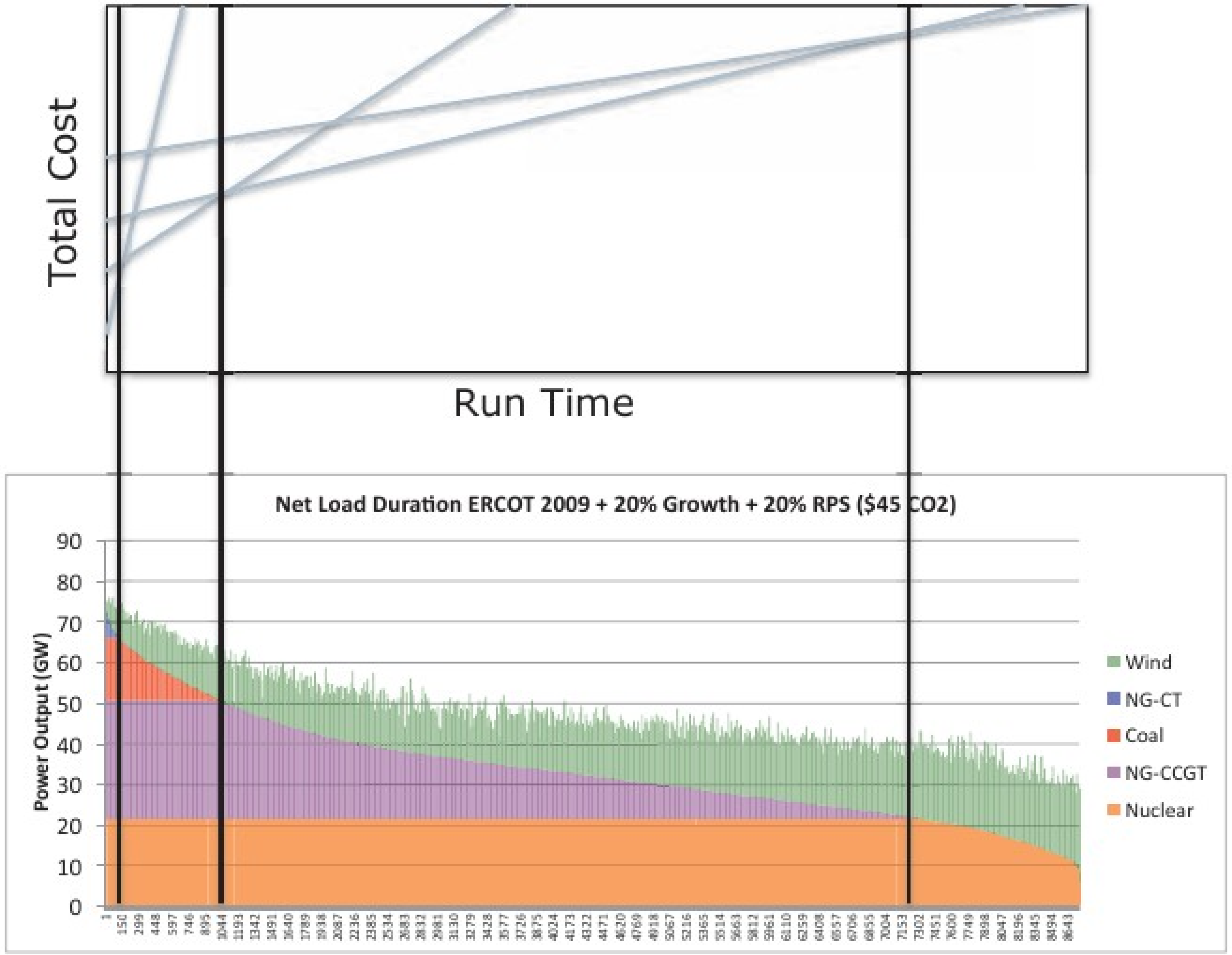
- Early days: screening curve method



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Planning Models: Before VRE

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- Early days: screening curve method
- 1957: Linear Programs (LP)
  - Low (and predictable) variability
  - Limited generator operational constraints

$$
\begin{array}{ll}
\textbf{minimize} & \text{Capital costs} + \text{Variable costs} \\
\text{subject to} & \text{Energy balance constraint} \\
& \text{Policy constraints} \\
& \text{Investment constraints} \\
& \text{Reserves constraints} \\
& N - 1 \text{ constraint} \\
& \ldots
\end{array}
$$

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Planning Models: Before VRE

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- Early days: screening curve method
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- 1960's – 1990's:
  - Hydro reservoir management
  - Lumpy investments (MILP)
  - ...

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Planning Models: Before VRE

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- 1960's – 1990's:
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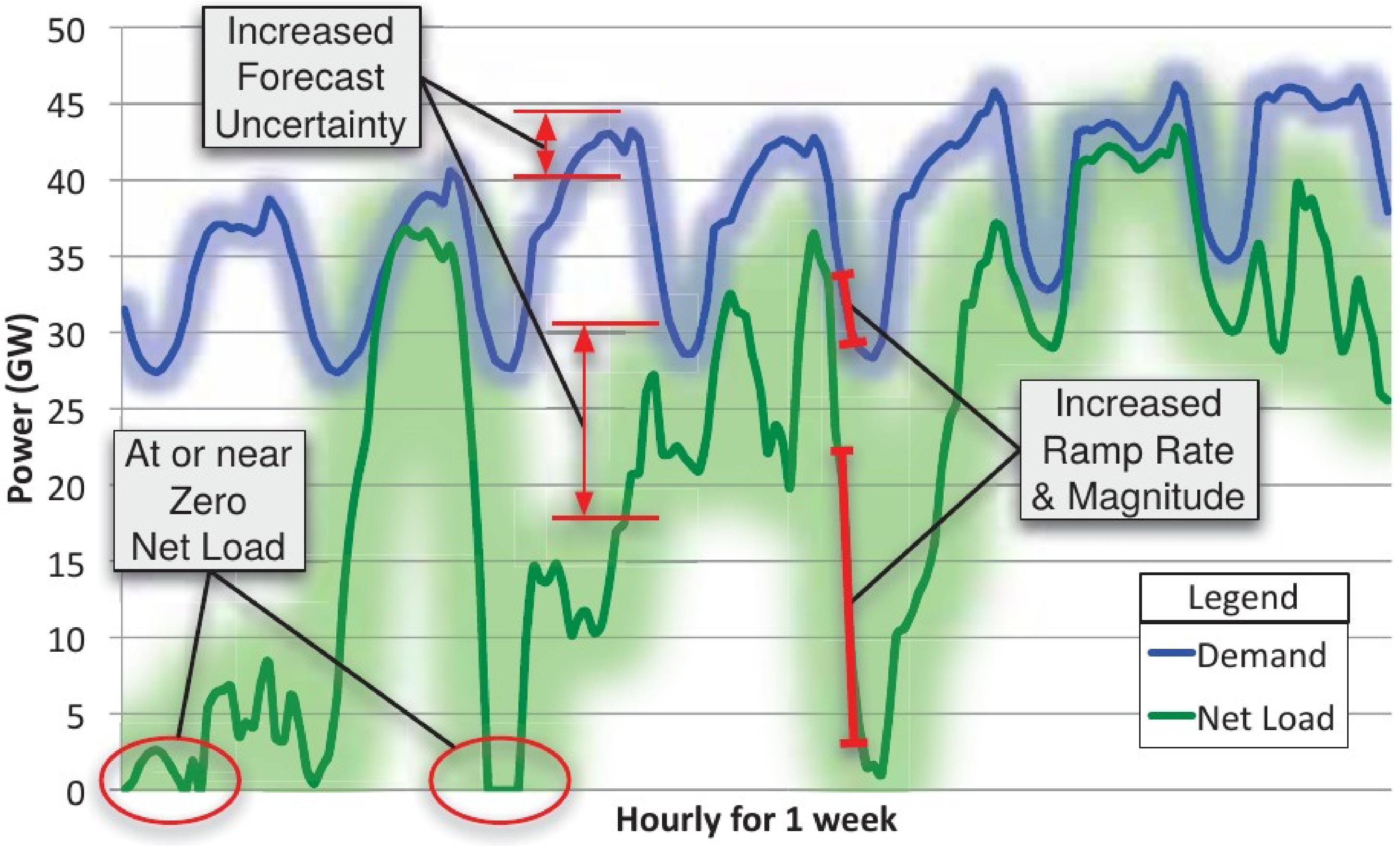
  - …
- 2000's
  - VRE challenges these models

Planning Models: With VRE



- Four key challenges:
  - **Uncertainty** → methodological improvements.
  - **Operational** characteristics of thermal generators now *very* important to include.
  - **Geographic** resolution.
    - Best wind / solar resource sites
    - Resource smoothing
  - **Temporal** resolution.
    - Focus of the talk.

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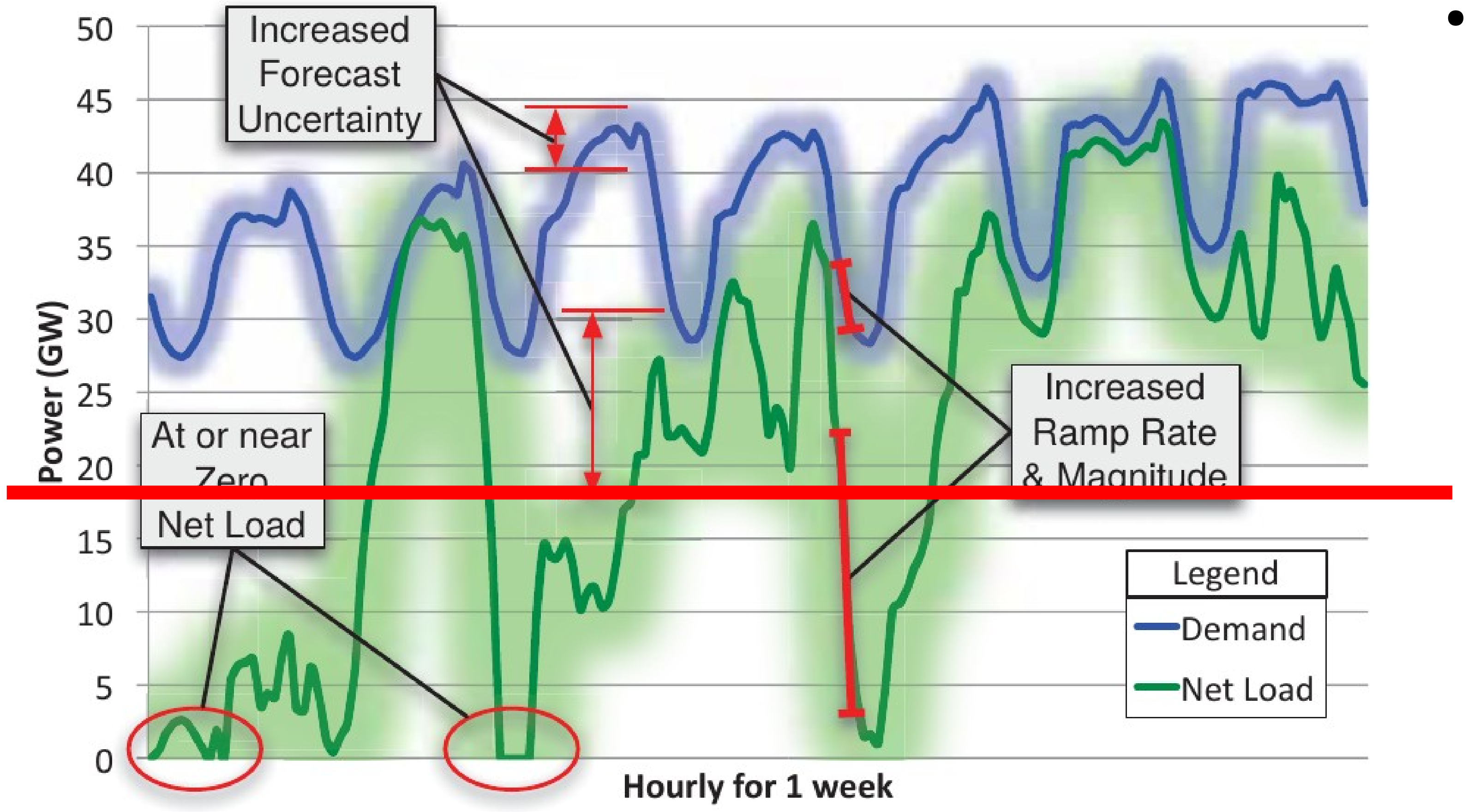

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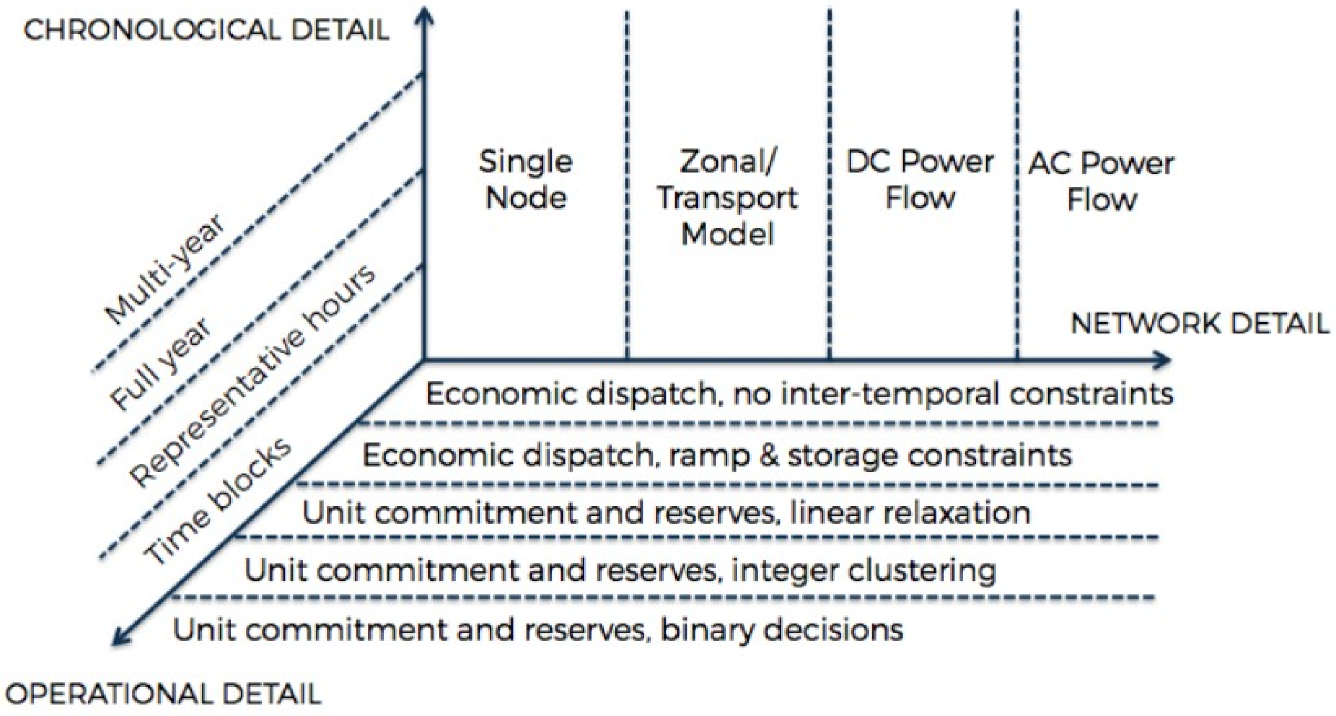
Planning Models: With VRE

- **Trade-offs** between model size and abstraction error in the three dimensions
- Tune resolution to specific research question.
- Poncelet (2016): for high share of VRE generation (35% - 50%) **temporal dimension more important.**



Jenkins, Jesse D., and Nestor A. Sepulveda. "Enhanced decision support for a changing electricity landscape: the GenX configurable electricity resource capacity expansion model." Cambridge, MA, MITEI-WP-2017-10 (2017).

