U.S. DEPARTMENT OF ENERGY

Load Forecasting

Training for States on Distribution System and Distributed Energy Resources Planning

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Western Regional Training

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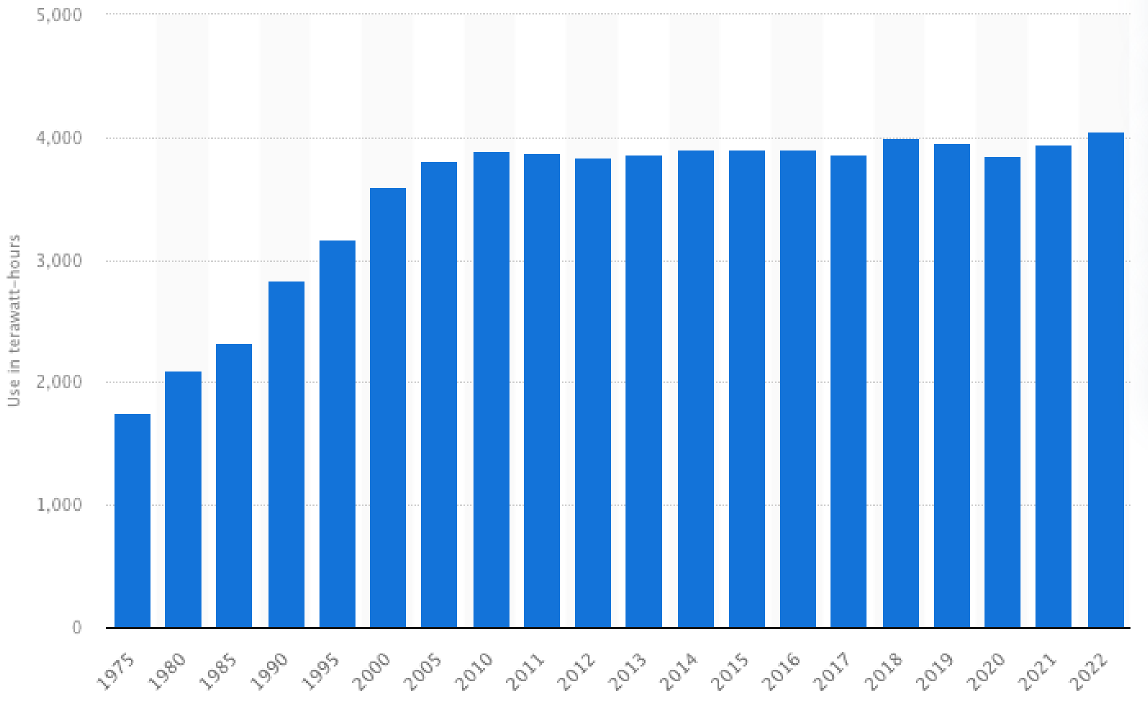
Load Forecasting – What Is the Status Quo?

- **Demand** has been **flat** for the past 20 years
- Utilities had time to **“react”** to local load growth from new customers and businesses
- **Past** consumption was a **good representation** of **future** consumption

Electricity end use in the United States from 1975 to 2022

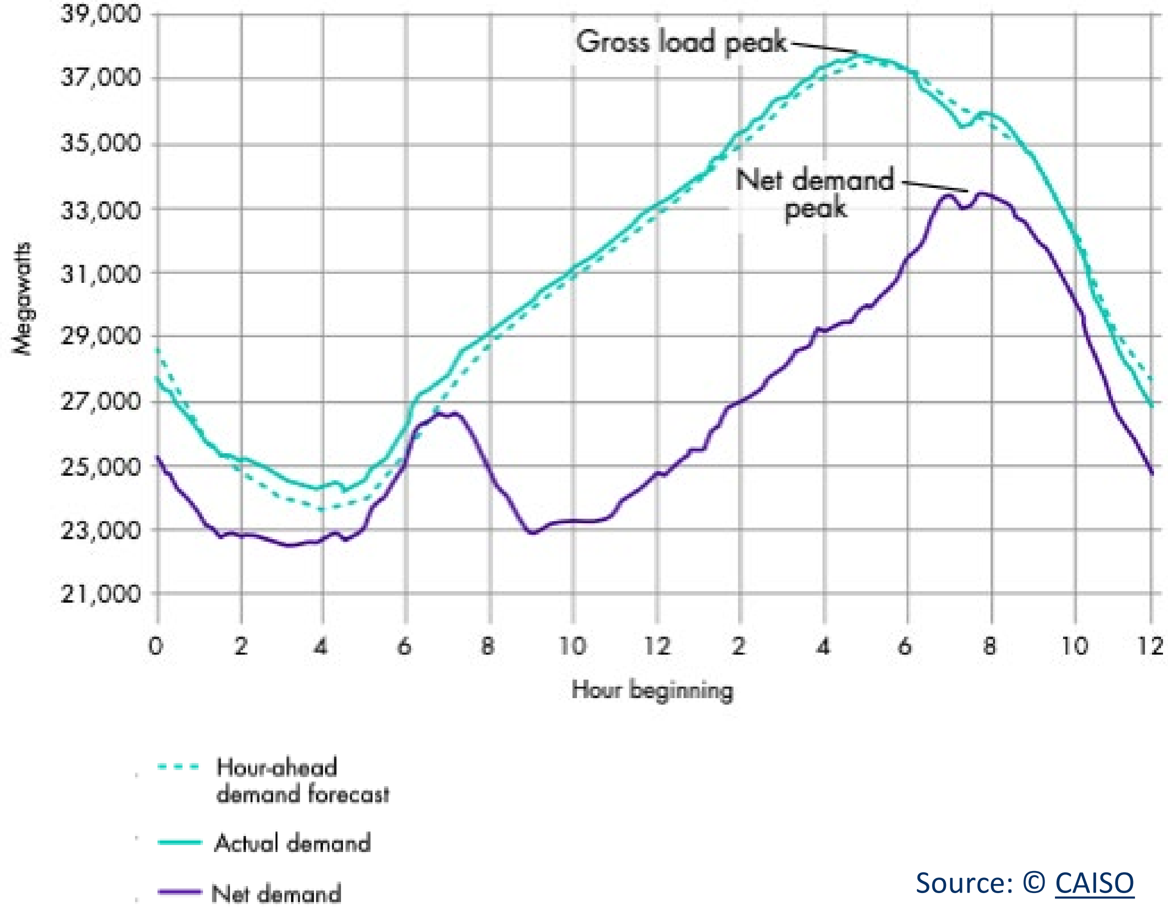


Source: © Statista 2023

Load Forecasting – What Has Changed?

- **Econometric modeling** using historical data (typically load, weather) **is not sufficient** to forecast future load
- **Customers are adopting** new **technologies** behind-the-meter
  - Need to understand *gross load* versus *net load*
  - Need to understand *where* and *when* technologies are being adopted today and in the future
  - *Rapid DER adoption trends* are very different than a new development or business customer
- **Past weather** is **not representative** of future weather

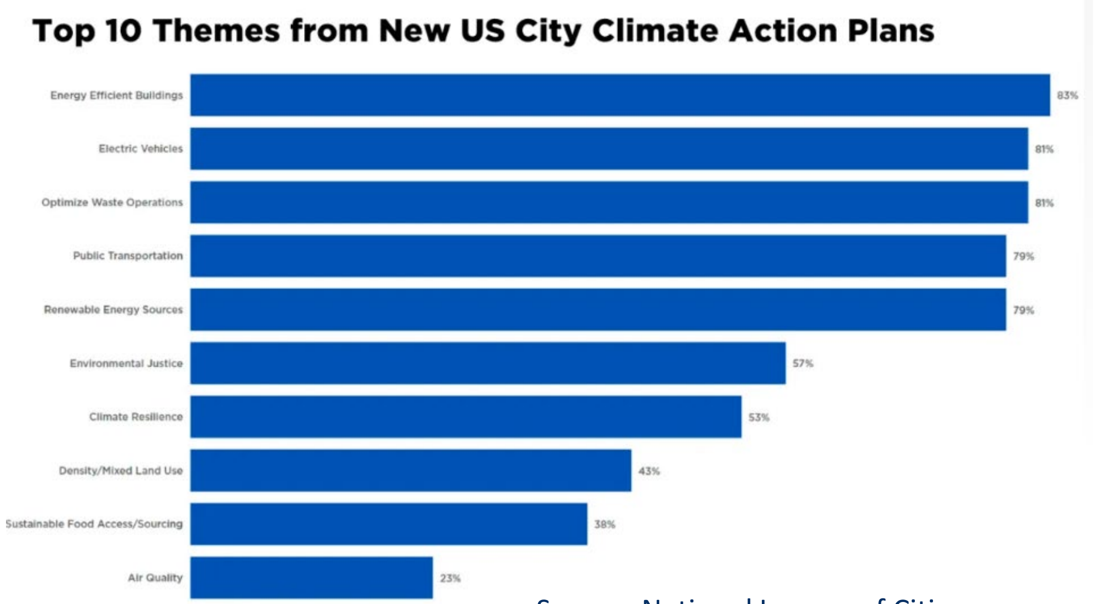
Gross load versus net load example



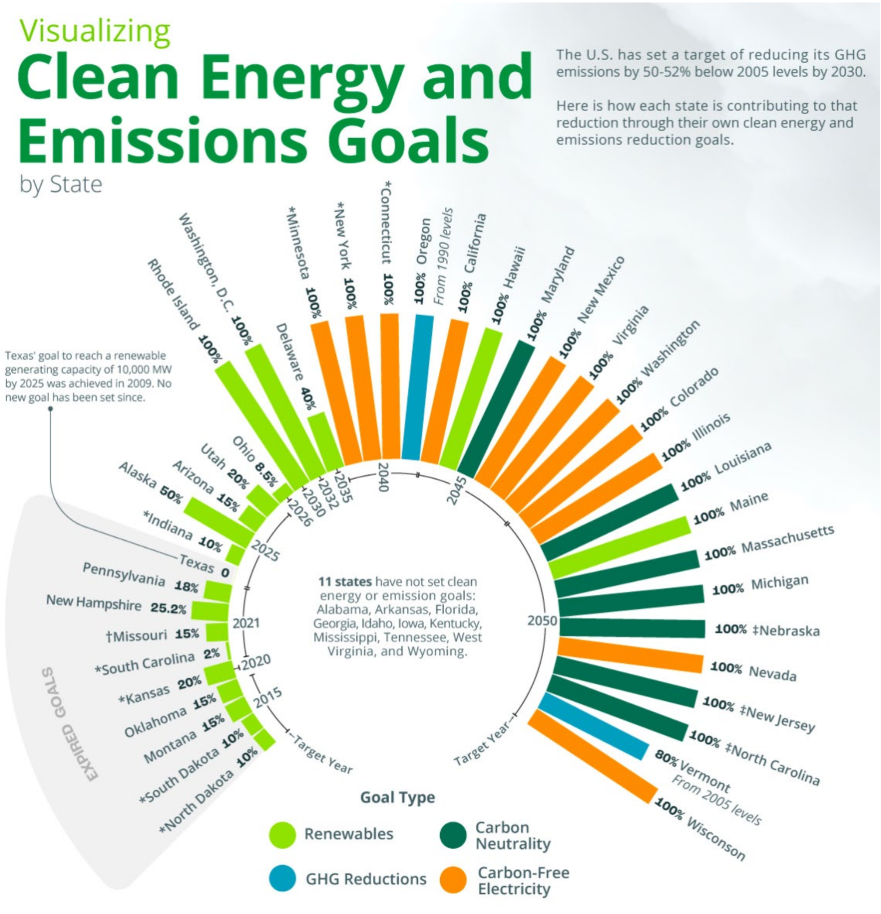
Source: © CAISO

Policy Is Greatly Influencing Load Forecasting

- **DER adoption is heavily influenced by federal/state/local/utility policies and goals**
  - Harder to quantify implications and what is possible
  - Initiatives and programs have to be converted into quantifiable input assumptions on technology adoption, utilization, operation