Outline

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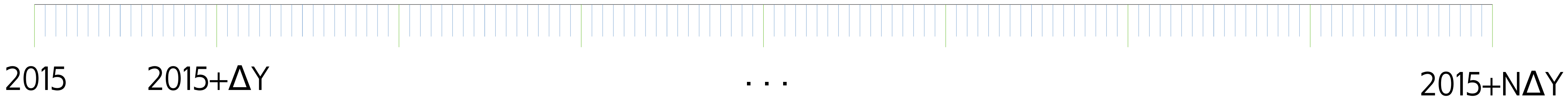
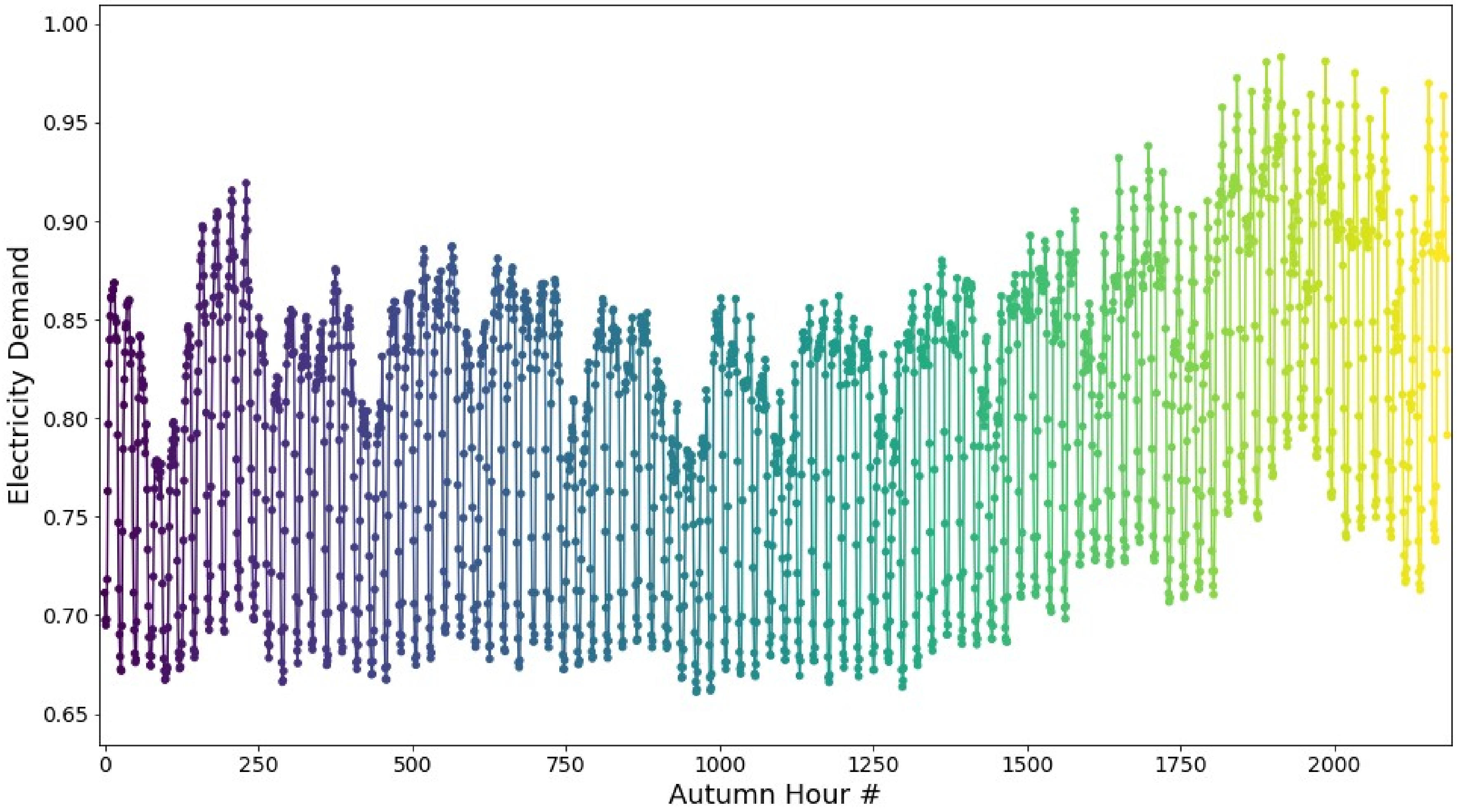
Temporal Aggregation: Before VRE

- Before VRE, only source of variability is **demand**
- Period selection reflected this
- Most common approach to aggregation: **Seasonal averaging** to produce **time slices:**
  - 1 year → 4 seasons
  - Season → 3 periods (peak, mid, low demand)
  - 12 time slices per year
  - Some add 1 additional ‘max peak’ time slice



Electricity Demand (Autumn)



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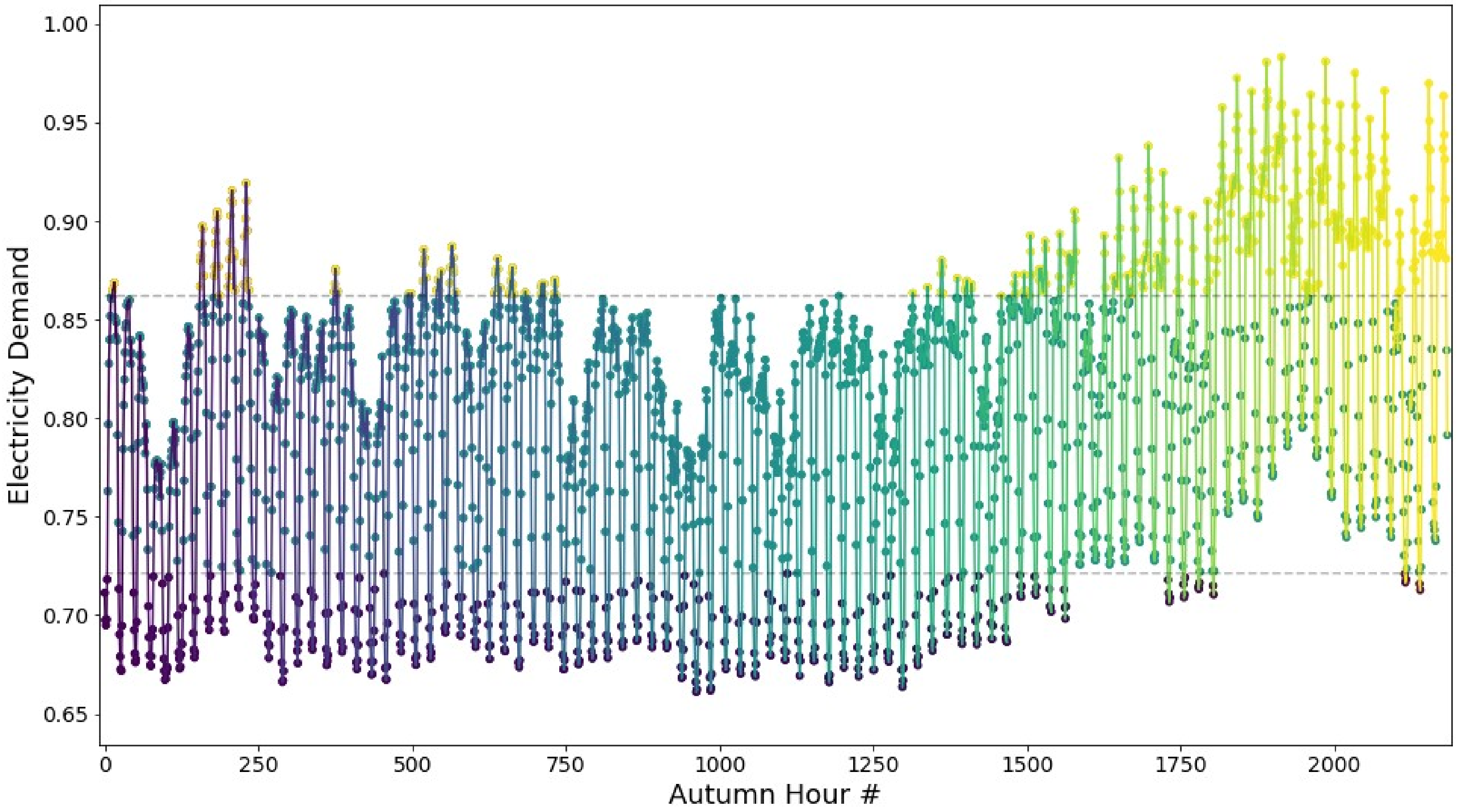

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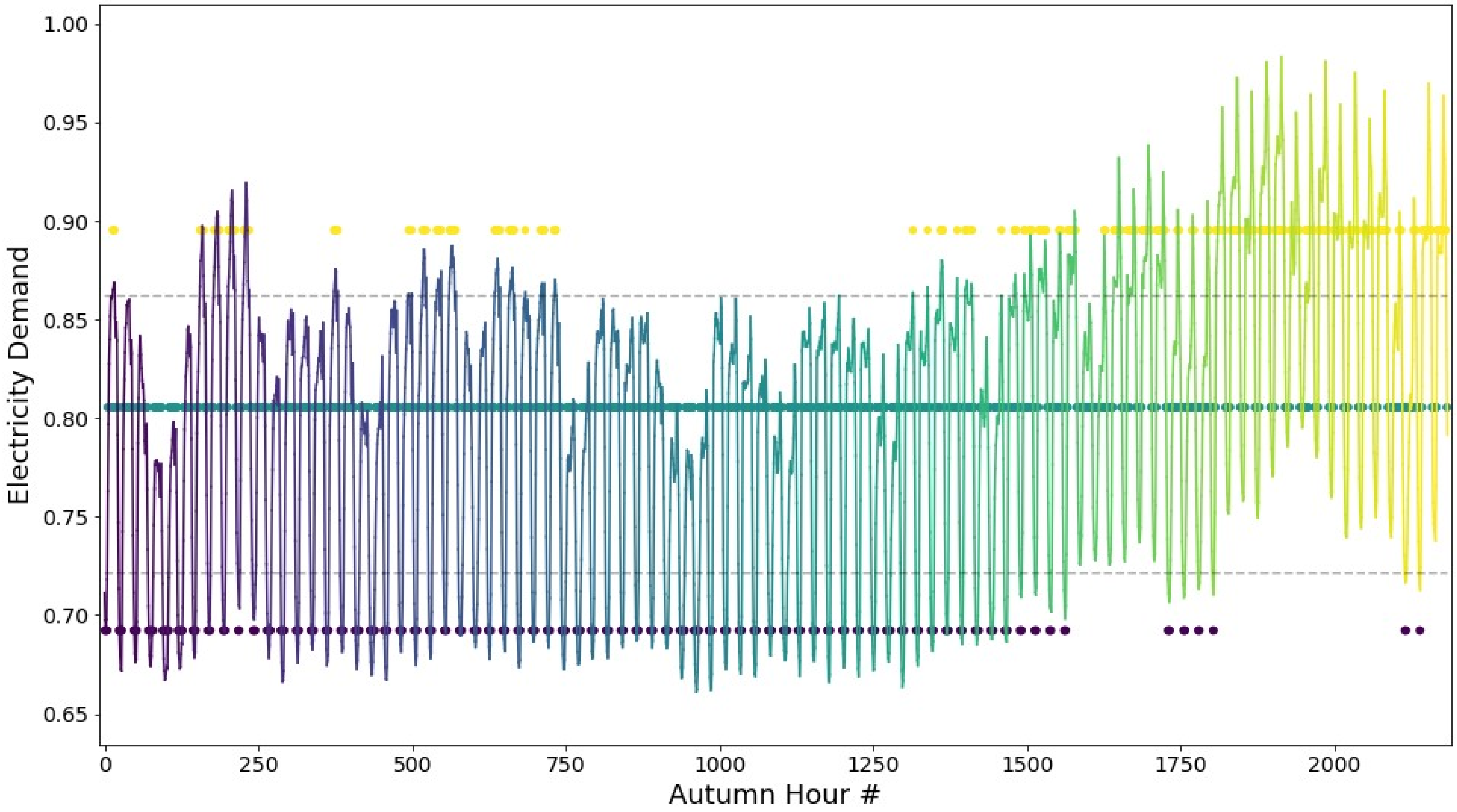

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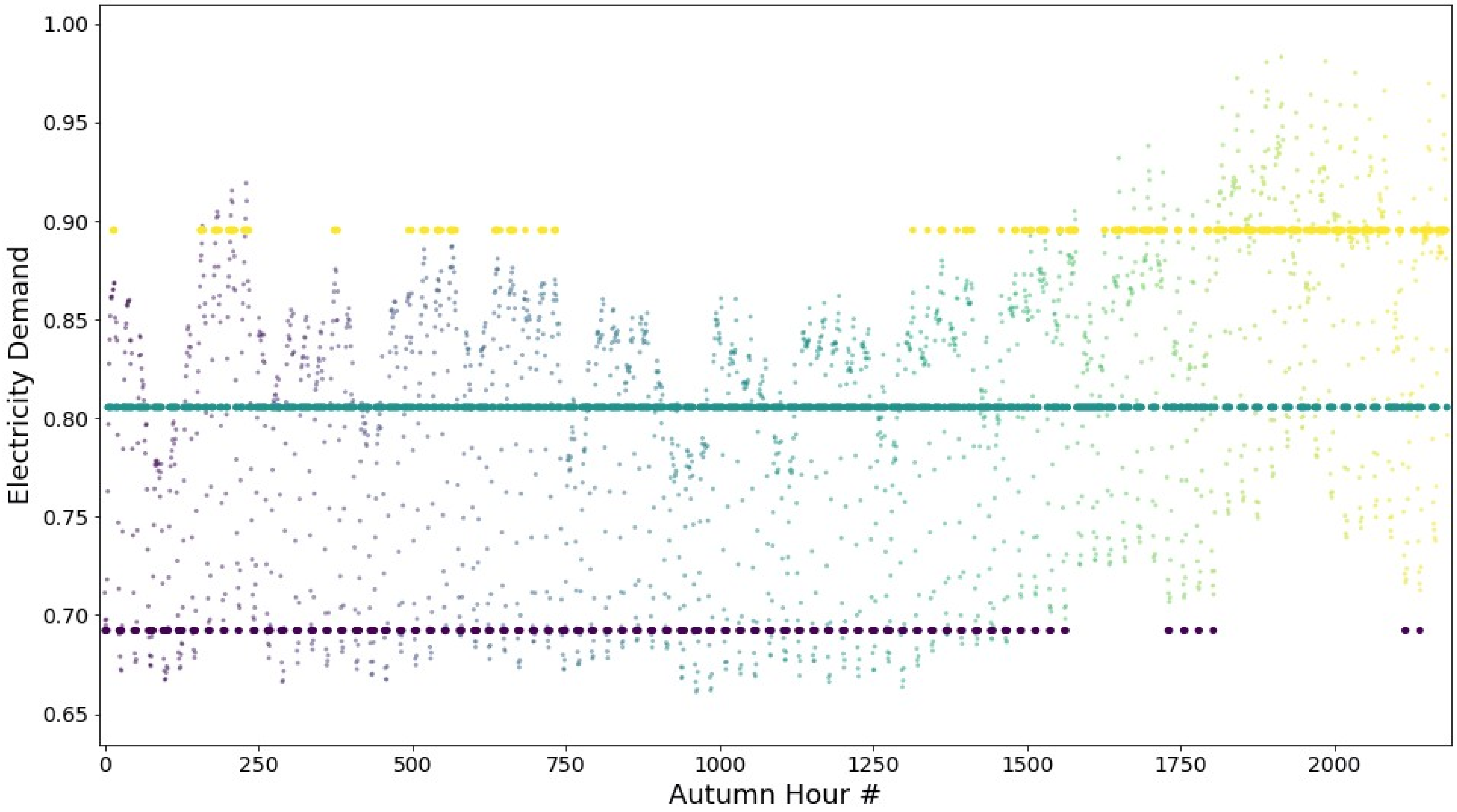