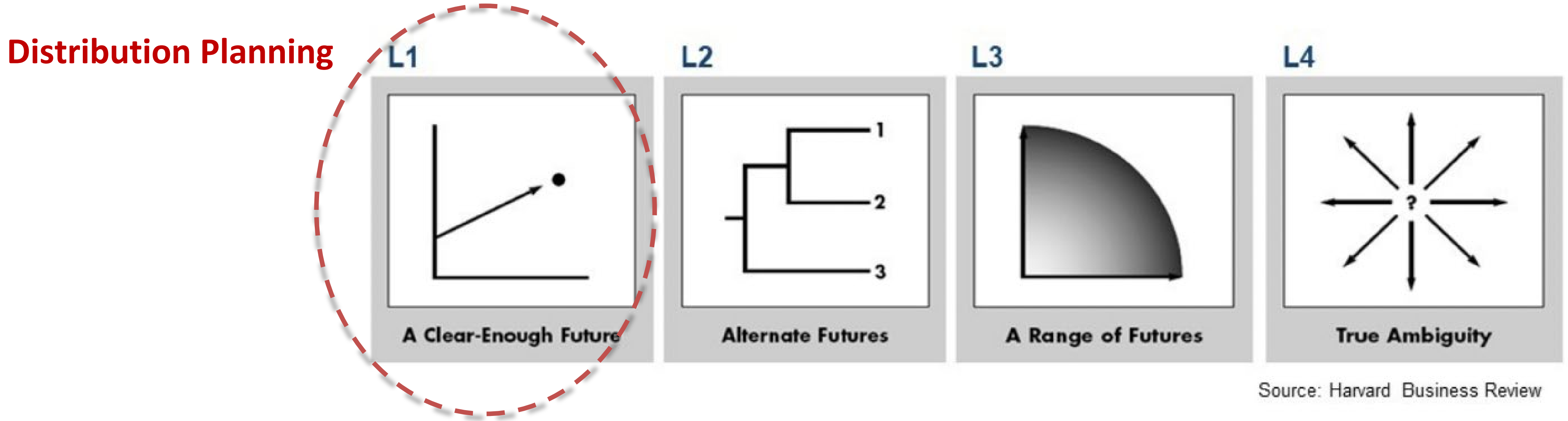
Source: National League of Cities



Source: National Public Utilities Council

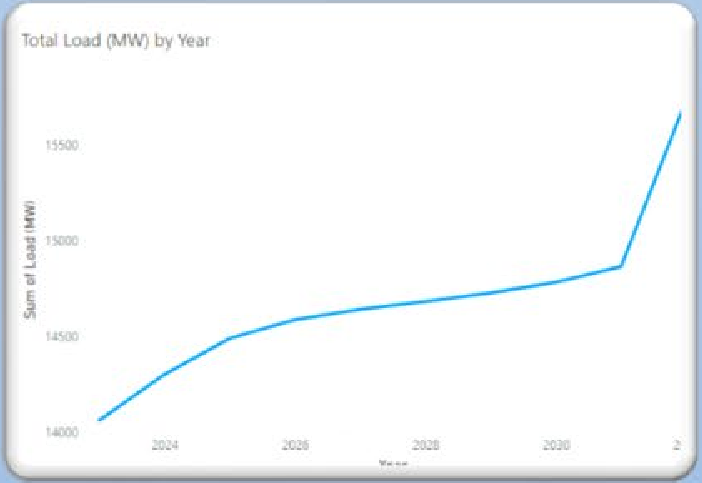
Policy Is Greatly Influencing Load Forecasting

- **Need to plan for longer time horizons**
  - Distribution planning has typically looked 3-5 years ahead
  - Long lead time on grid assets and transmission constraints are increasing the pressure on distribution planning
- **Need to consider multiple scenarios**



Past - Current - Future in Load Forecasting for Distribution Planning

Past

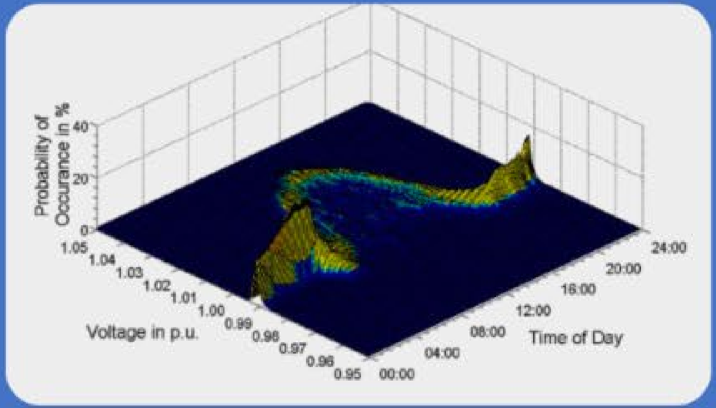


- 5 year time horizon
- Econometrics trends
- DER adjustments
- System level
- Deterministic

Present

- 5, 10, 30 year time horizon
- 8760 trends
- DER adoption and spatial allocation
- Substation / feeder level
- Deterministic scenarios

Future



- Customer level
- 8760 + disaggregated load components
- Parametric distributions for variable to consider uncertainty
- Probabilistic

Source: Eversource

Who Performs Load Forecasting?

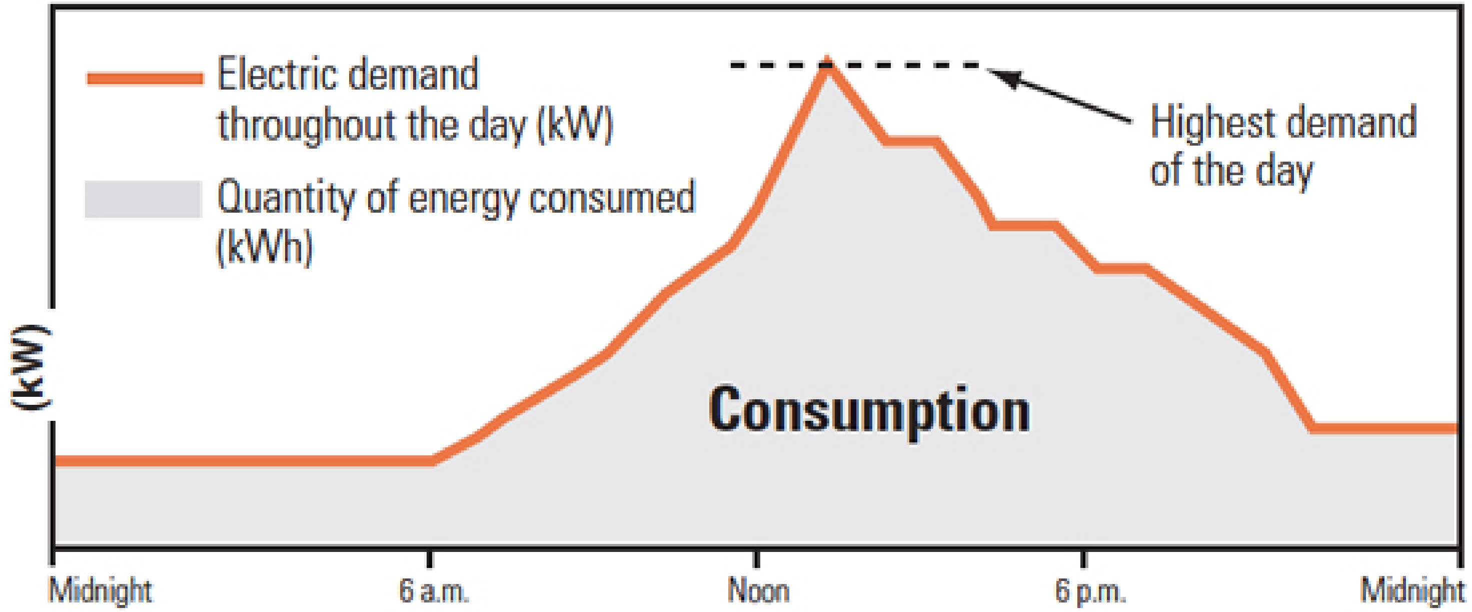
Forecasters
Research organizations
State energy offices
Independent system operators
Utilities – load forecasting departments (typically, the rates department)
Utilities – distribution planning department

Use Cases
National and state studies
Integrated resource planning, renewable portfolio standard plan
Resource adequacy
Transmission planning
Rate design
Corporate forecast & revenue projections
Procurement
Distribution planning

Distribution planning has traditionally not used the forecast from the load forecasting department.