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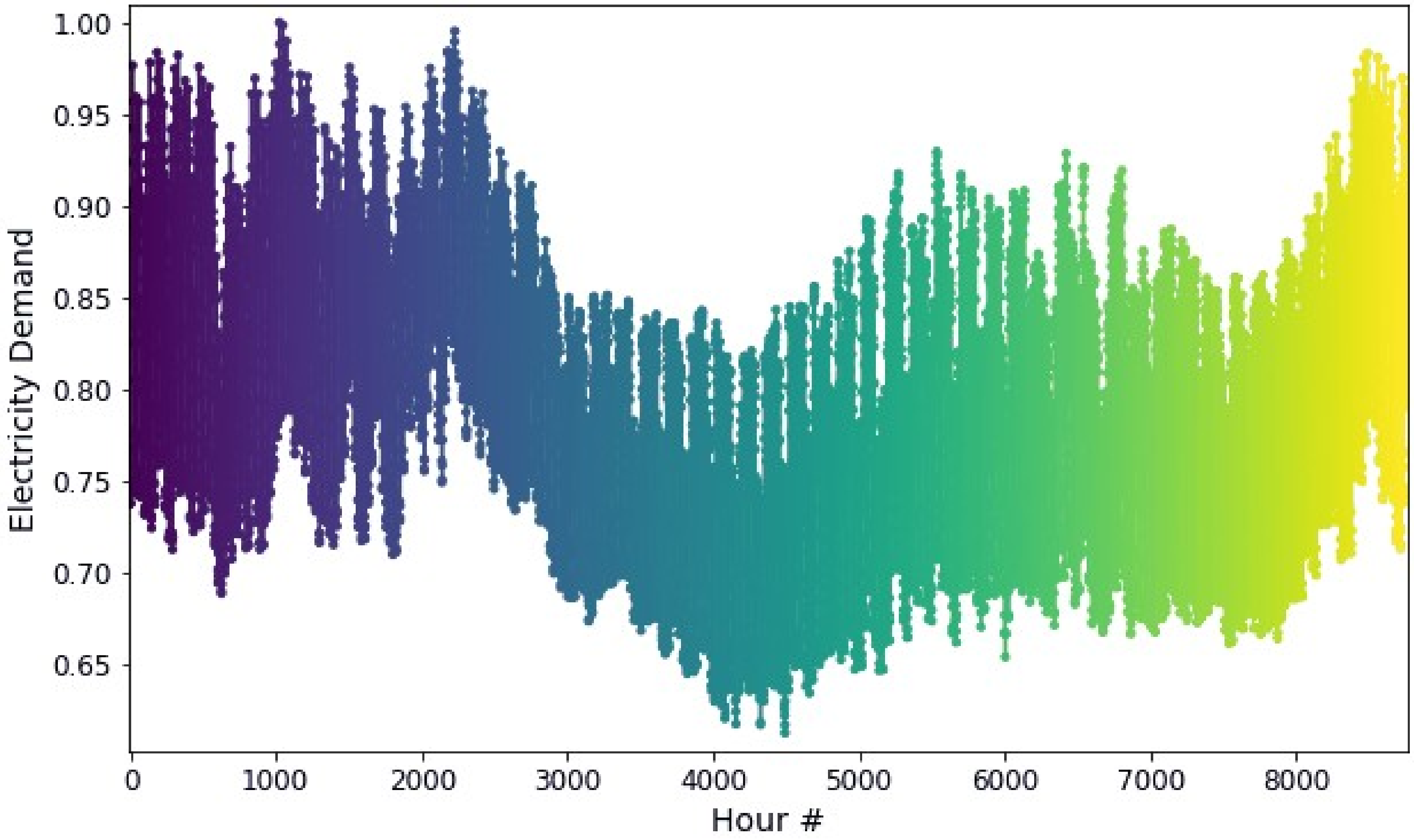
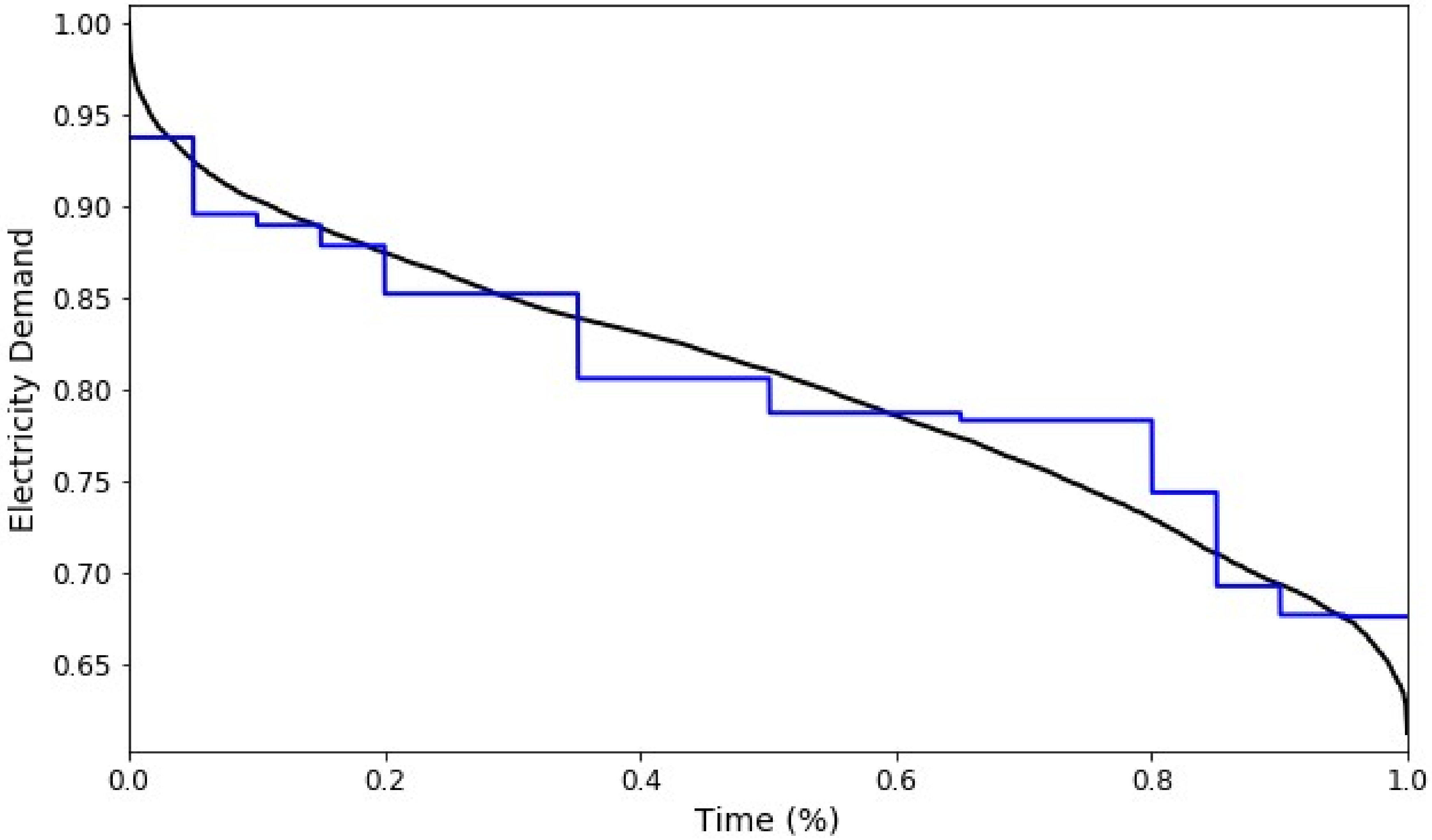
Electricity Demand (Full Year)



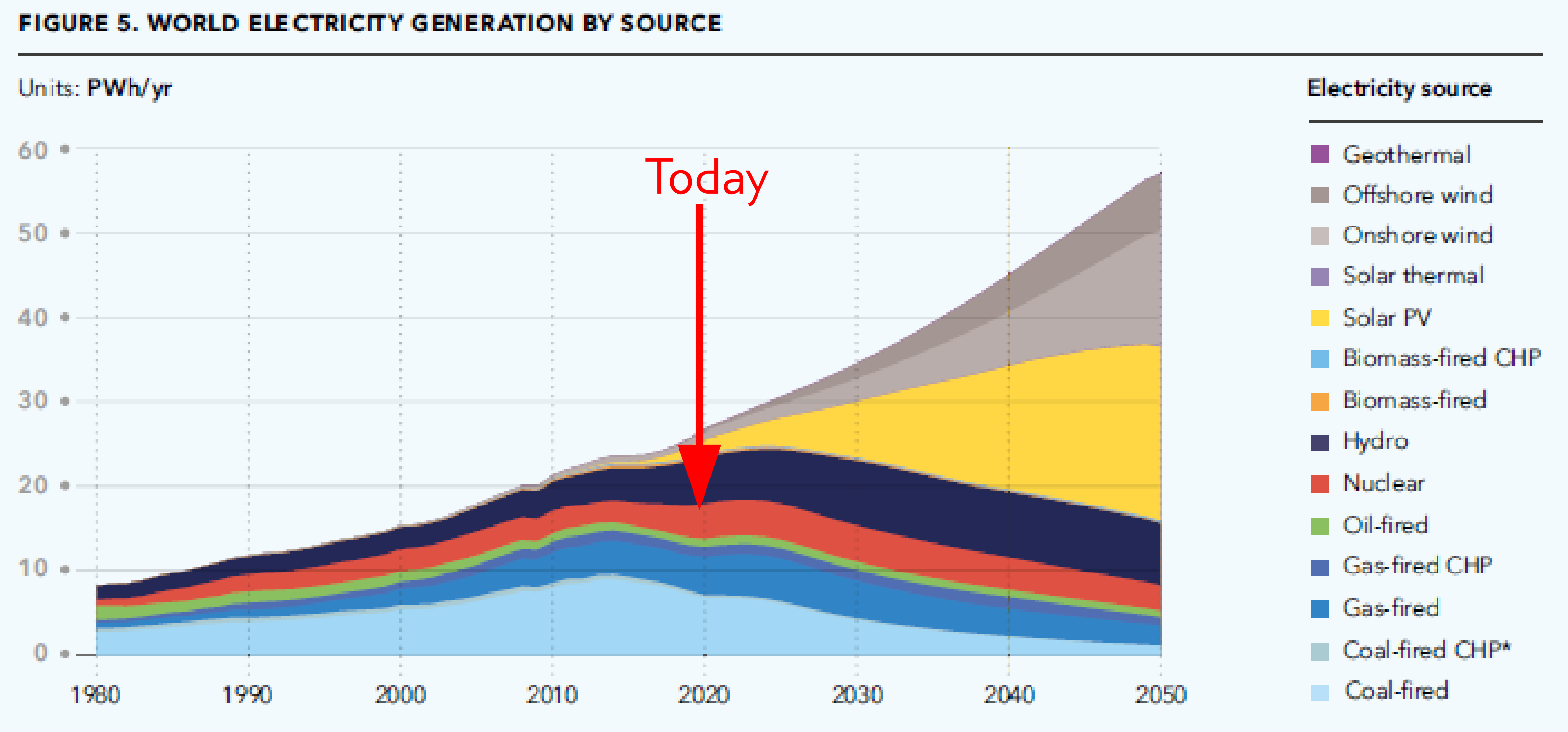
Electricity Demand (Full Year)



Seasonal Averaging Roundup

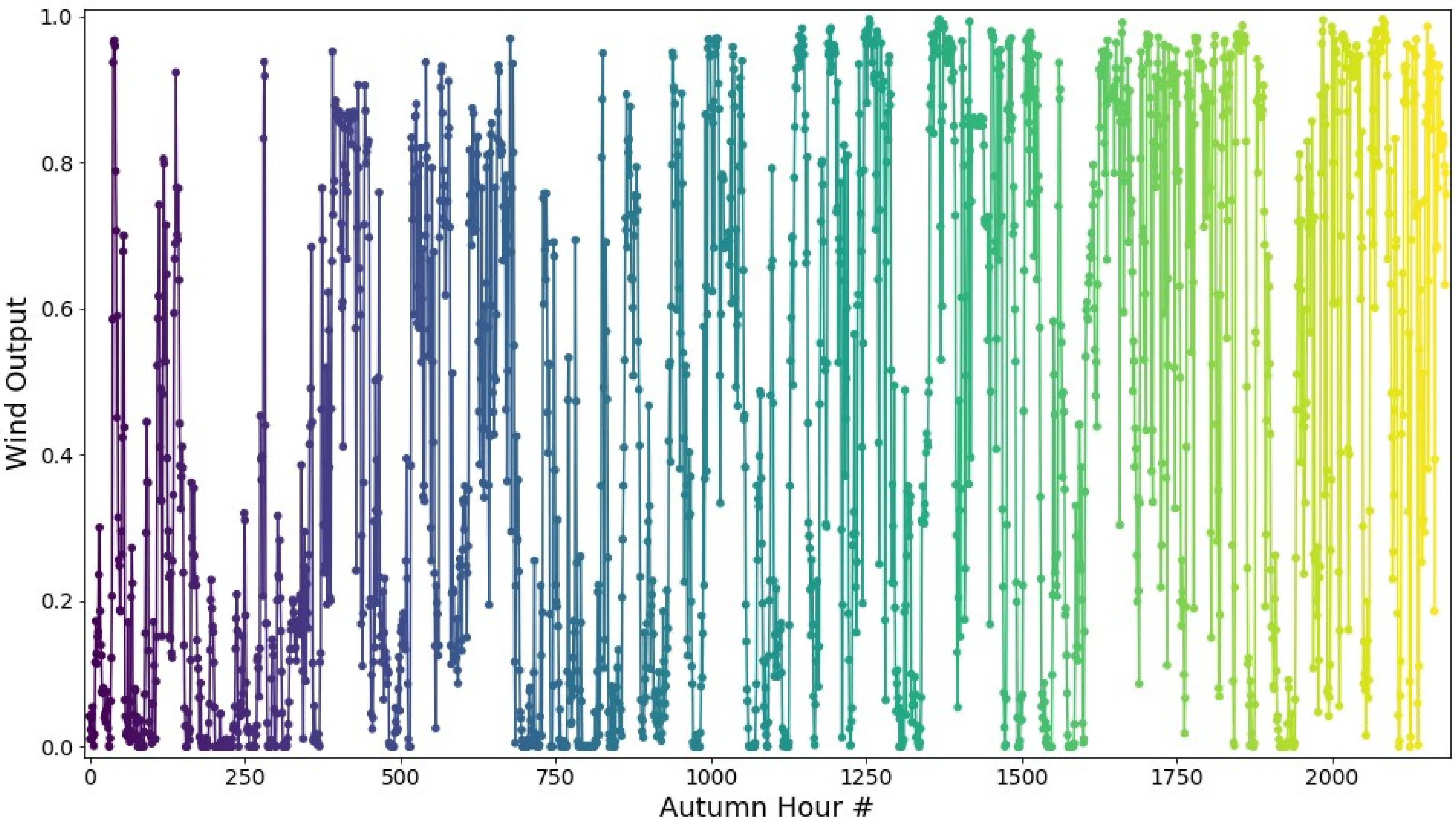
- Is adequate in a no-VRE world
- Still in use today by *many* models
- Lose short-term dynamics → Can't model
  - Generator operational constraints
  - Intra-day storage
- Maintain seasonal chronology →
  - Coarse representation of seasonal storage

Seasonal Averaging with VRE



DNV, GL. "Energy Transition Outlook." (2017).

Wind Availability (Autumn)



Wind Availability (Autumn)

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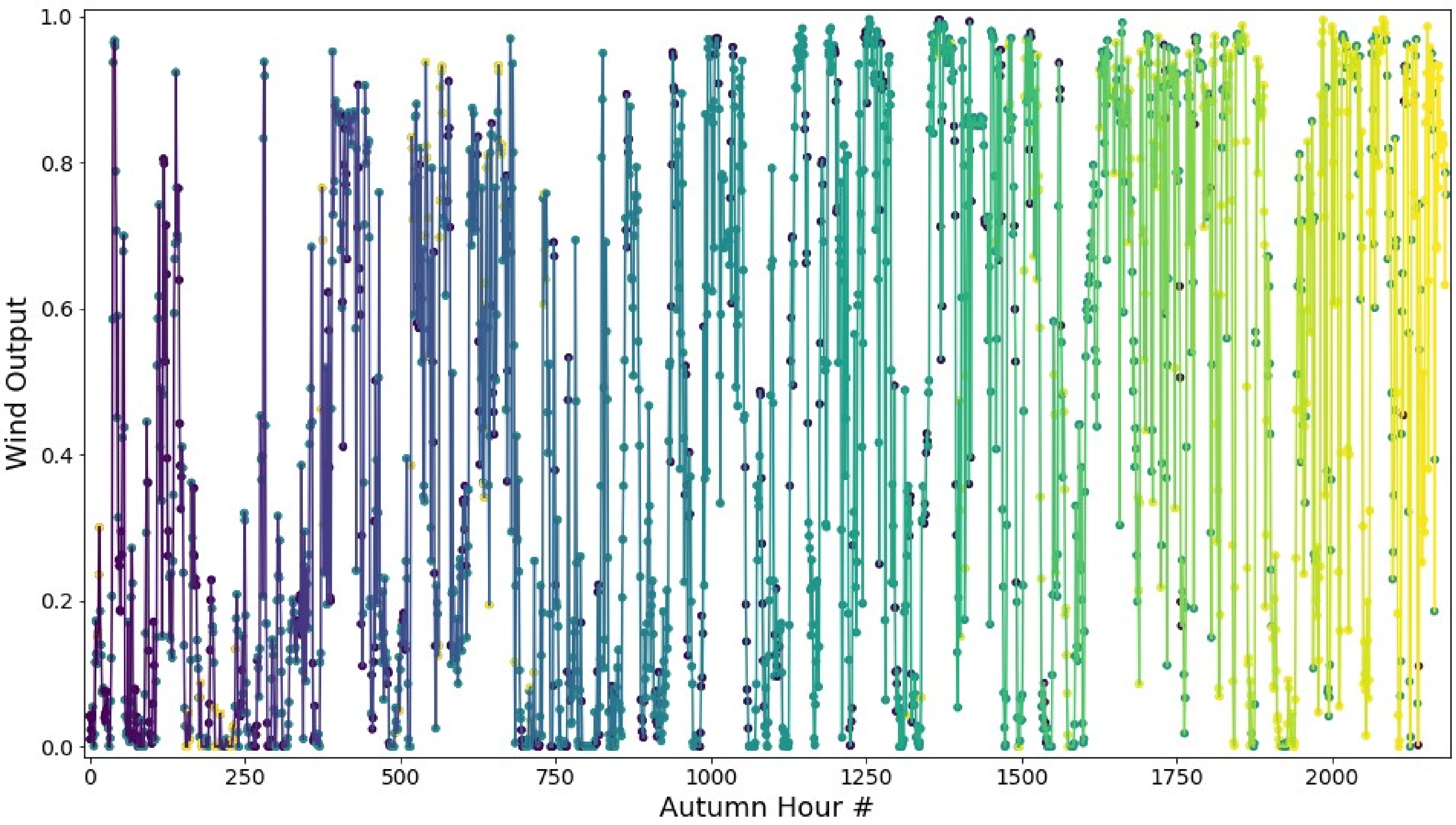

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Wind Availability (Autumn)

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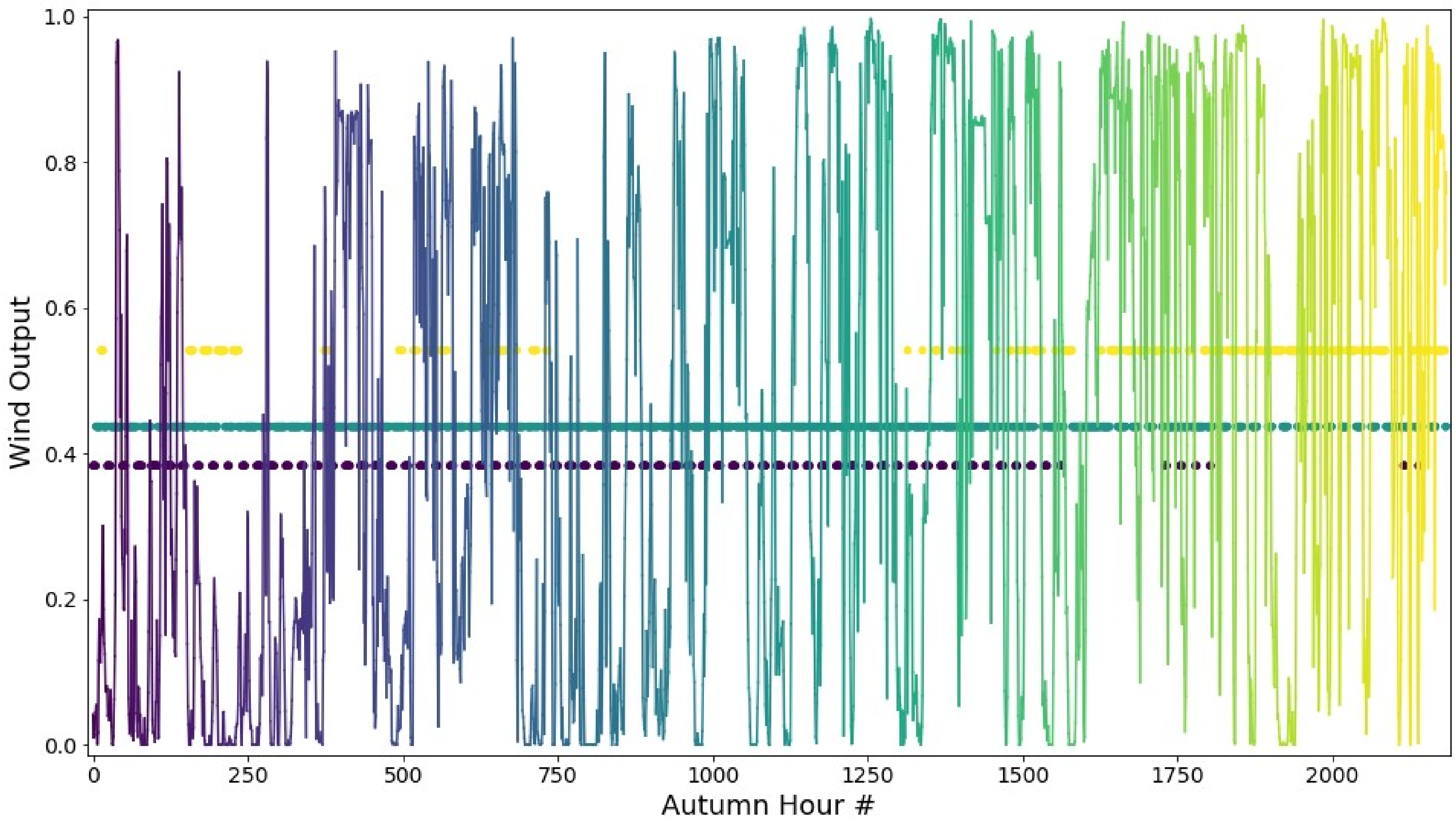

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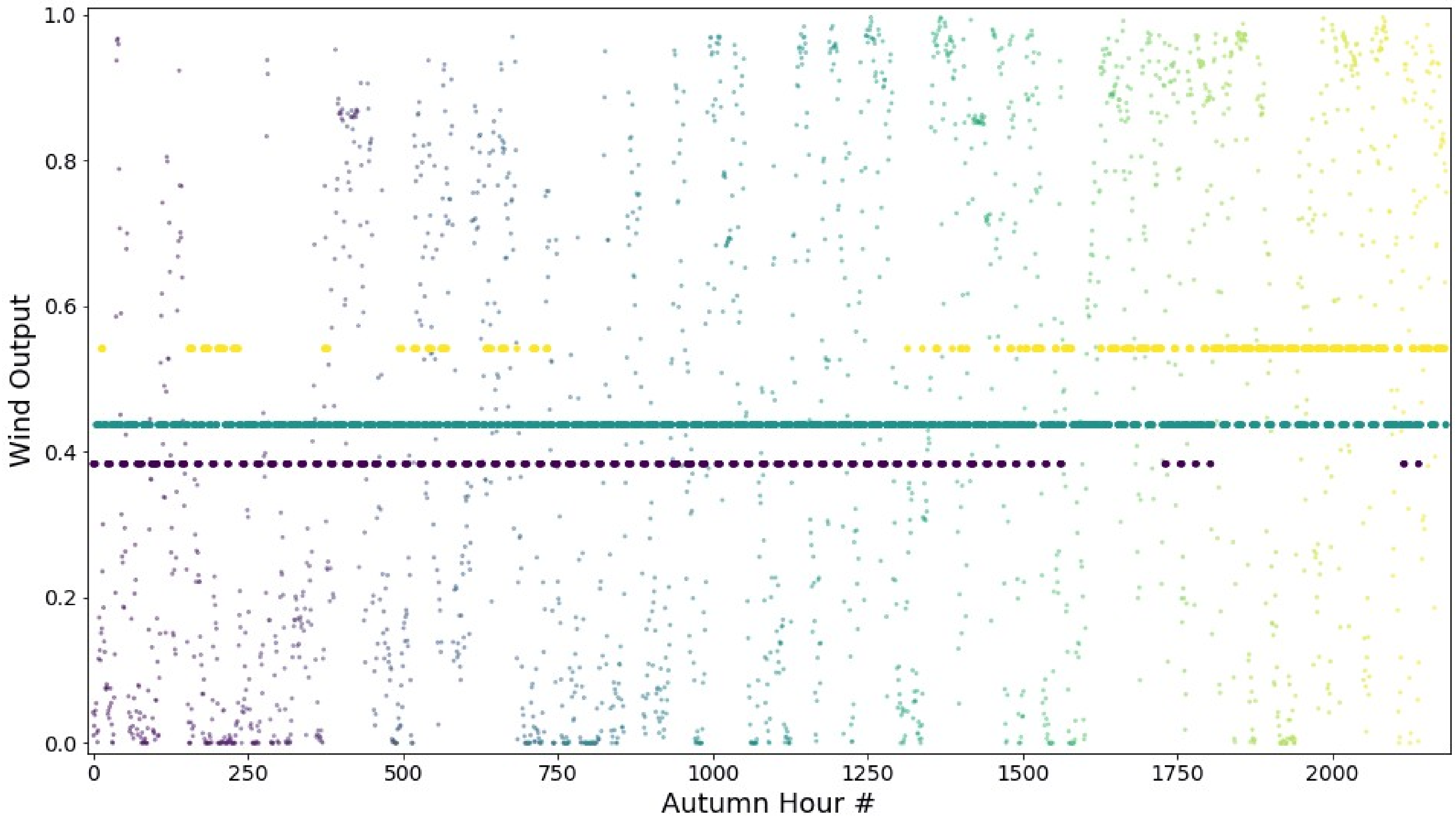

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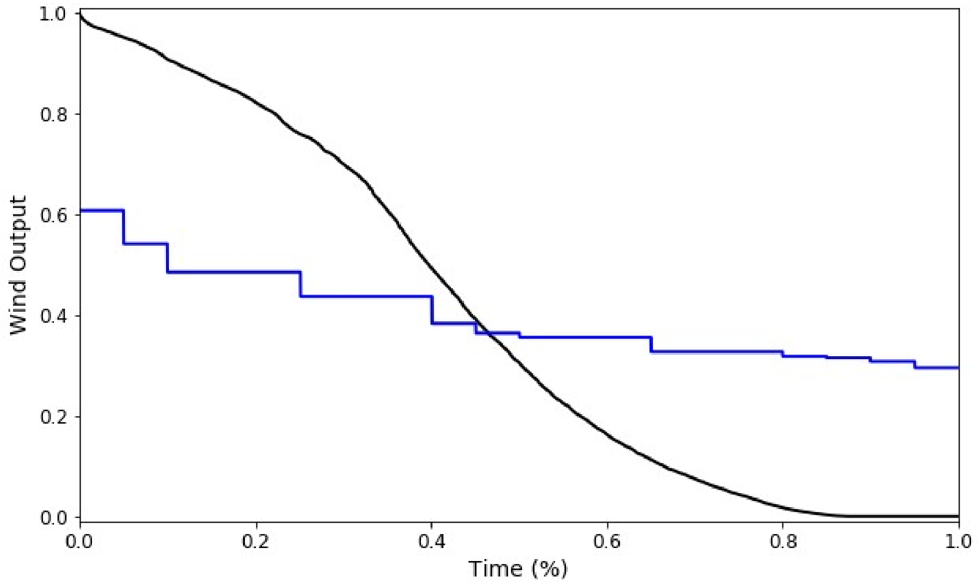
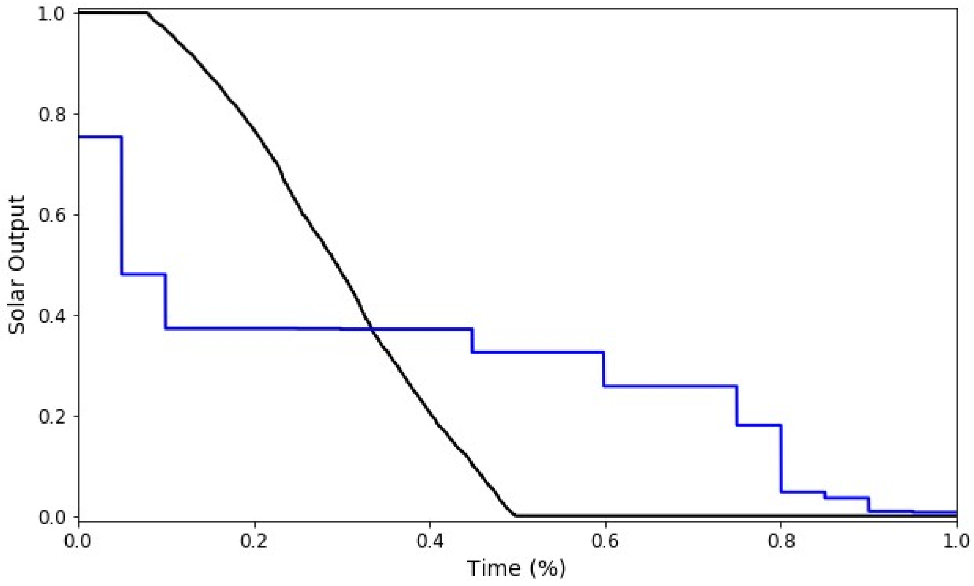
Results...

Wind



Solar



- Under represents supply side variability
- Results in:
  - over-investment in VRE and baseload generators
  - Under-investment in flexible generators

So, what to do?

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- Ignore it and tell the masses about your optimal power system composed solely of VRE and nuclear.
- Simply increasing resolution (e.g. 12 months instead of 4 seasons) dœs little to address the problem
- **Soft-link** capacity planning model with a detailed operational model in an iterative process.
- **Re-examine the temporal dimension in planning models.**

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Representative Periods

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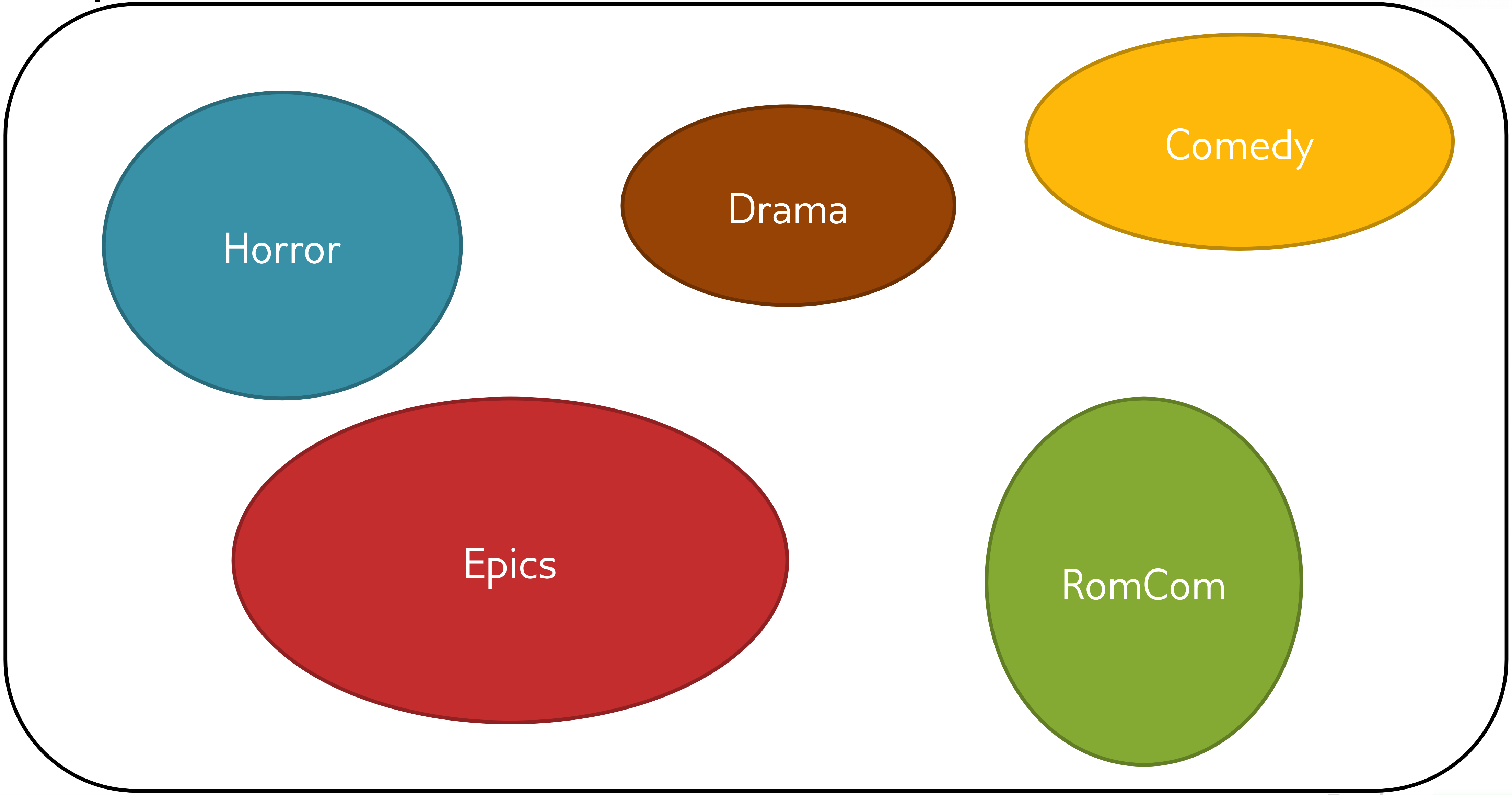

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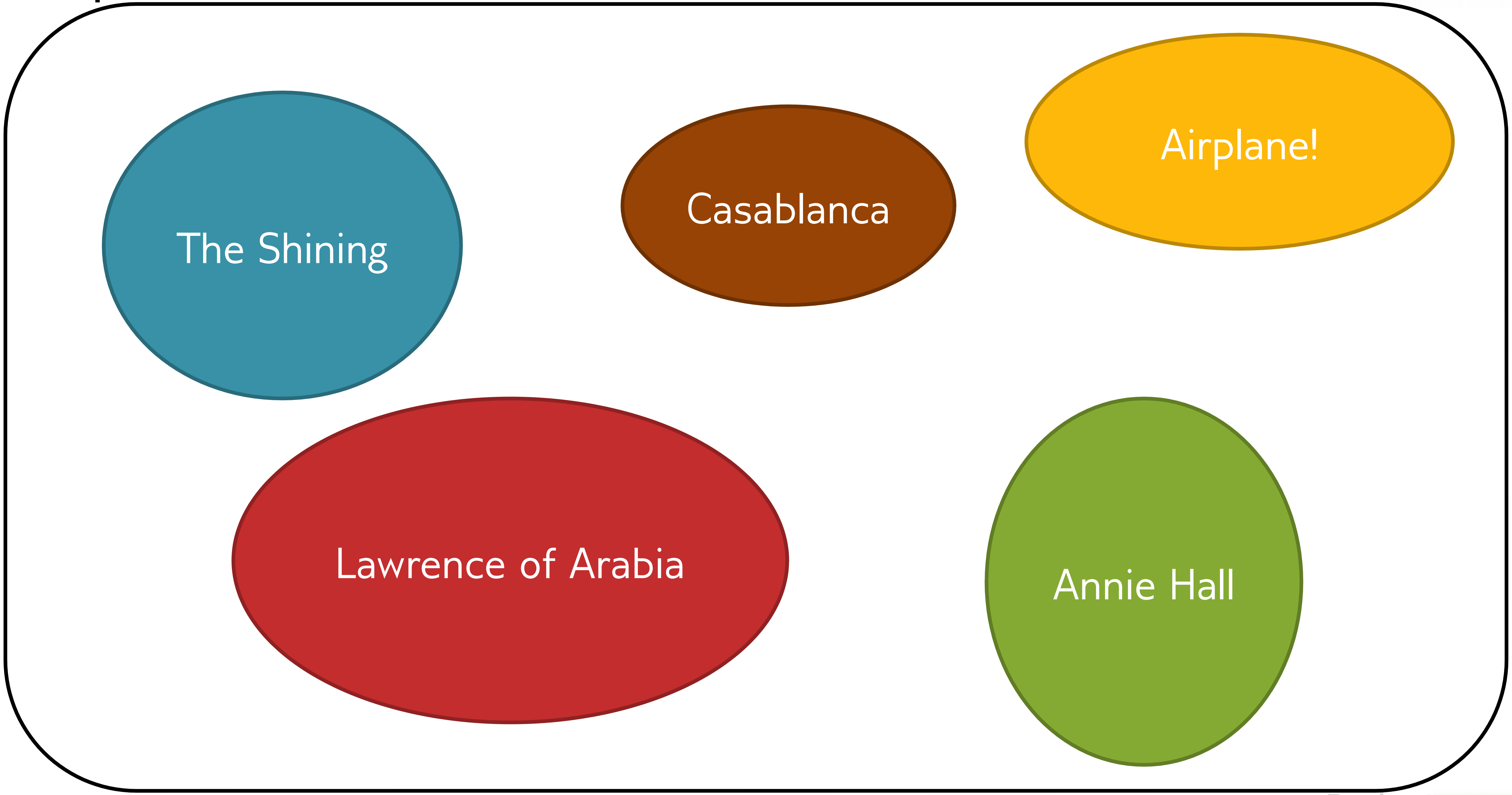
Representative Periods