Peak versus Energy Load Forecasting

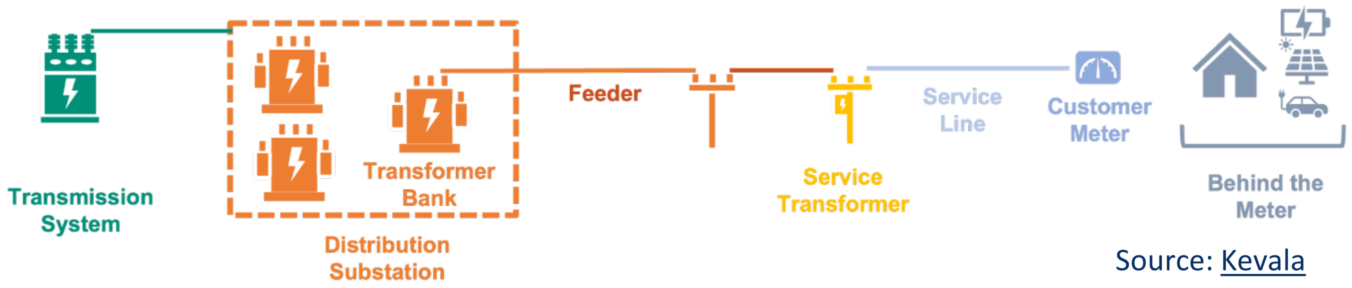
- Load forecasting departments at utilities typically forecast energy and demand separately
- **Distribution Planning** has traditionally only been concerned about **substation/ feeder peak load** to determine how big the infrastructure needs to be



Source: We Energies

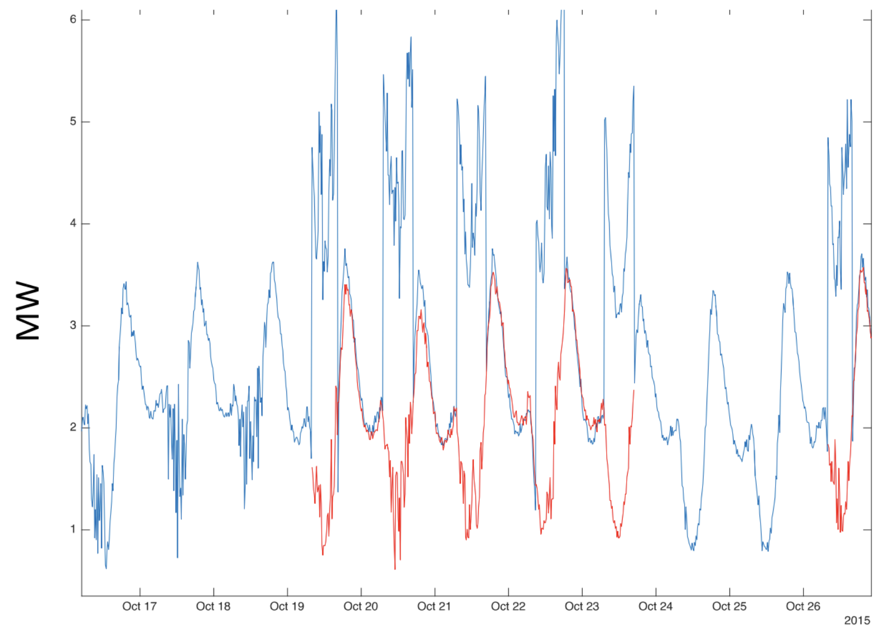
Peak Load Forecast Modeling in Distribution Planning

- **Historical peaks from SCADA measurements at substation and/or feeder-head**
  - SCADA needs to be processed to confirm the ”normal” peak (vs. an abnormality)
    - Typically, a manual and burdensome task
  - Generate a 1-in-10 (90th percentile) load forecast based on historical weather



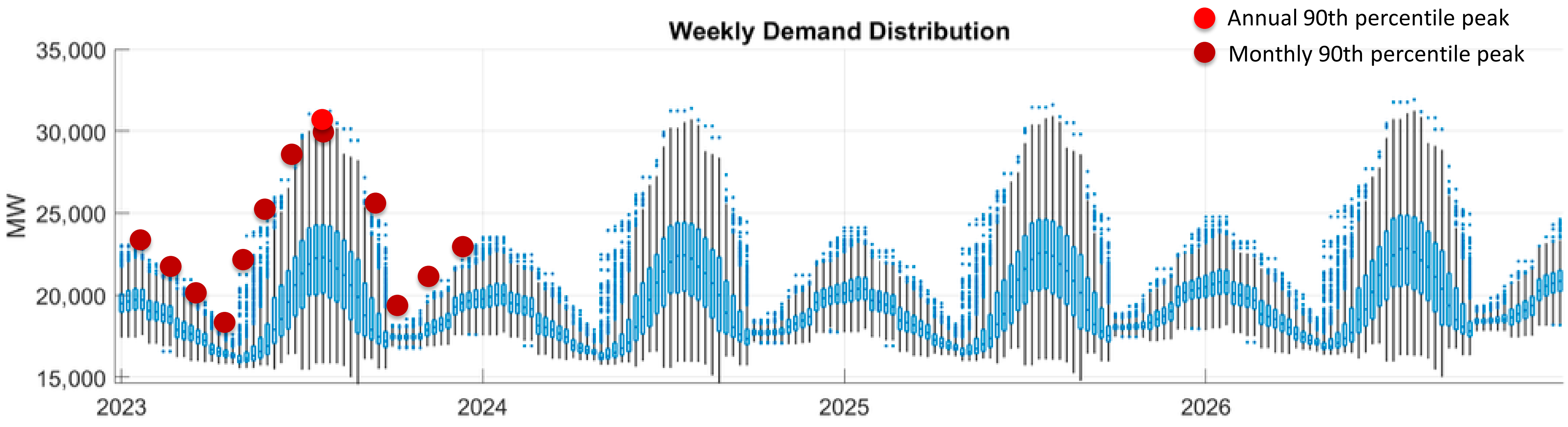
Source: Kevala

Example of Outliers for Abnormal Reconfiguration Event



Source: NREL

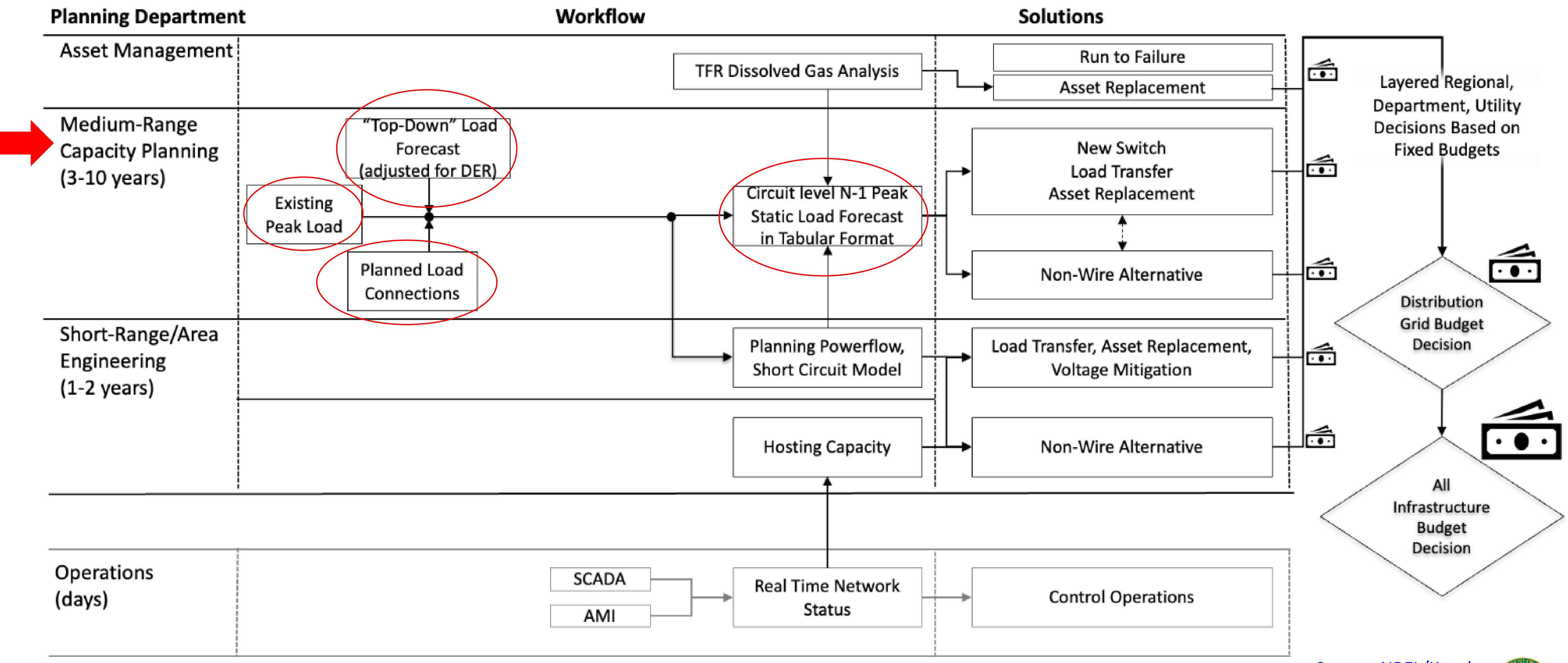
Load Forecast Modeling in Distribution Planning



Source: Modified from ISO-NE

- Distribution Planning typically uses **annual peak 1-in-10-year** load forecasting at the substation and/or feeder levels and might or not disaggregate top-down forecasts for load or DERs
- New local **large customer interconnection requests** are added to the historical peak

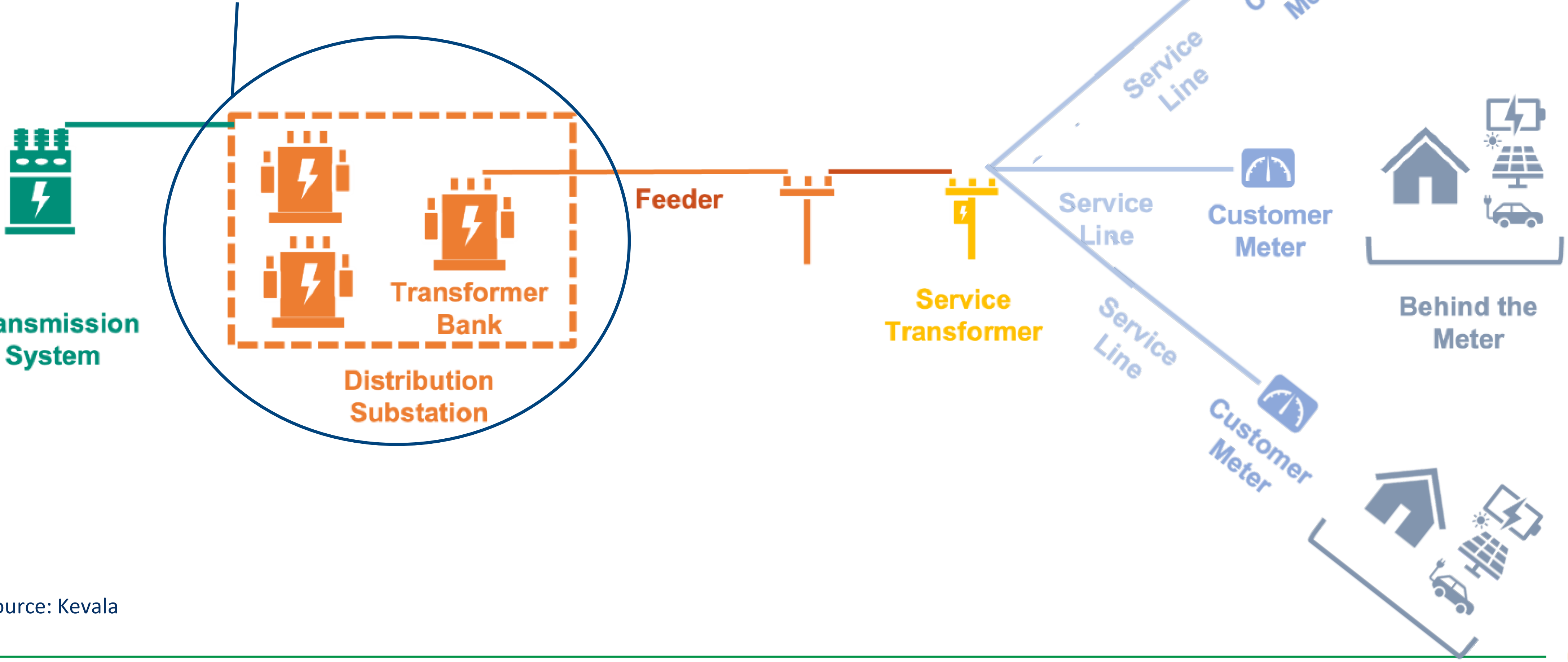
Distribution Planning Load Forecasting



Source: NREL/Kevala

Use-Case: Capacity Planning

<u>"Long-Term" Capacity Planning (5-10 years):</u> thermal evaluation at the substation or feeder-head level.