Representative Periods

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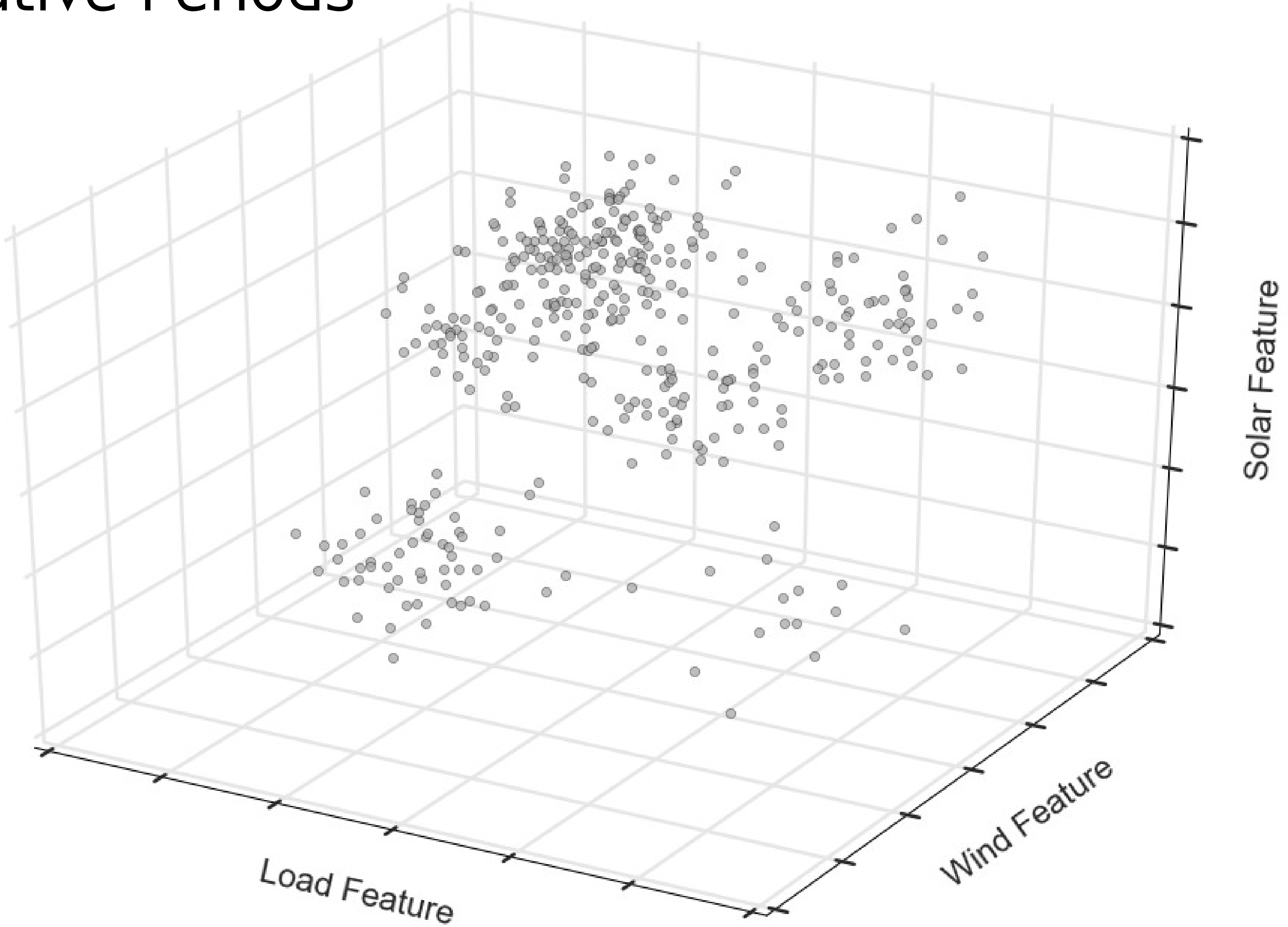
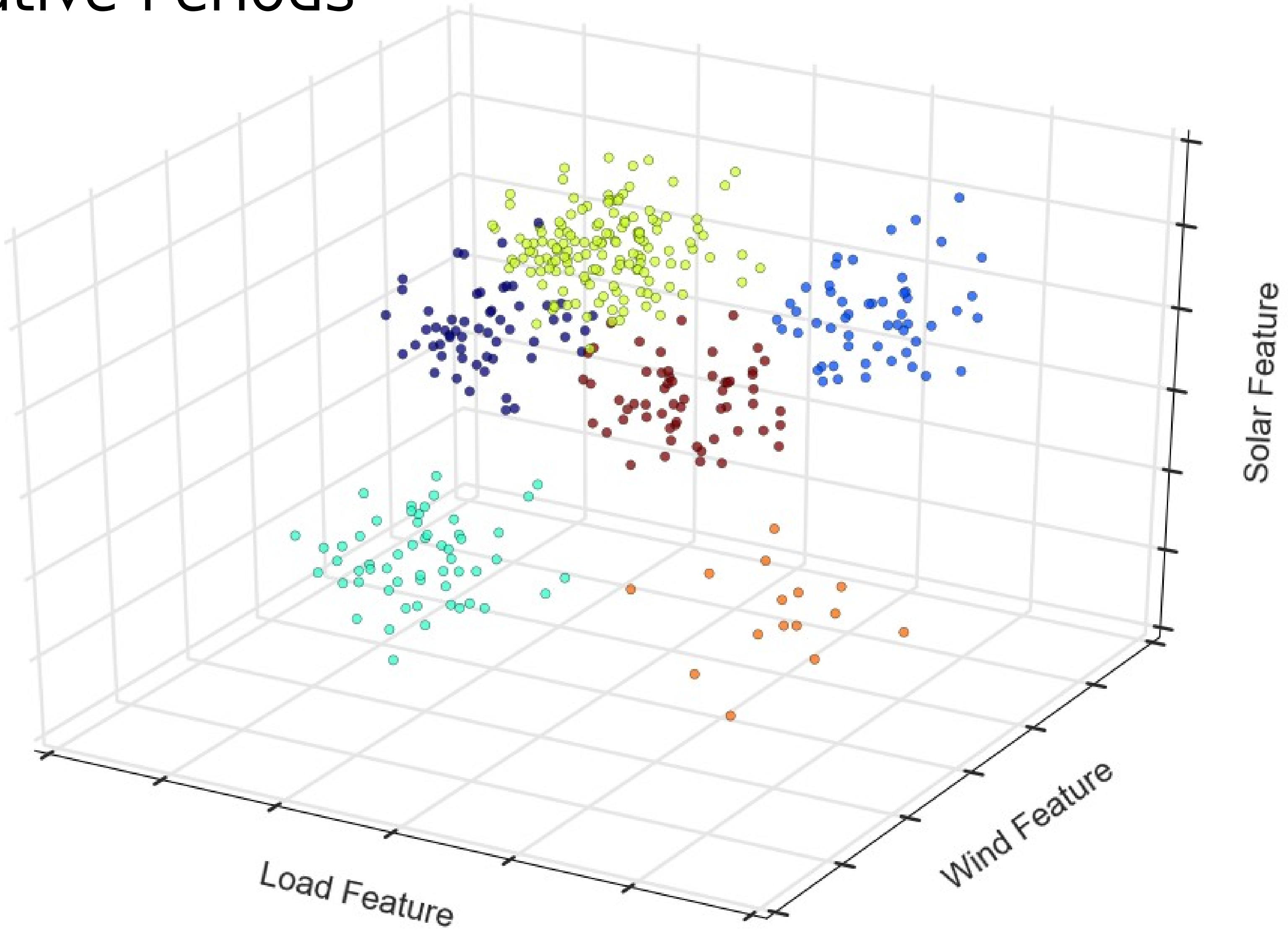
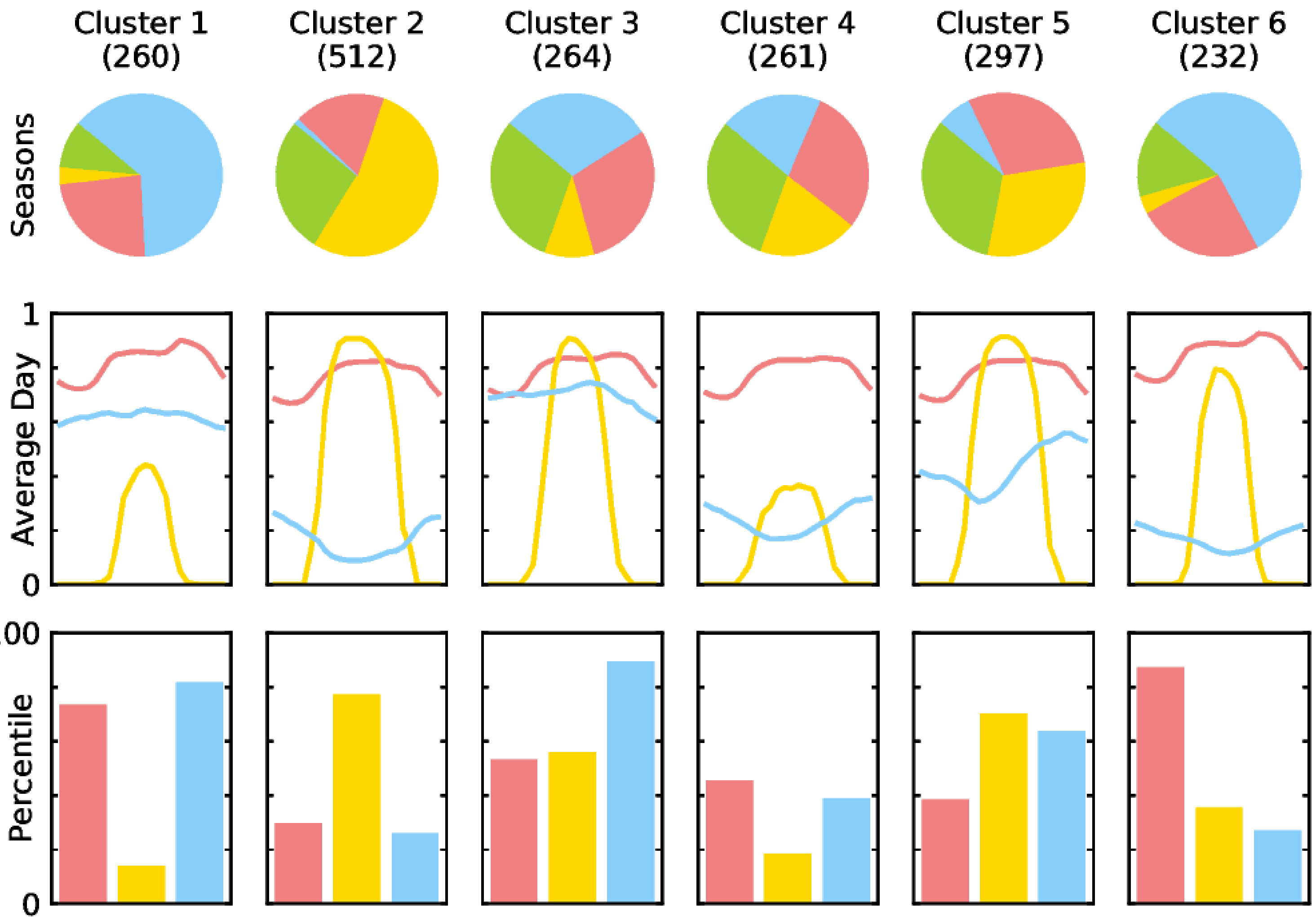
- Choose period length (e.g. hour, **day**, week).
- Amass a bunch of historical data (demand, VRE resource profiles)
- Create daily vectors from data (either raw time series or feature vector).
- Systematically select K representative days from N historical days with K << N.
  - Heuristically
  - Optimization problem
  - **Clustering**

Representative Periods



Representative Periods




Cluster 1
(260)
Cluster 2
(512)
Cluster 3
(264)
Cluster 4
(261)
Cluster 5
(297)
Cluster 6
(232)
Seasons
Average Day
1
0
Percentile
100
0

Representative Periods

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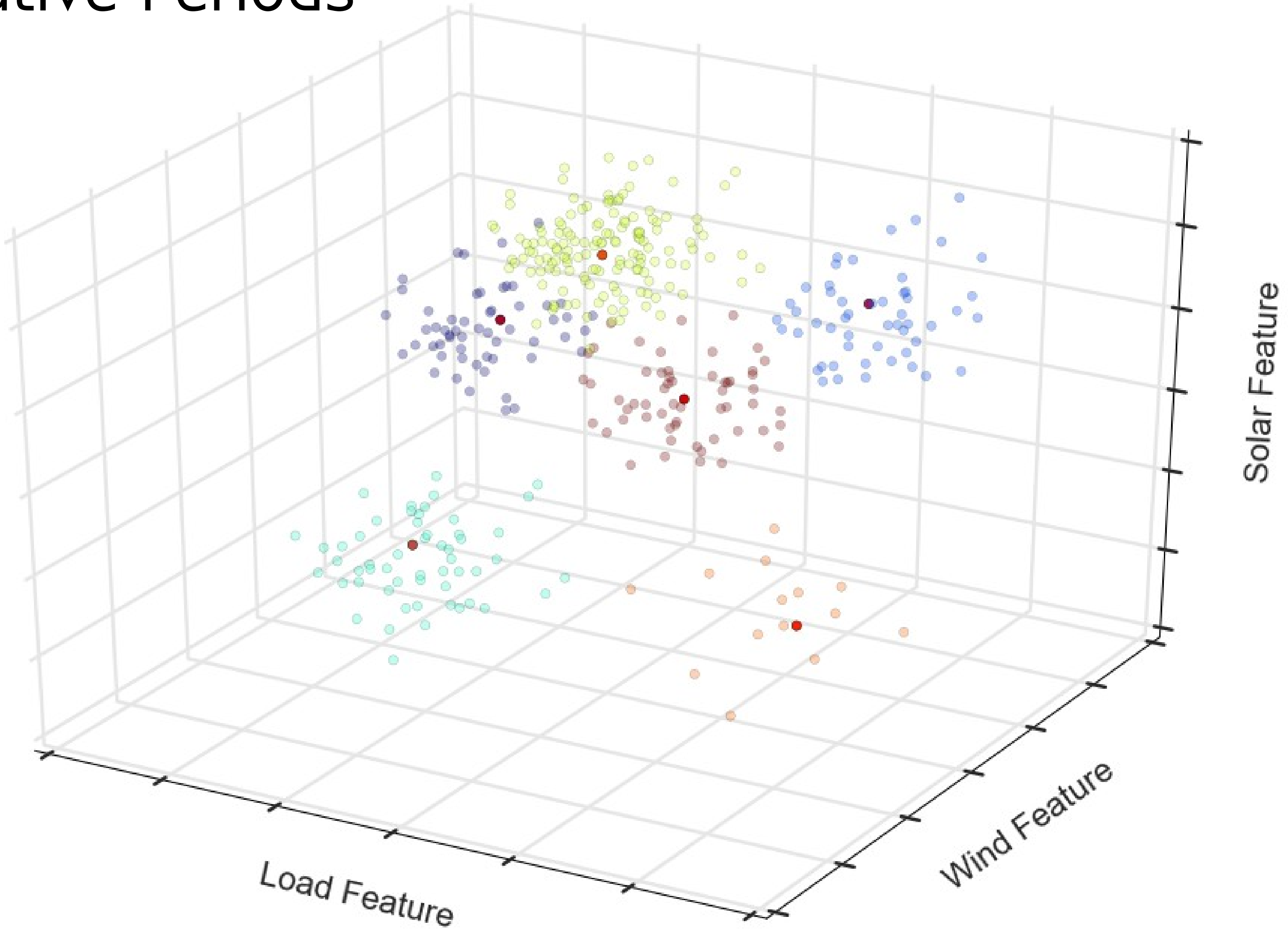

Representative Periods – **Demand**

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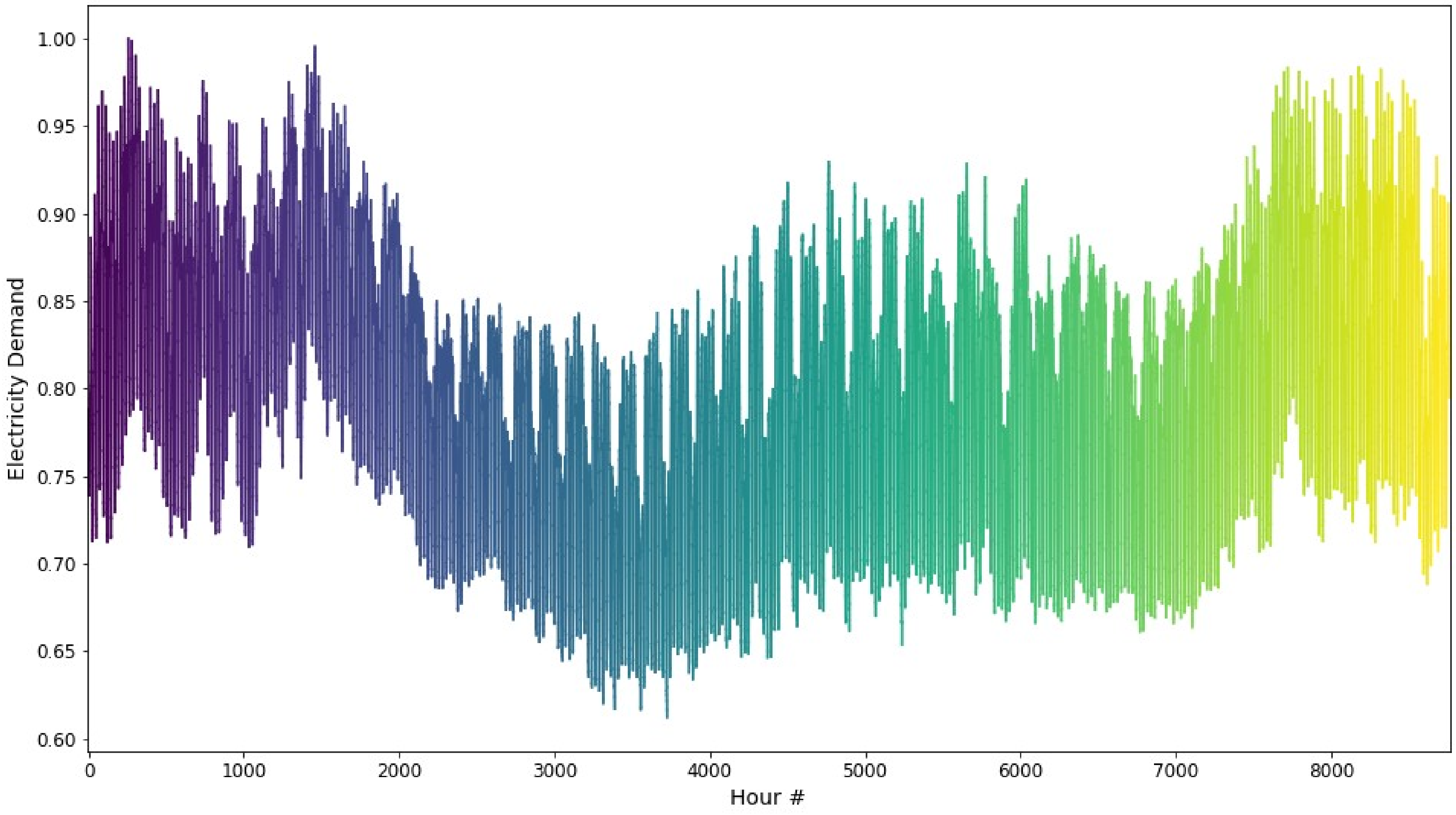
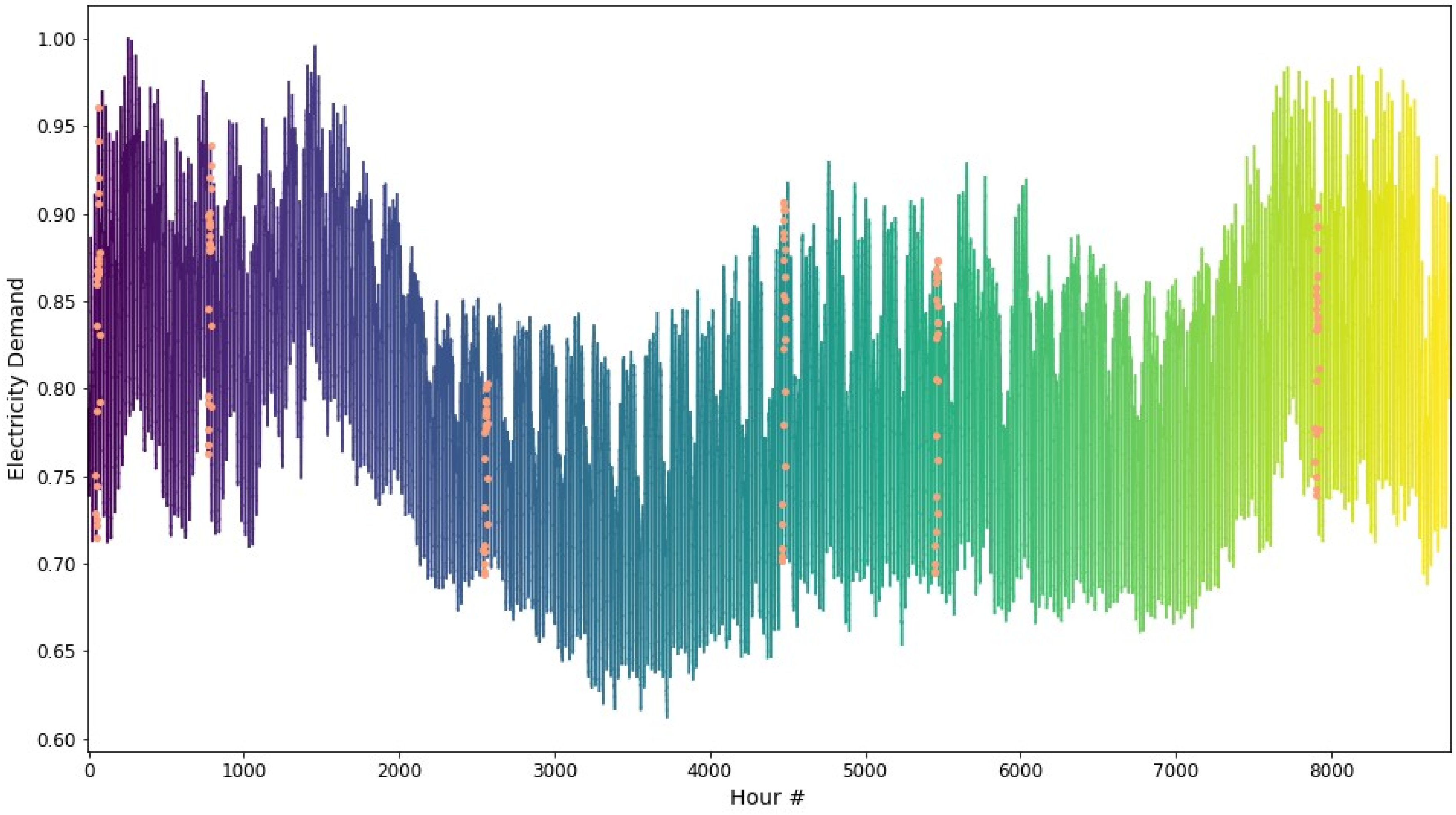
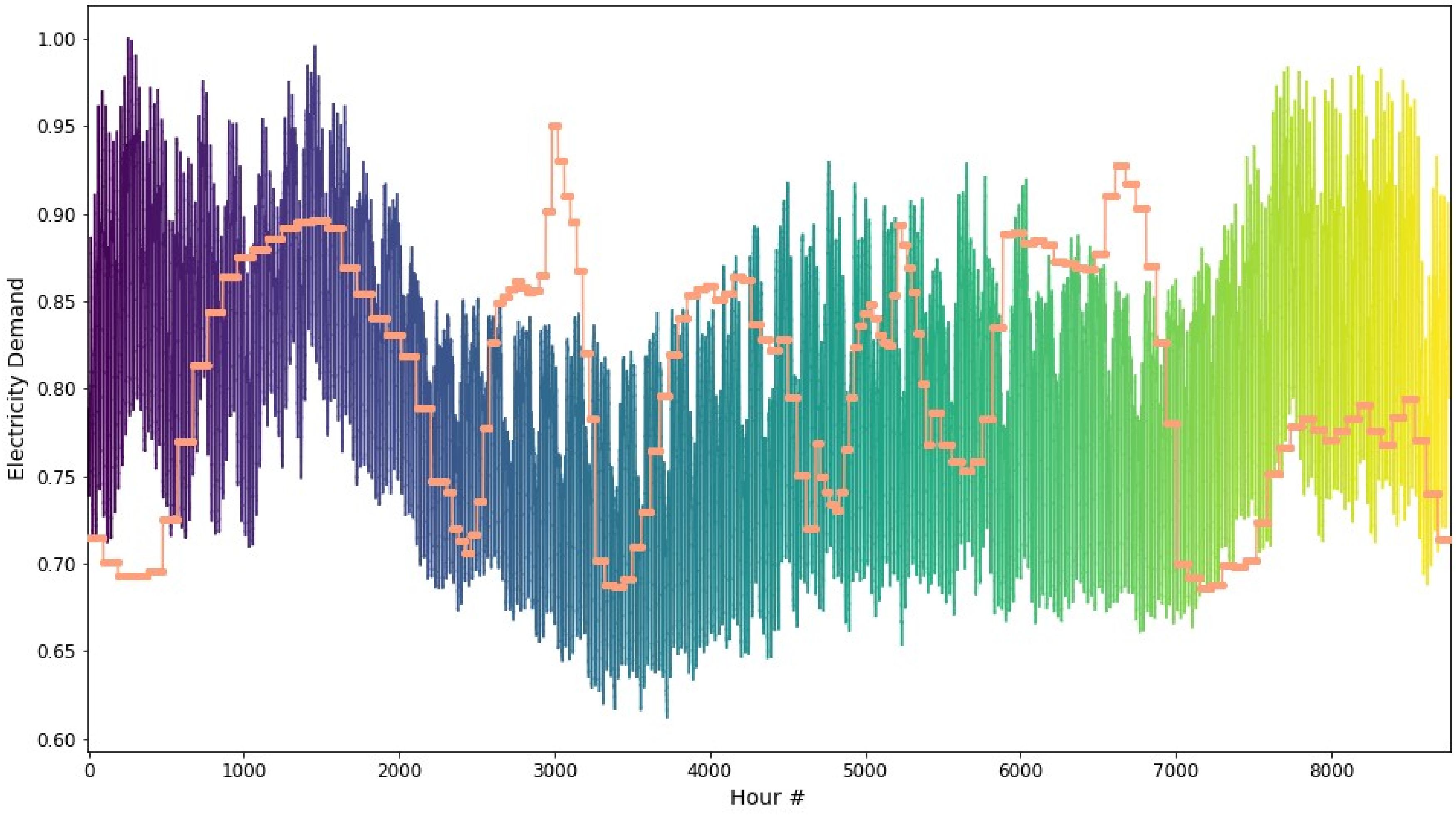


Representative Periods – **Demand**



Representative Periods – **Demand**



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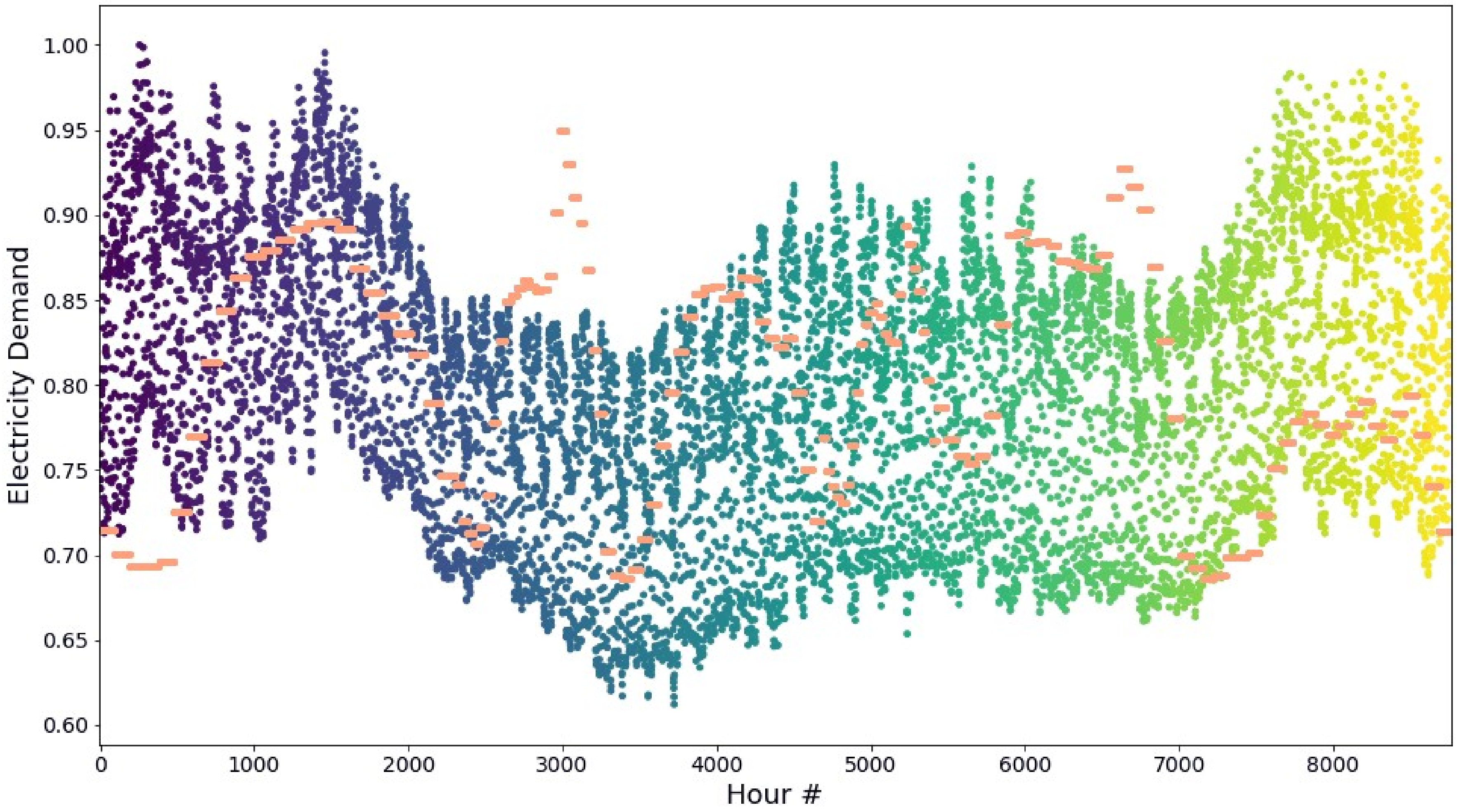
Representative Periods – **Demand**