Source: Kevala

Load Forecast - Key Input to Capacity Planning

- Spreadsheet exercise to predict peak load at every substation and/or feeder
- Single deterministic forecast
- Overload criteria typically 100%
  - When equipment is overloaded, it may fail

Peak Deficiency and Loading			2021				
Peak Facility Loading (%) 2021-2025	Peak Facility Deficiency (MW) 2021-2025	Peak Facility Deficiency (%) 2021-2025	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)
80%	0.00	0%	15.05	11.64	77%	0	0%
76%	0.00	0%	8.40	6.17	73%	0	0%
66%	0.00	0%	11.82	7.75	66%	0	0%
91%	0.00	0%	6.49	5.71	88%	0	0%
31%	0.00	0%	10.16	2.93	29%	0	0%
31%	0.00	0%	10.16	3.14	31%	0	0%
36%	0.00	0%	9.28	3.11	34%	0	0%
20%	0.00	0%	6.50	1.04	16%	0	0%
84%	0.00	0%	3.04	2.55	84%	0	0%
CC	CC	CC	10.39	CC	CC	CC	CC
CC	CC	CC	10.28	CC	CC	CC	CC

PG&E 2021 Grid Needs Assessment (GNA)
Appendix E: GNA Results - Bank & Feeder Capacity Needs
Version Date: 08/16/21
Public

	Facility Information					Distribution Service			Peak Deficiency and Loading		
GNA Need ID	Distribution Planning Region	Division	Facility Name	Facility ID	Facility Type	Primary Driver	Distribution Service Required	Anticipated Need Date	Peak Facility Loading (%) 2021-2025	Peak Facility Deficiency (MW) 2021-2025	Peak Facility Deficiency (%) 2021-2025
GNA_1822901_Capacity	Central Coast	Central Coast	HATTON BANK 1	1822901	Bank	None	None	None	80%	0.00	0%
GNA_182291101_Capacity	Central Coast	Central Coast	HATTON 1101	182291101	Feeder	None	None	None	76%	0.00	0%
GNA_182291102_Capacity	Central Coast	Central Coast	HATTON 1102	182291102	Feeder	None	None	None	66%	0.00	0%
GNA_1823701_Capacity	Central Coast	Central Coast	LAURELES BANK 1	1823701	Bank	None	None	None	91%	0.00	0%
GNA_182371111_Capacity	Central Coast	Central Coast	LAURELES 1111	182371111	Feeder	None	None	None	31%	0.00	0%
GNA_182371112_Capacity	Central Coast	Central Coast	LAURELES 1112	182371112	Feeder	None	None	None	31%	0.00	0%
GNA_1829401_Capacity	Central Coast	Central Coast	OTTER BANK 1	1829401	Bank	None	None	None	36%	0.00	0%
GNA_182941101_Capacity	Central Coast	Central Coast	OTTER 1101	182941101	Feeder	None	None	None	20%	0.00	0%
GNA_182941102_Capacity	Central Coast	Central Coast	OTTER 1102	182941102	Feeder	None	None	None	84%	0.00	0%
GNA_1820702_Capacity	Central Coast	Central Coast	CAMPHORA BANK 2	1820702	Bank	None	None	None	CC	CC	CC
GNA_182071101_Capacity	Central Coast	Central Coast	CAMPHORA 1101	182071101	Feeder	None	None	None	CC	CC	CC

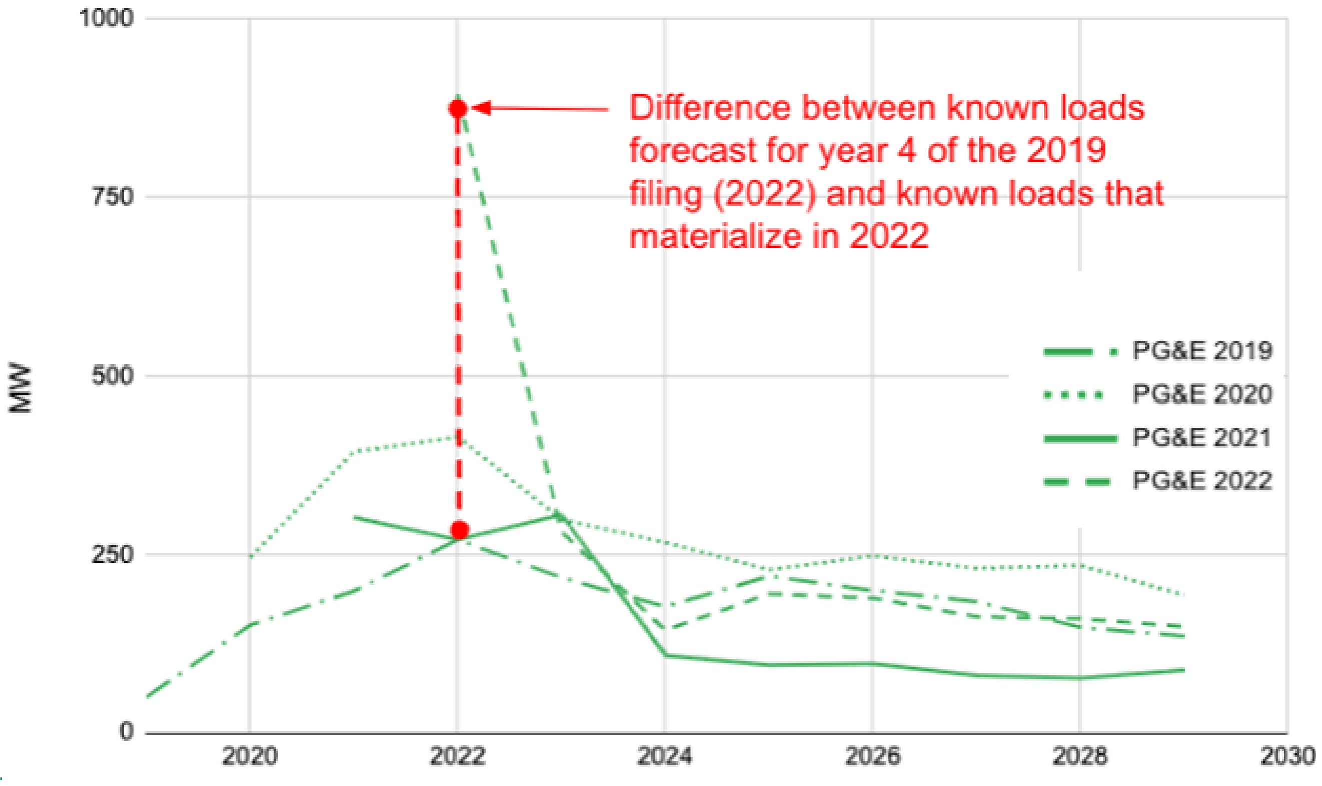
	2021					2022				
GNA Need ID	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)
GNA_1822901_Capacity	15.05	11.64	77%	0	0%	15.05	11.72	78%	0	0%
GNA_182291101_Capacity	8.40	6.17	73%	0	0%	8.40	6.22	74%	0	0%
GNA_182291102_Capacity	11.82	7.75	66%	0	0%	11.82	7.75	66%	0	0%
GNA_1823701_Capacity	6.49	5.71	88%	0	0%	6.49	5.76	89%	0	0%
GNA_182371111_Capacity	10.16	2.93	29%	0	0%	10.16	2.98	29%	0	0%
GNA_182371112_Capacity	10.16	3.14	31%	0	0%	10.16	3.14	31%	0	0%
GNA_1829401_Capacity	9.28	3.11	34%	0	0%	9.28	3.16	34%	0	0%
GNA_182941101_Capacity	6.50	1.04	16%	0	0%	6.50	1.1	17%	0	0%
GNA_182941102_Capacity	3.04	2.55	84%	0	0%	3.04	2.53	83%	0	0%
GNA_1820702_Capacity	10.39	CC	CC	CC	CC	10.39	CC	CC	CC	CC
GNA_182071101_Capacity	10.28	CC	CC	CC	CC	10.28	CC	CC	CC	CC