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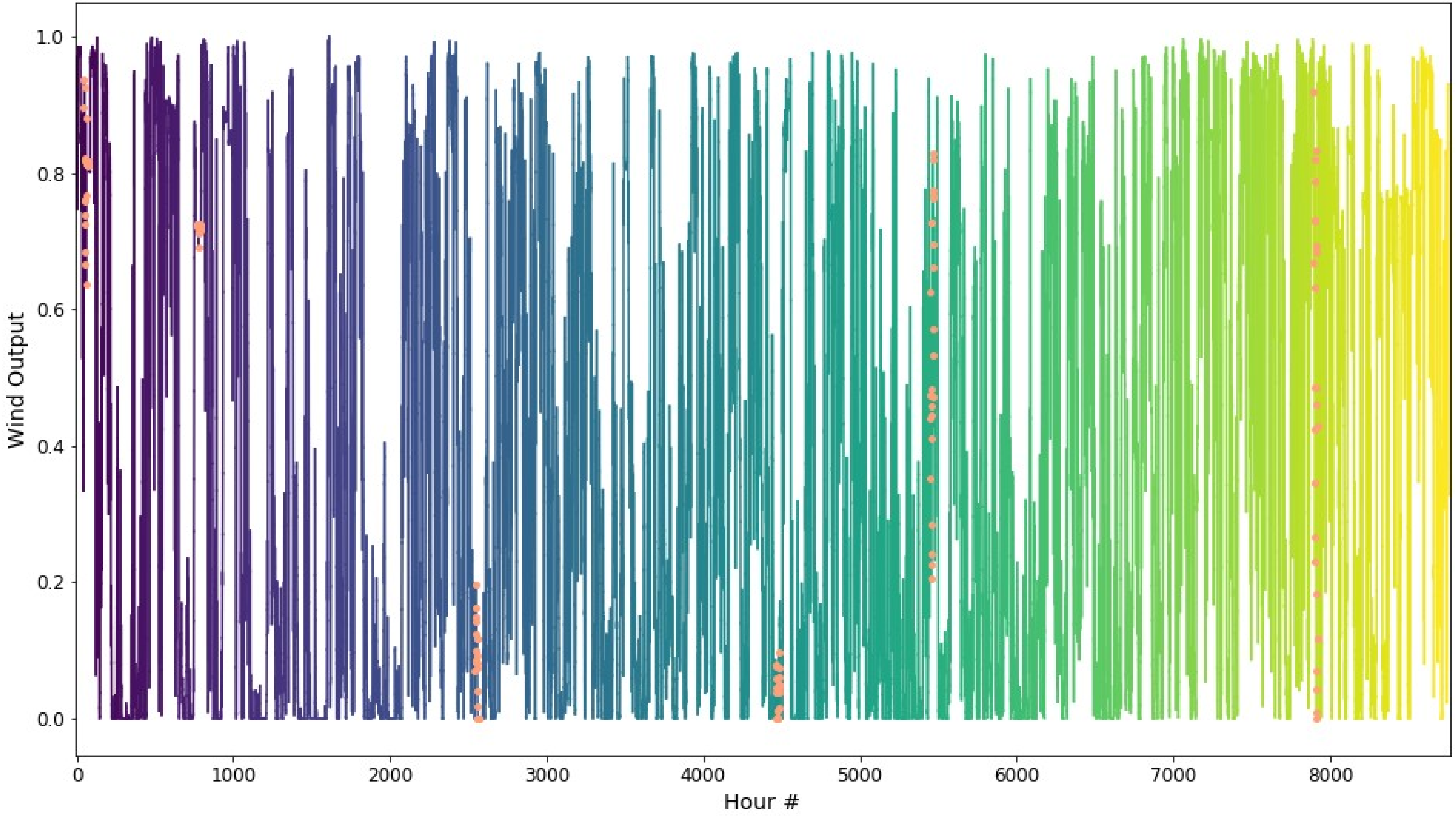
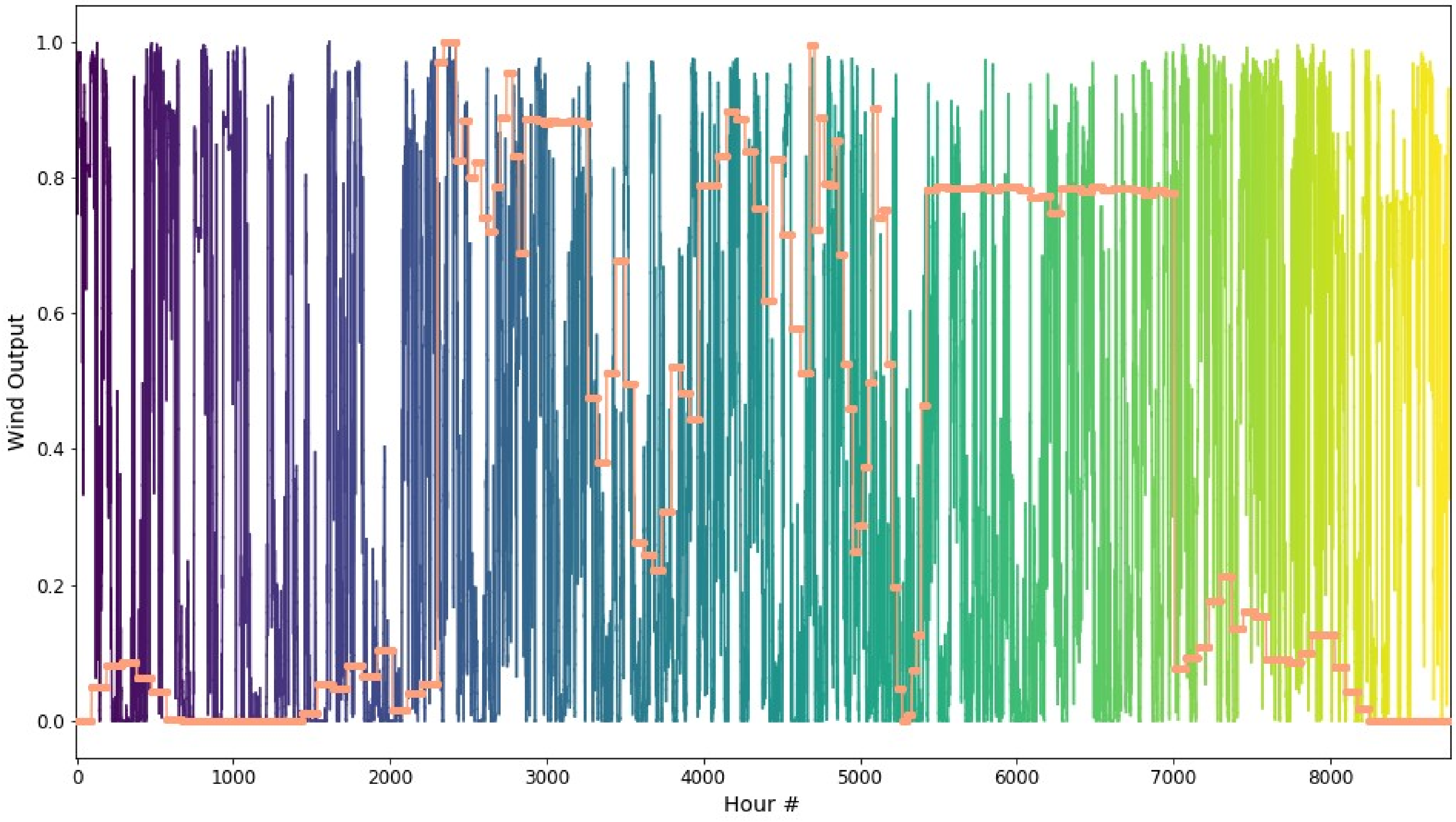
Representative Periods – **Wind**



Representative Periods – **Wind**



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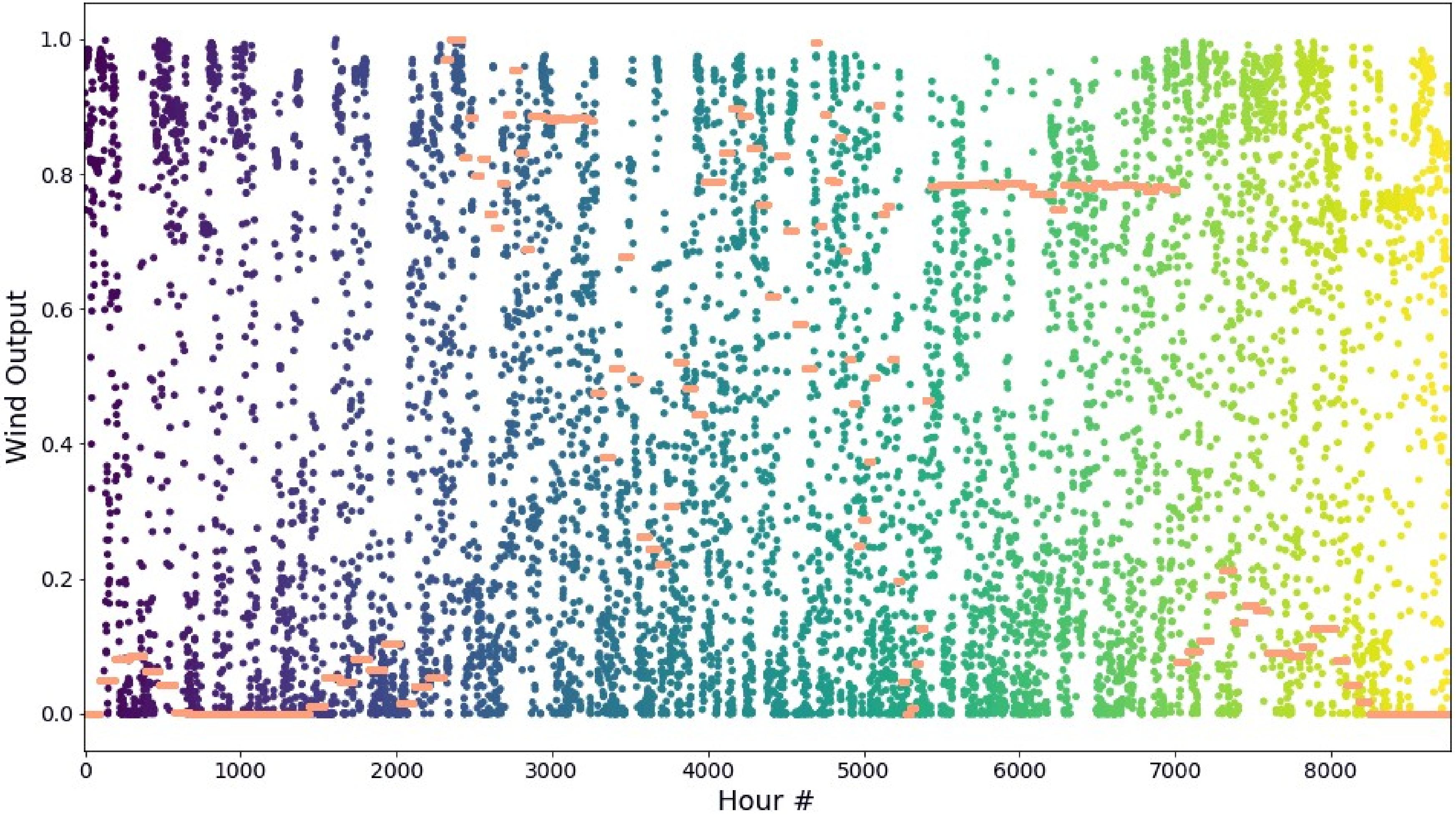
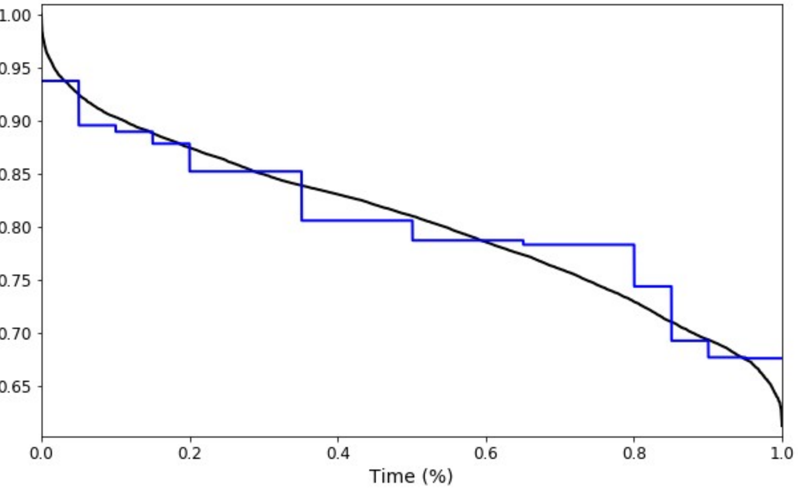
Representative Periods – **Wind**