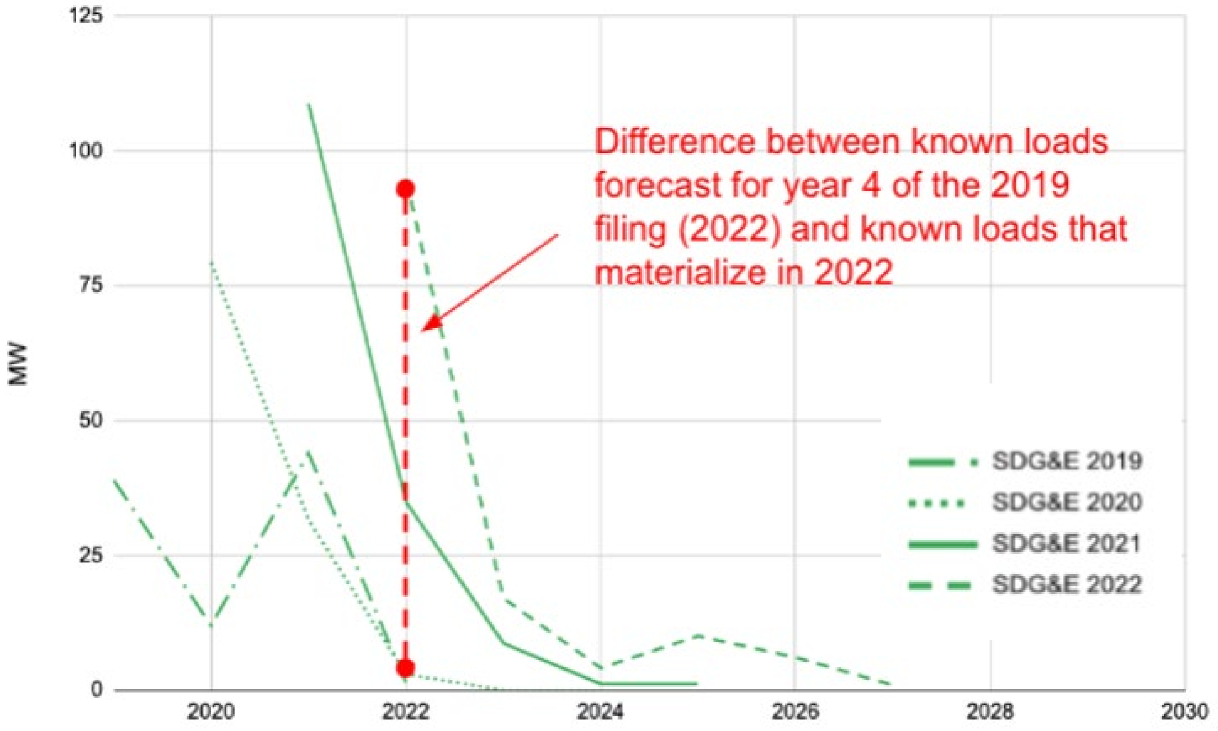
	2023					2024					2025				
GNA Need ID	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)	Facility Rating (MW)	Facility Loading (MW)	Facility Loading (%)	Deficiency (MW)	Deficiency (%)
GNA_1822901_Capacity	15.05	11.81	78%	0	0%	15.05	11.9	79%	0	0%	15.05	12	80%	0	0%
GNA_182291101_Capacity	8.40	6.27	75%	0	0%	8.40	6.33	75%	0	0%	8.40	6.38	76%	0	0%
GNA_182291102_Capacity	11.82	7.74	65%	0	0%	11.82	7.72	65%	0	0%	11.82	7.7	65%	0	0%
GNA_1823701_Capacity	6.49	5.82	90%	0	0%	6.49	5.88	91%	0	0%	6.49	5.93	91%	0	0%
GNA_182371111_Capacity	10.16	3.03	30%	0	0%	10.16	3.09	30%	0	0%	10.16	3.14	31%	0	0%
GNA_182371112_Capacity	10.16	3.14	31%	0	0%	10.16	3.14	31%	0	0%	10.16	3.14	31%	0	0%
GNA_1829401_Capacity	9.28	3.21	35%	0	0%	9.28	3.26	35%	0	0%	9.28	3.31	36%	0	0%
GNA_182941101_Capacity	6.50	1.16	18%	0	0%	6.50	1.22	19%	0	0%	6.50	1.28	20%	0	0%
GNA_182941102_Capacity	3.04	2.52	83%	0	0%	3.04	2.51	83%	0	0%	3.04	2.49	82%	0	0%
GNA_1820702_Capacity	10.39	CC	CC	CC	CC	10.39	CC	CC	CC	CC	10.39	CC	CC	CC	CC
GNA_182071101_Capacity	10.28	CC	CC	CC	CC	10.28	CC	CC	CC	CC	10.28	CC	CC	CC	CC

Source: PG&E

New Business Customers Driving Investments Is Reactive

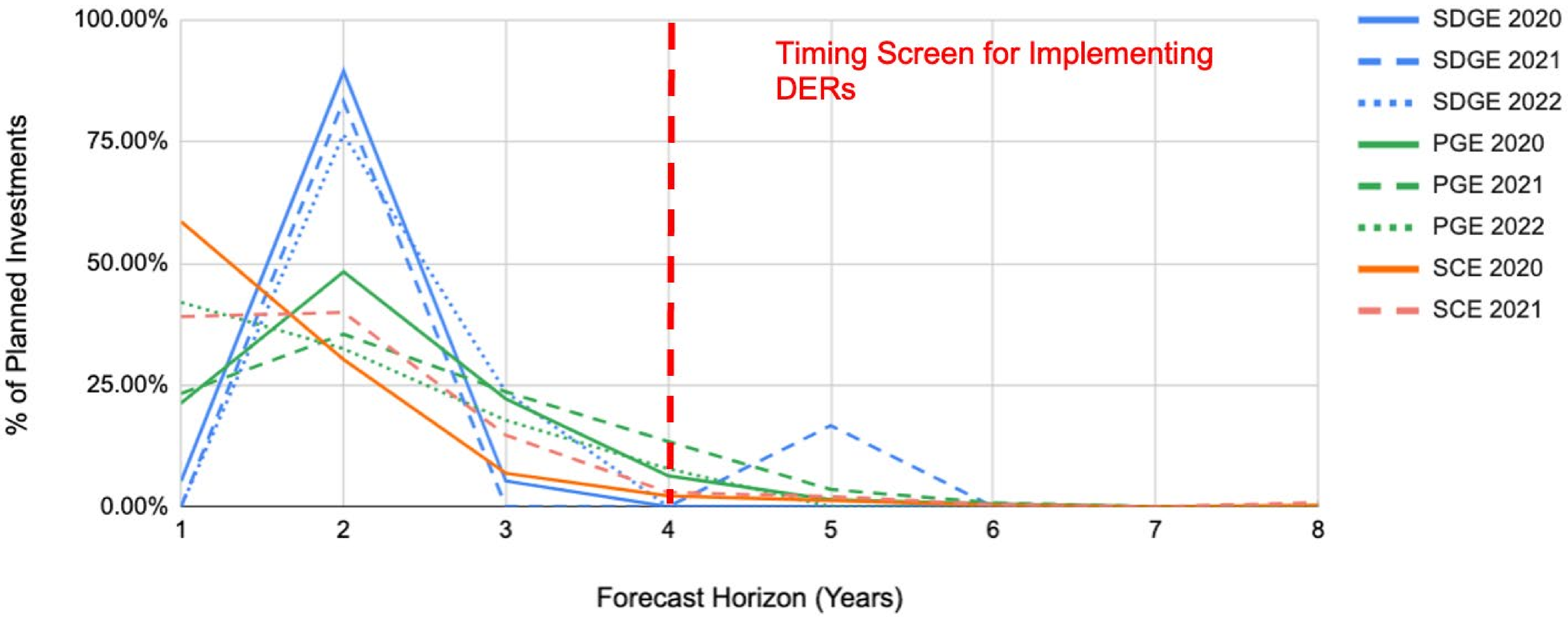
- Load growth is consistently missed



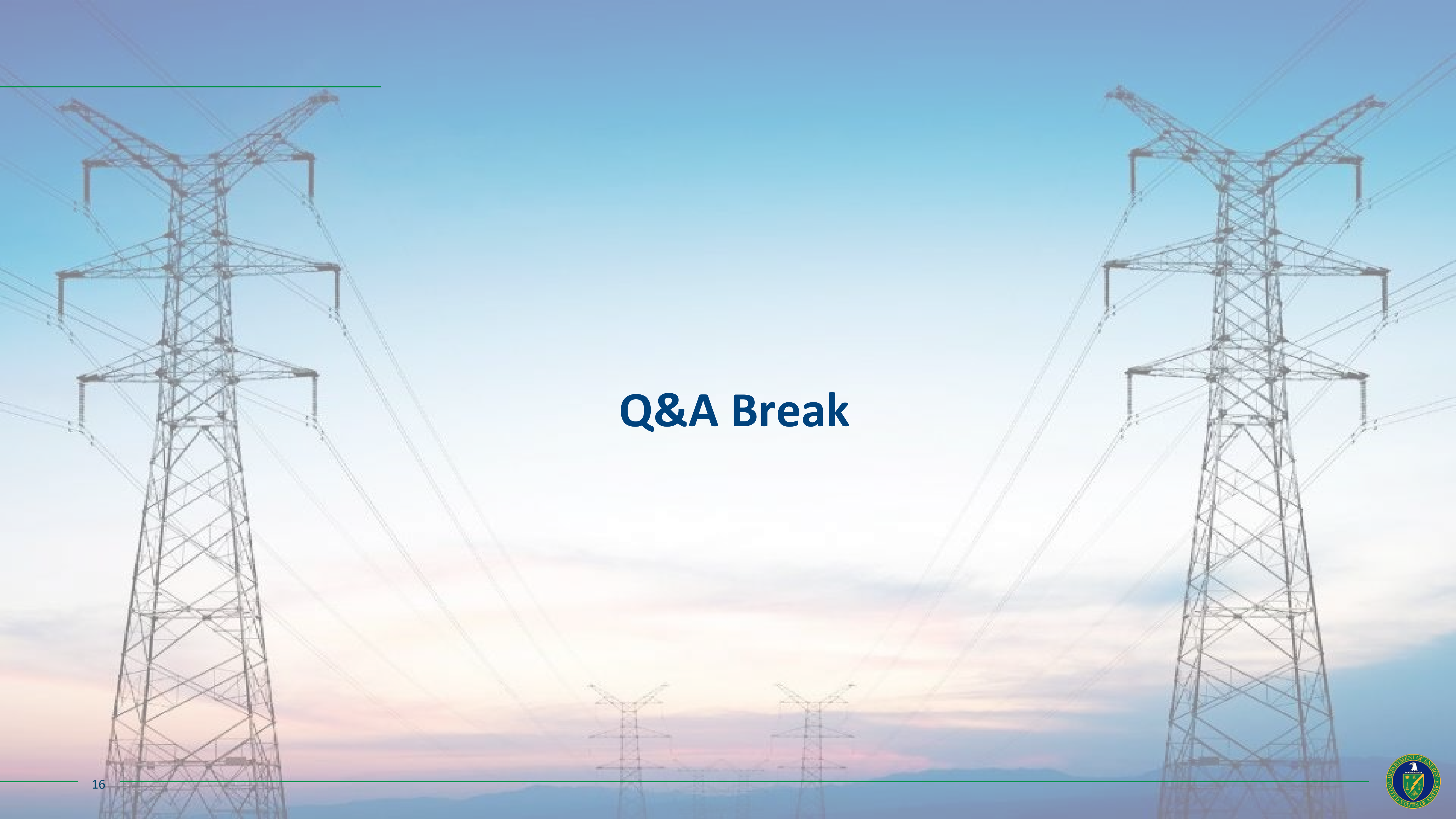


Source: [Distribution Investment Deferral Framework: Evaluation and Recommendations]