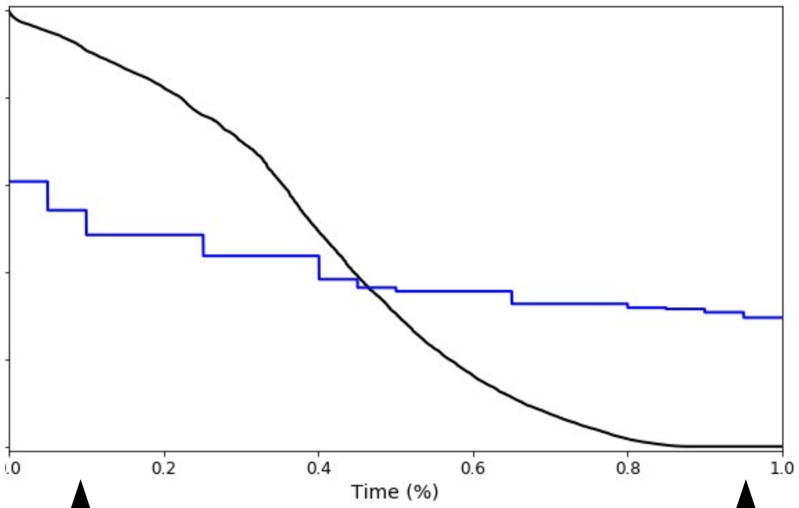


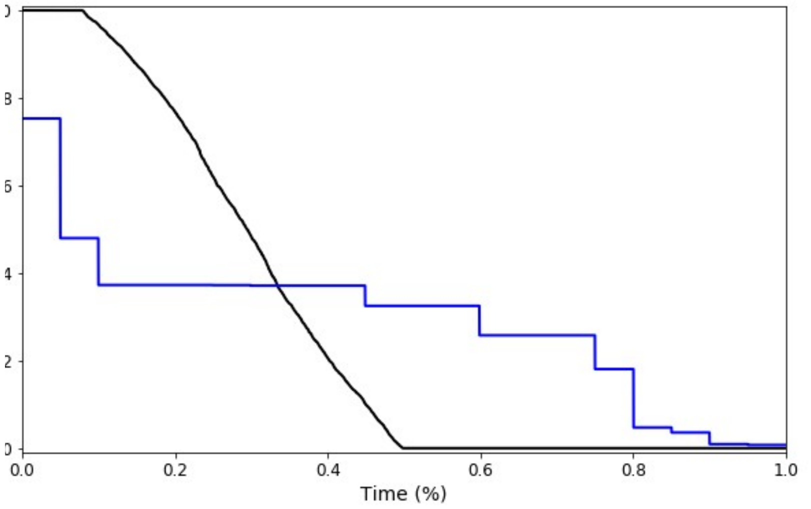
Demand

Wind

Solar

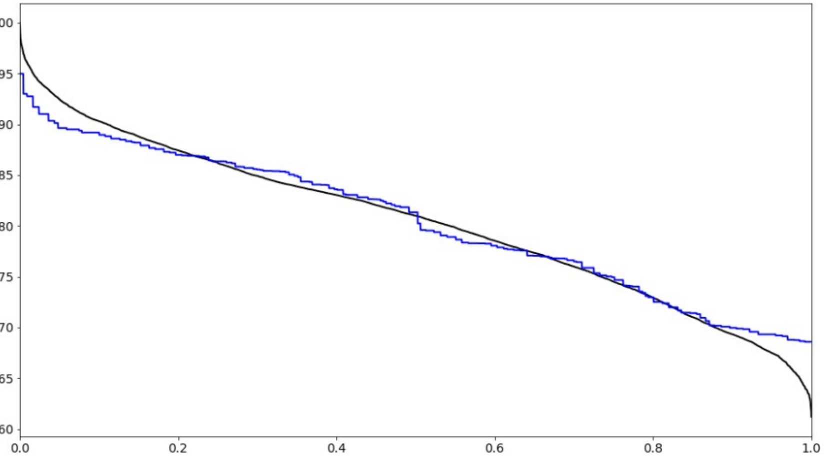


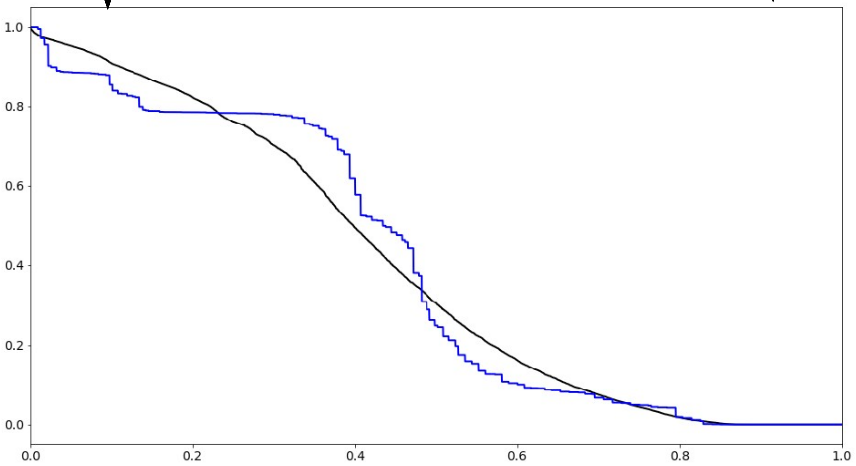


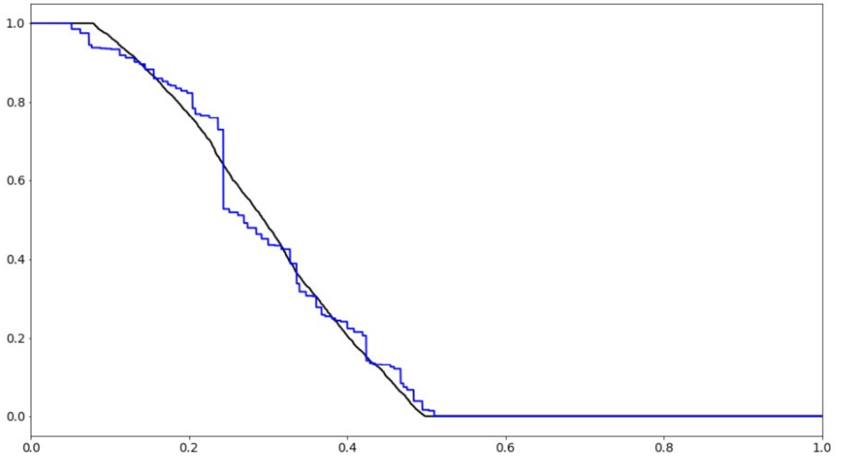


Seasonal Averaging

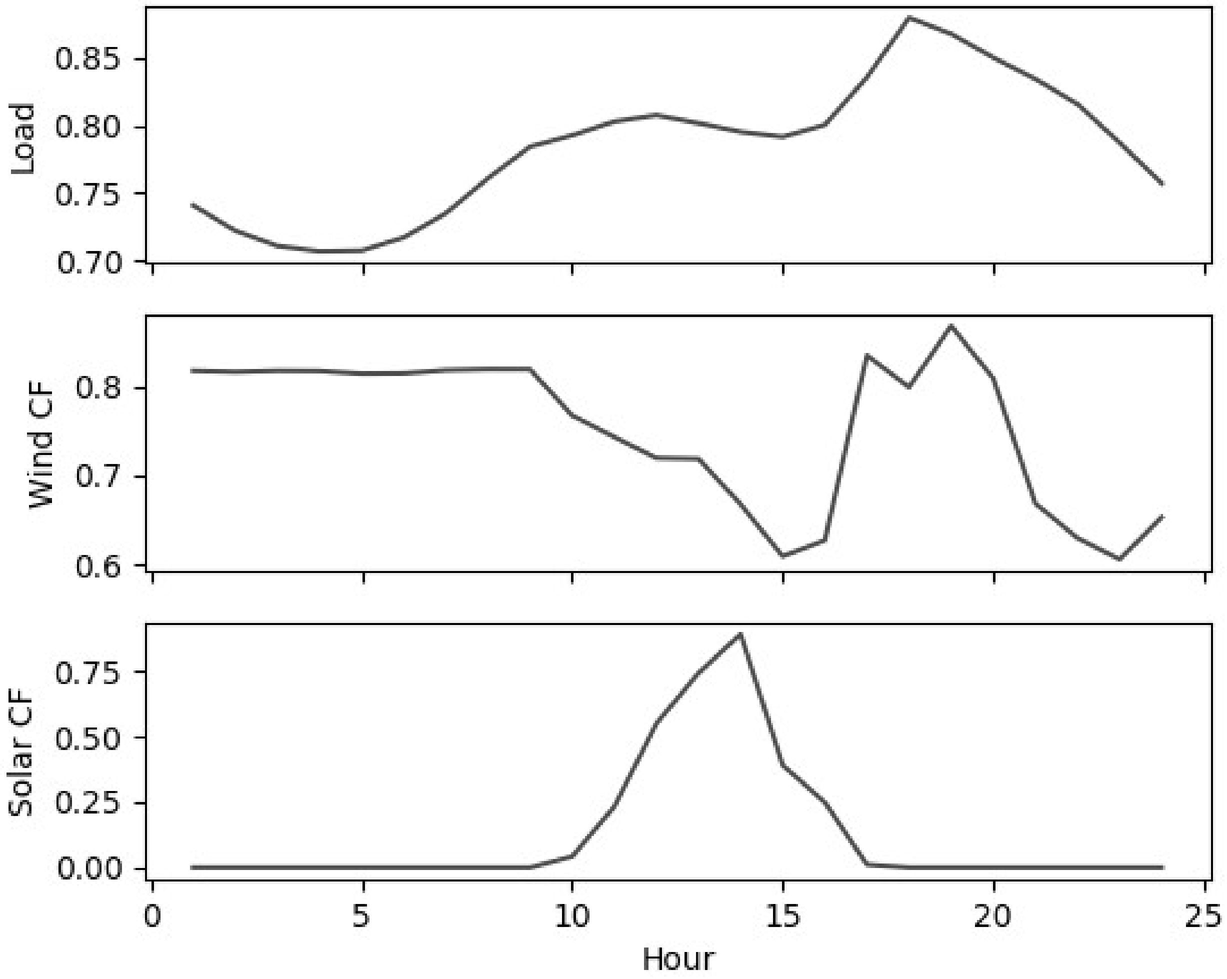
Representative Periods







Further reducing resolution



Further reducing resolution

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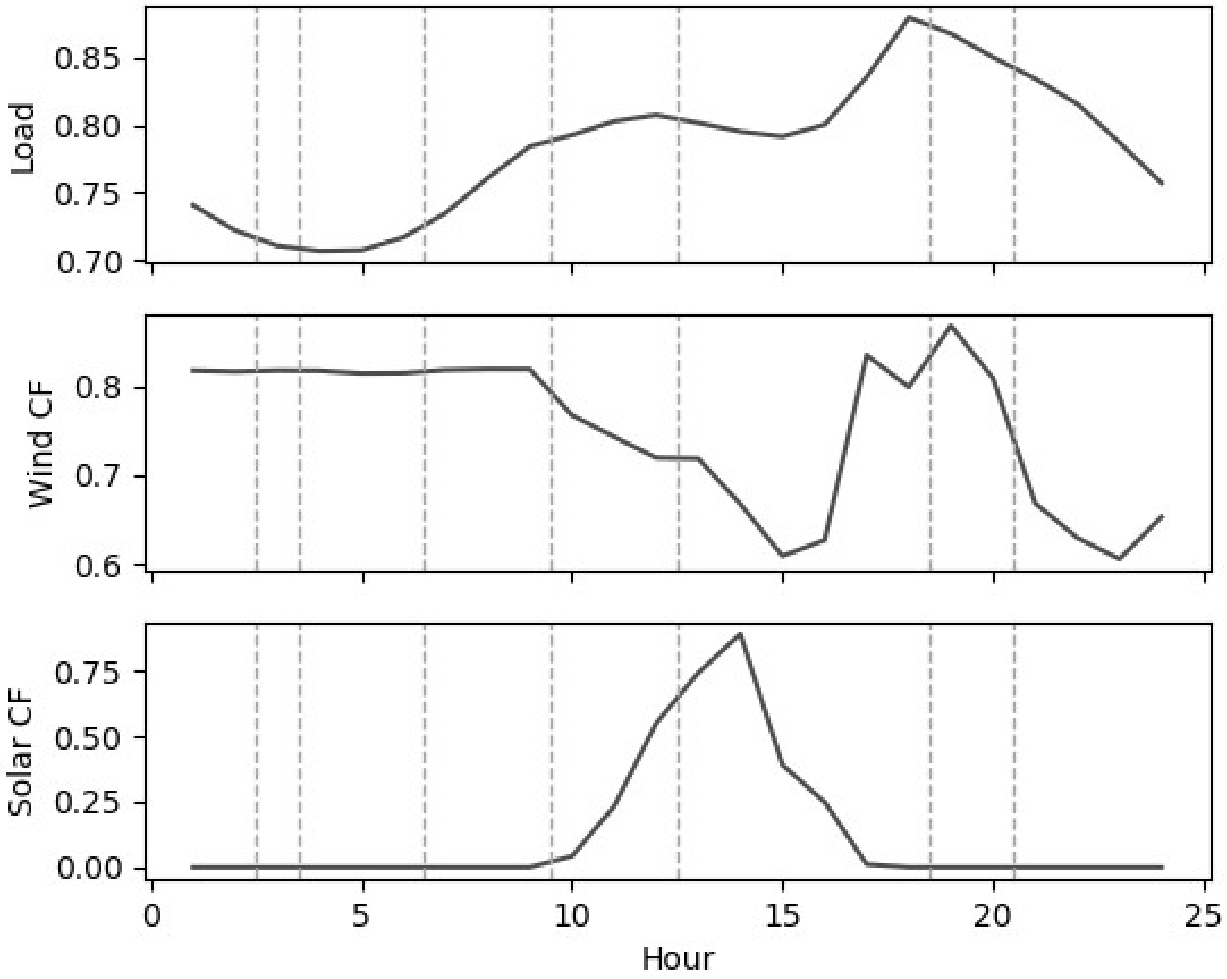

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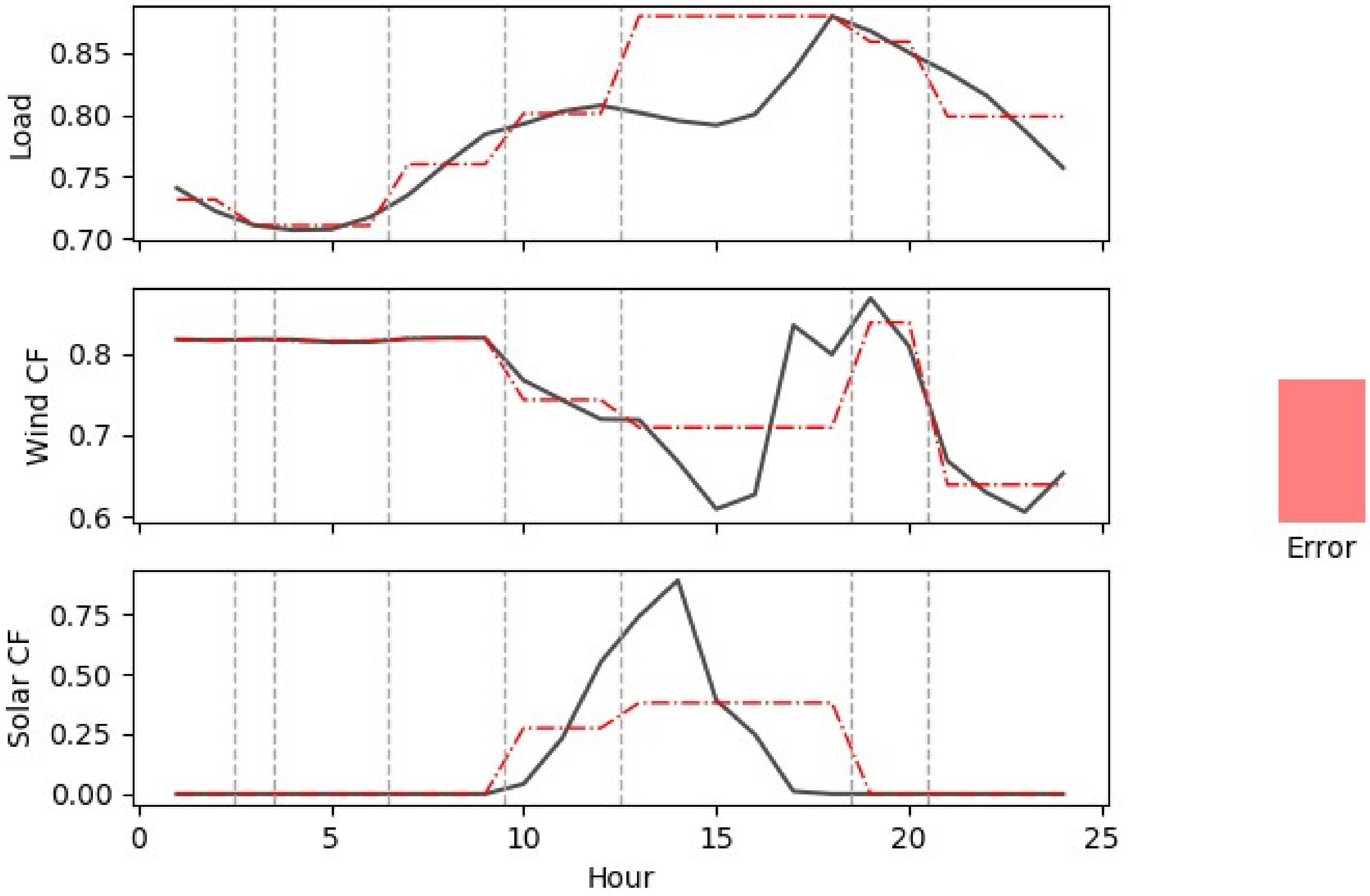

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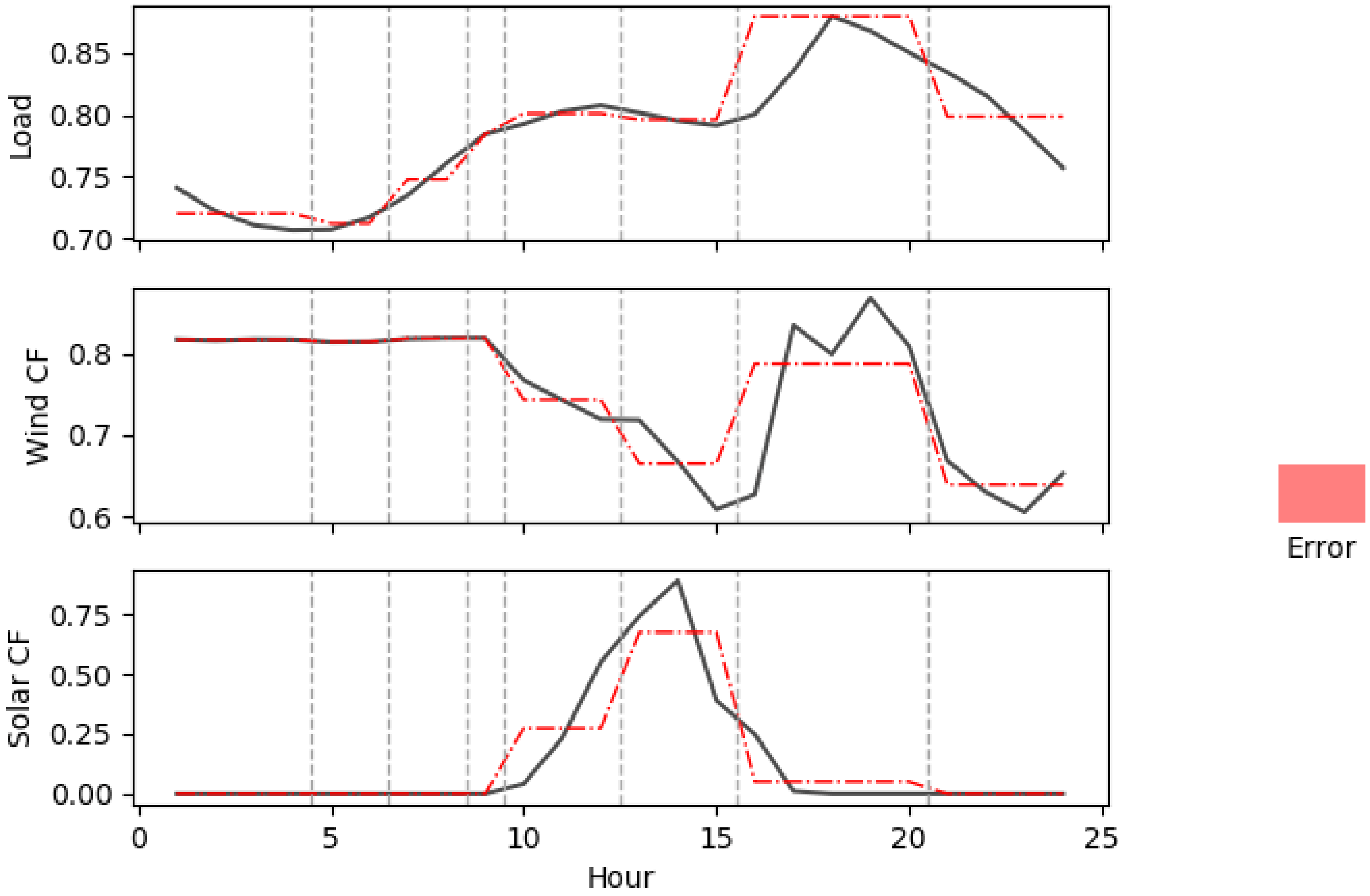

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Take-aways

- VRE challengs past (and current) power system planning models
- Must reconsider spatial, operational, temporal dimensions
- Temporal is good place to start
- Seasonal averaging → Representative Periods
  - Results: very good (you'll have to take my word for it)
- **Still many problems / imperfections with power system models**
  - Increasing amounts of data to work with
  - Maths community can help!!
- Nailing the transition is important!

Thank you!

cameronwade@uvic.ca

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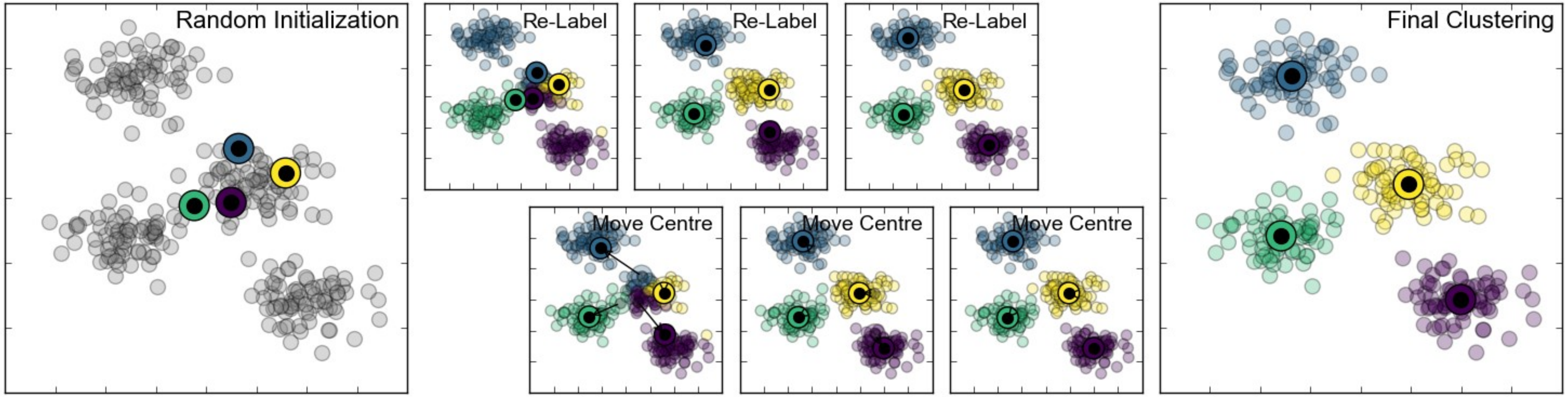
Knowledge. Insight. Action.

K-Means Clustering Primer



Project