Investments Consistently Needed



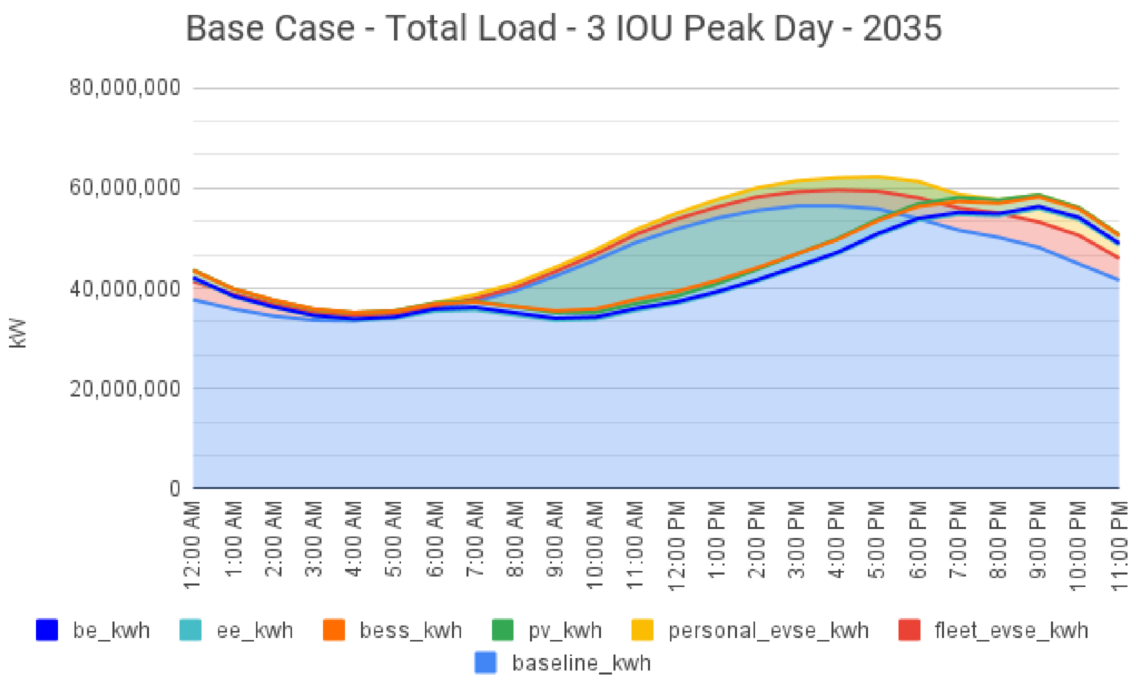
Source: [Distribution Investment Deferral Framework: Evaluation and Recommendations]

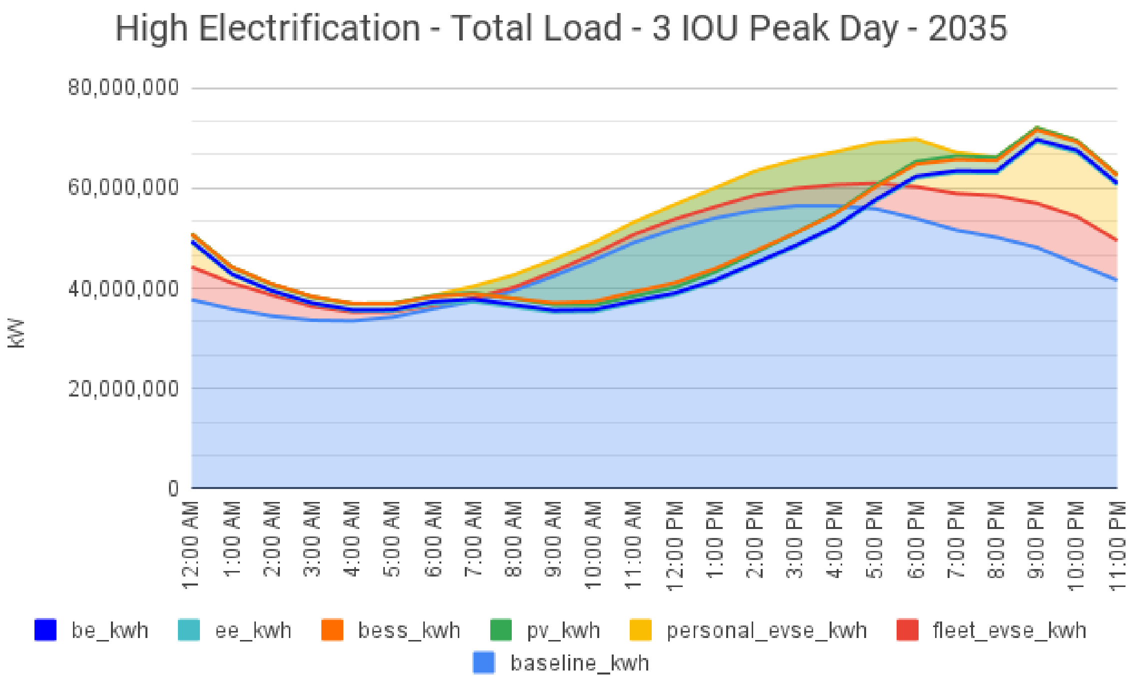


Q&A Break

DERs Are Challenging the Peak Load Forecast Model

- **Increasing need to understand [full load-shape profile] to model future peak load quantity and time of year and day**
  - Overall load can be taken apart (disaggregated) to identify individual end use trends
  - Customer segment at the substation/feeder level by customer class is used for DER adoption and forecasts
- **Full bottom-up models leveraging AMI and SCADA are starting to be used**
  - Kevala - CPUC Electrification Impacts Study - Part 1





Source: Kevala

CPUC Electrification Impacts Study - Part 1 - Impact of EV Charging

Adding between 3.2M and 10.0M light-duty (LD) ZEVs by 2035 across the three IOUs has roughly the same energy impacts as adding 2.9M to 8.7M residential customers' worth of new energy demands.

Base Case

ZEV adoption sources:
- **LD:** CEC 2021 IEPR Base Case
- **Medium duty/heavy duty (MD/HD)**: CEC 2021 IEPR Base Case

2035 ZEV-equivalent energy:
- **3.2M LDs:** 2.9M residential customers
- **227k MD/HDs:** 173k commercial customers

High Electrification

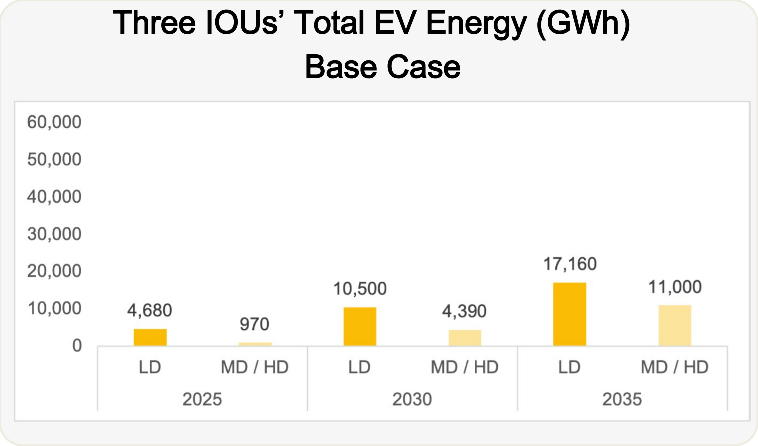
ZEV adoption sources:
- **LD**: CARB ACC II
- **MD/HD**: CARB 2020 SSS (ACT & ACF)

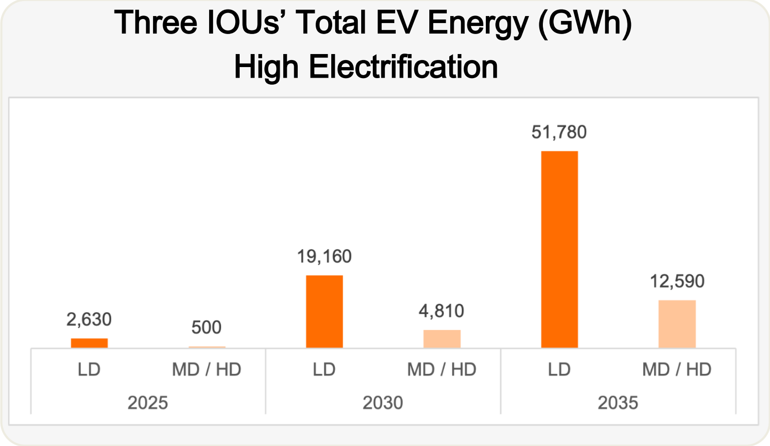
2035 ZEV-equivalent energy:
- **10.0M LDs:** 8.7M residential customers
- **219k MD/HDs:** 198k commercial customers

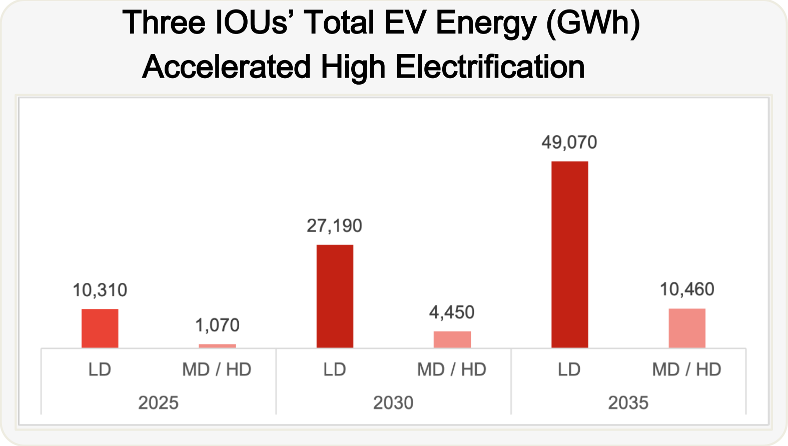
Accelerated High Electrification

ZEV adoption sources:
- **LD**: CEC 2021 IEPR Bookend Case
- **MD/HD**: CEC 2021 IEPR High Case

2035 ZEV-equivalent energy:
- **9.5M LDs:** 8.2M residential customers
- **231k MD/HDs:** 164k commercial customers



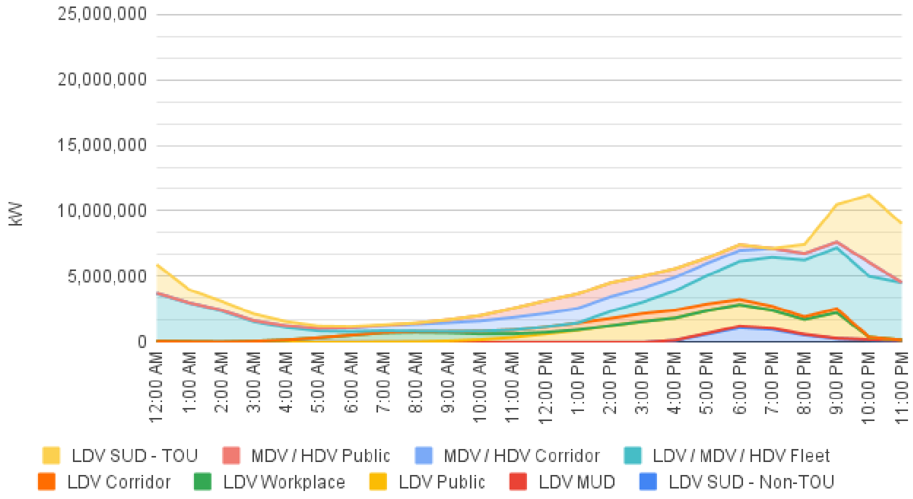




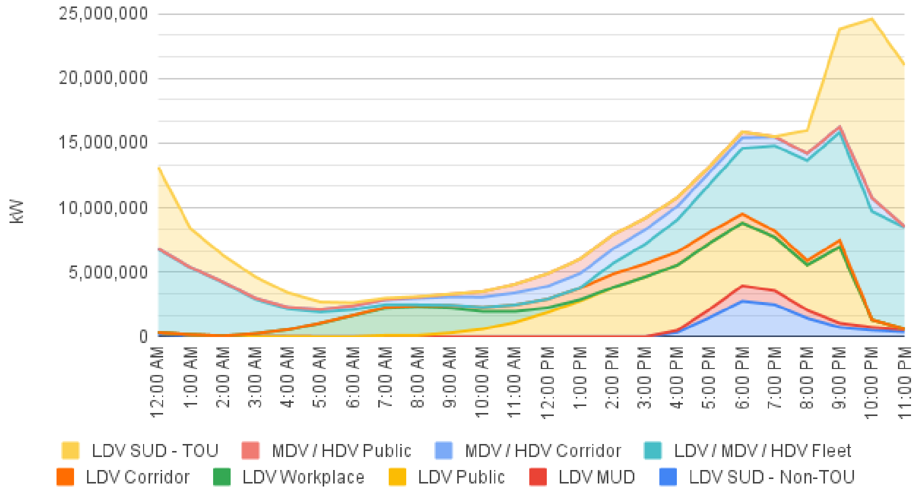
Source: Kevala

Example Electrification Scenarios – Base Case versus High

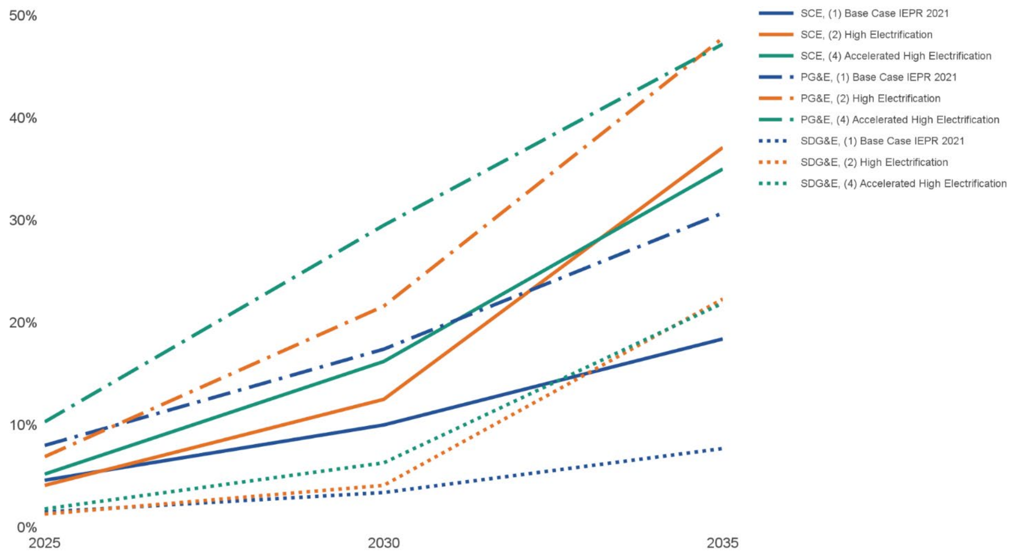
Base Case - EVSE Load - 3 IOU Peak Day - 2035



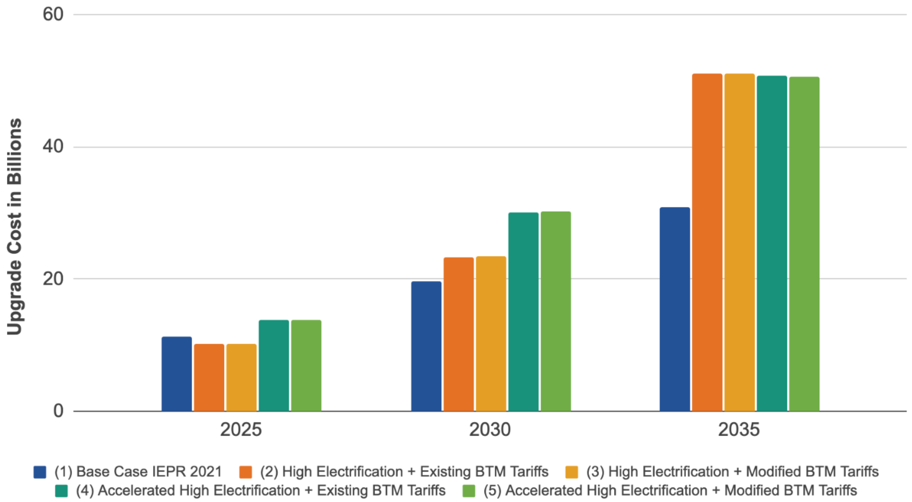
High Electrification - EVSE Load - 3 IOU Peak Day - 2035



Overloaded Feeders



Total Capacity Upgrades Costs - PG&E, SCE and SDG&E



Source: Kevala

DERs – Demand-Side Modifiers

- **How to predict where (which substation and feeder) and when will each technology be adopted?**

Behind -the - Meter Photovoltaics (PV)

Behind -the - Meter Battery Energy Storage System (BESS)

Building Electrification (BE)

Electric Vehicles (EV) and Electric Vehicle Service Equipment (EVSE)

Energy Efficiency (EE)

Demand Response (DR)

Pricing & Programs (P&P)

Smart Controls

Source: Kevala

Challenges with EE & BE Adoption and Behavior in Distribution Planning

- **EE methods in distribution planning often rely on ratio of savings rather than specific measure adoption**
  - In contrast, for other DERs, the specific technology adopted is estimated along with load implications (size and behavior) of that technology
  - The type of load conversion could dramatically impact the behavior and level of BE adoption.
- **Assumes uniform savings across baseline loads, potentially attributing savings in hours when savings may not occur**
  - For example, savings of 2% could be due primarily to lighting, yet lighting savings are limited during the day or early mornings
  - Could miss compounding benefits from temperature-sensitive measures
  - Converting heating loads from natural gas to electricity (for both commercial and residential sectors) could transition a customer with low energy use to a much higher electric bill in exchange for a much lower (or nonexistent) gas bill
- **Methods typically model savings proportional to size of customer's load**
  - While intuitive (customers with high energy usage potentially have more opportunities for greater savings), this results in very large customers capturing the 'target' savings first, potentially missing smaller premises that also could adopt

Challenges with EE & BE in Adoption and New Load Growth

Need to consider recent state and federal level legislation:

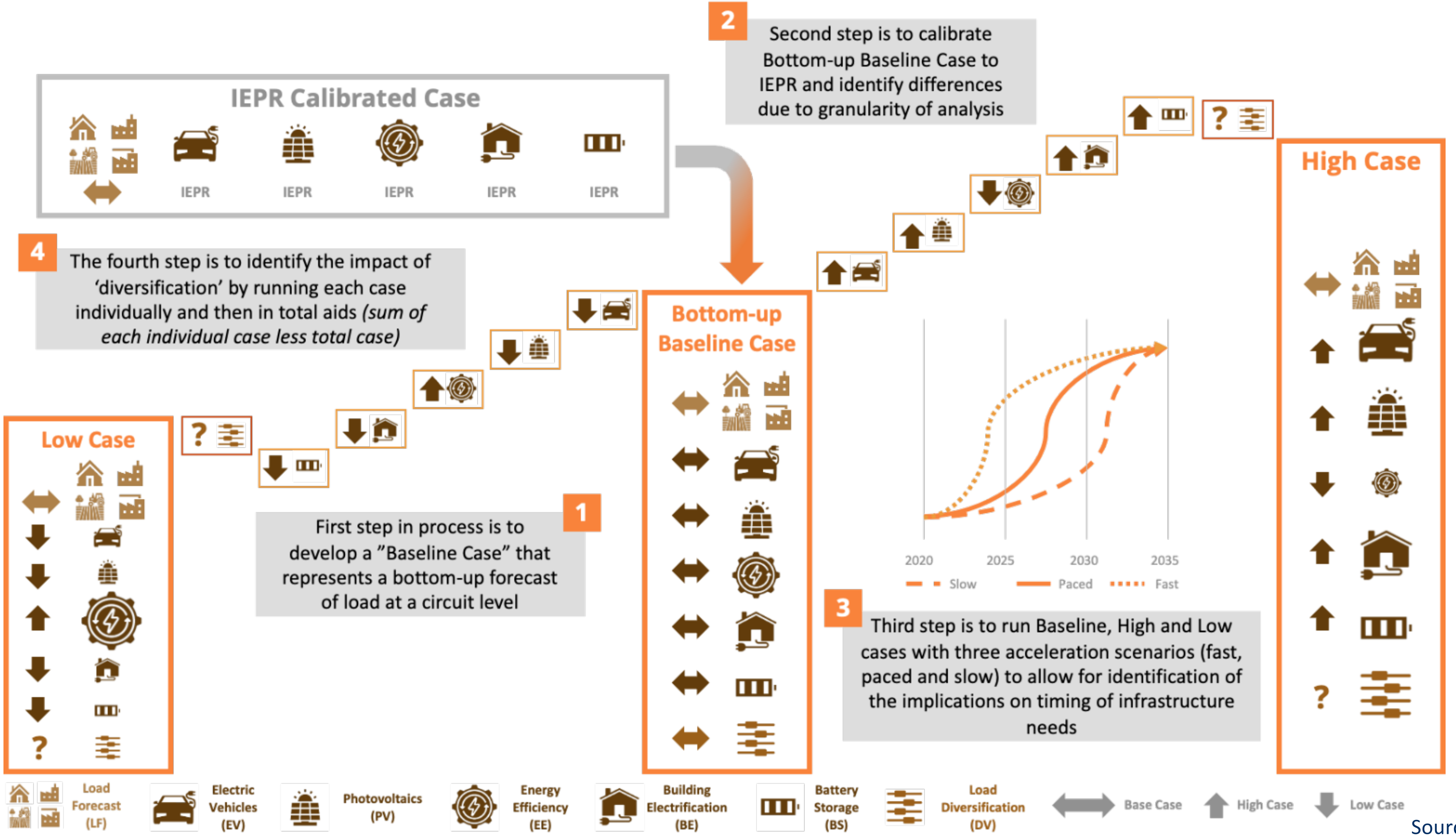
- IRA appliance rebates
- CA example
  - SB 1477 (2018) calls on the CPUC to develop two programs (BUILD and TECH) aimed at reducing greenhouse gas emissions associated with buildings.
  - AB 3232 (2018) directs the California Energy Commission (CEC) to "assess the potential … to reduce the emissions of greenhouse gases in … residential and commercial building stock by at least 40 percent below 1990 levels by January 1, 2030."
  - SB 68 (2021) directed the CEC to develop guidance and best practices to overcome barriers to building electrification and electric vehicle charging equipment.
  - CEC 2022 building code - Encourages electric heat pump technology and electric-ready requirements for other technologies for new construction

Deterministic Scenarios vs. Probabilistic Load Forecast

- **Deterministic Scenarios**
  - Change assumptions for final target and speed of DER adoption
  - Results in a range but does not quantify uncertainty
- **Probabilistic Load Forecasting**
  - Determines a range and probability distribution for each of the driving variables of the forecast
  - Individual components of the load and DER forecast are turned into probabilistic forecasts with calculated uncertainty

Challenge: How to combine uncertainty from every load and DER model into one capacity planning model that can be used to make investment decisions

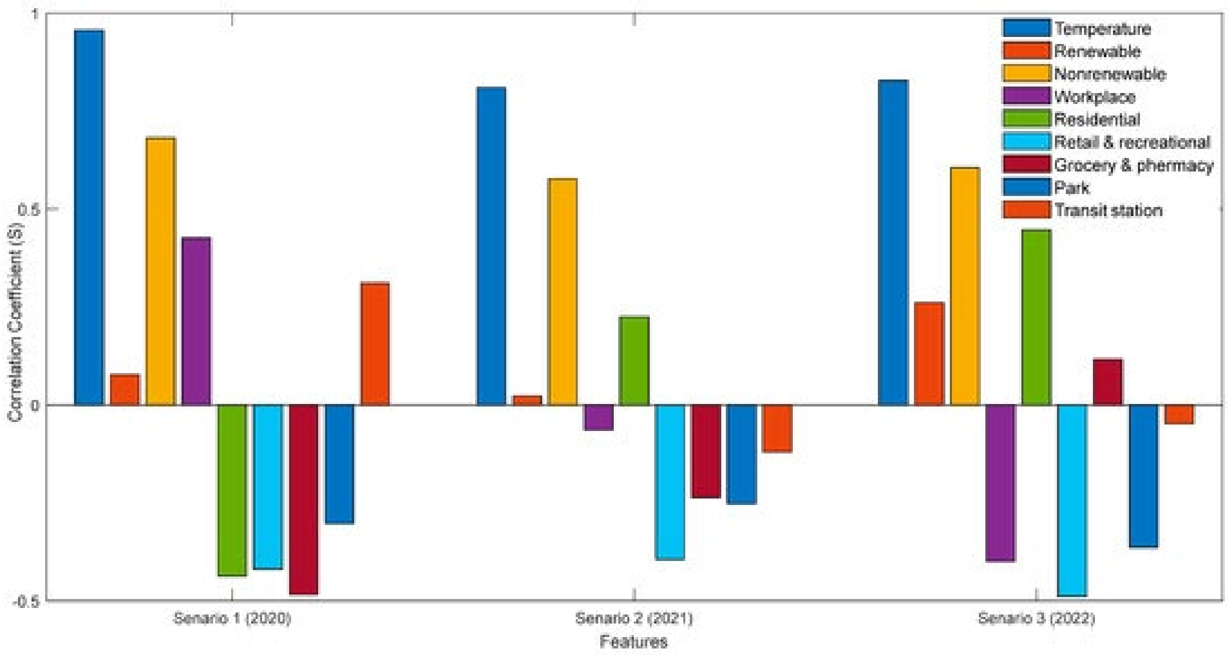
Deterministic Scenario Matrix Design

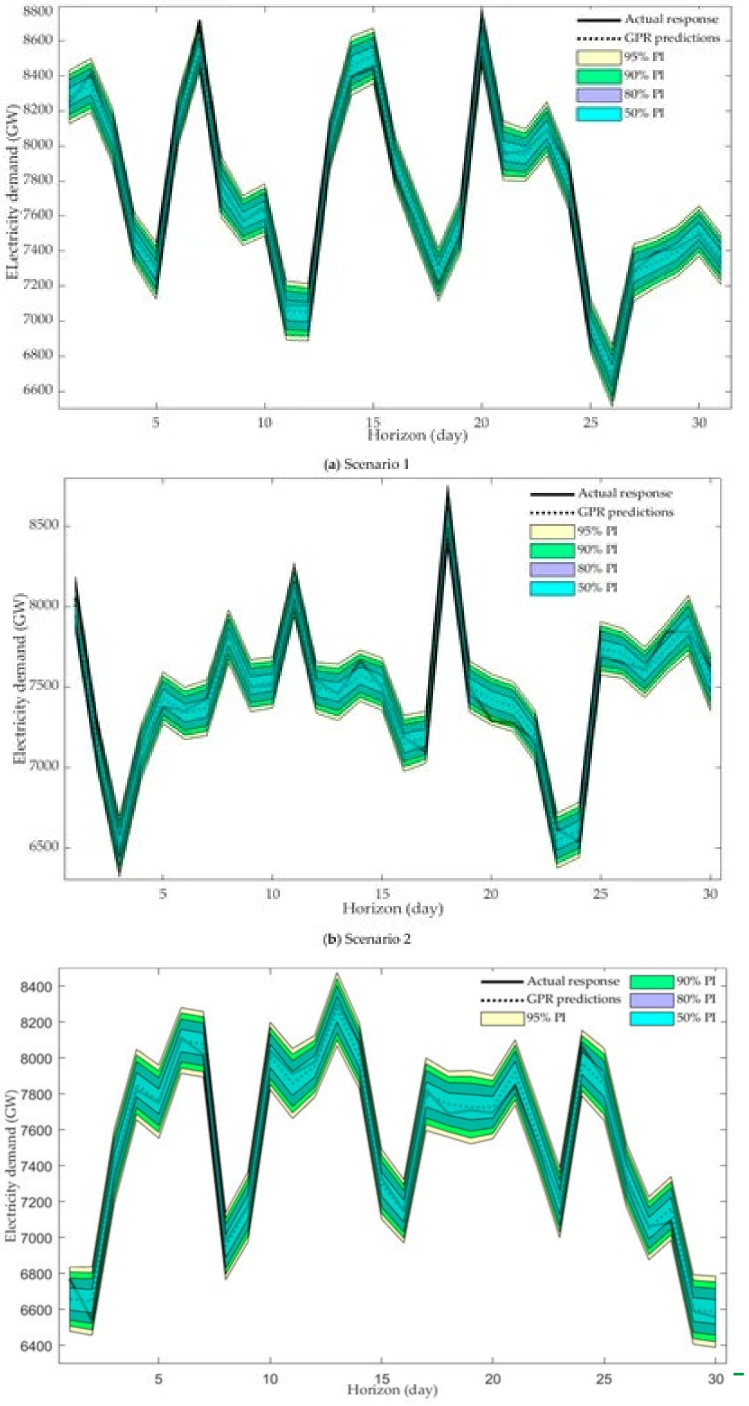


Source: Kevala

Probabilistic Load Forecasting

- **Quantifies uncertainty for each scenario**
  - Probabilistic component forecasts





(a) Scenario 1

(b) Scenario 2

(c) Scenario 3

Source: Appl. Sci. **2023**, *13*(11), 6520; **https://doi.org/10.3390/app13116520**

Key Gaps and Needs in Distribution Planning Load Forecasting

- Statistical load forecasting based on historical load and weather events will miss extreme weather events

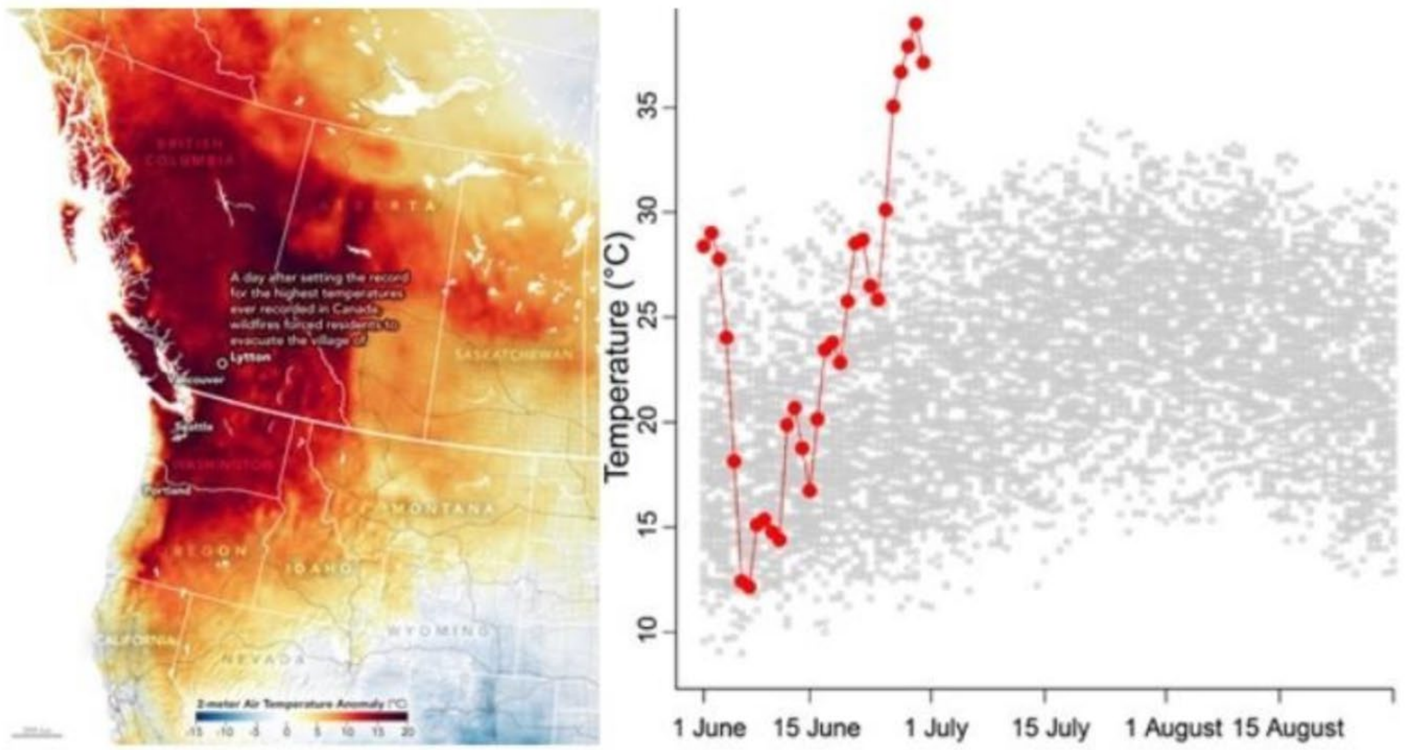
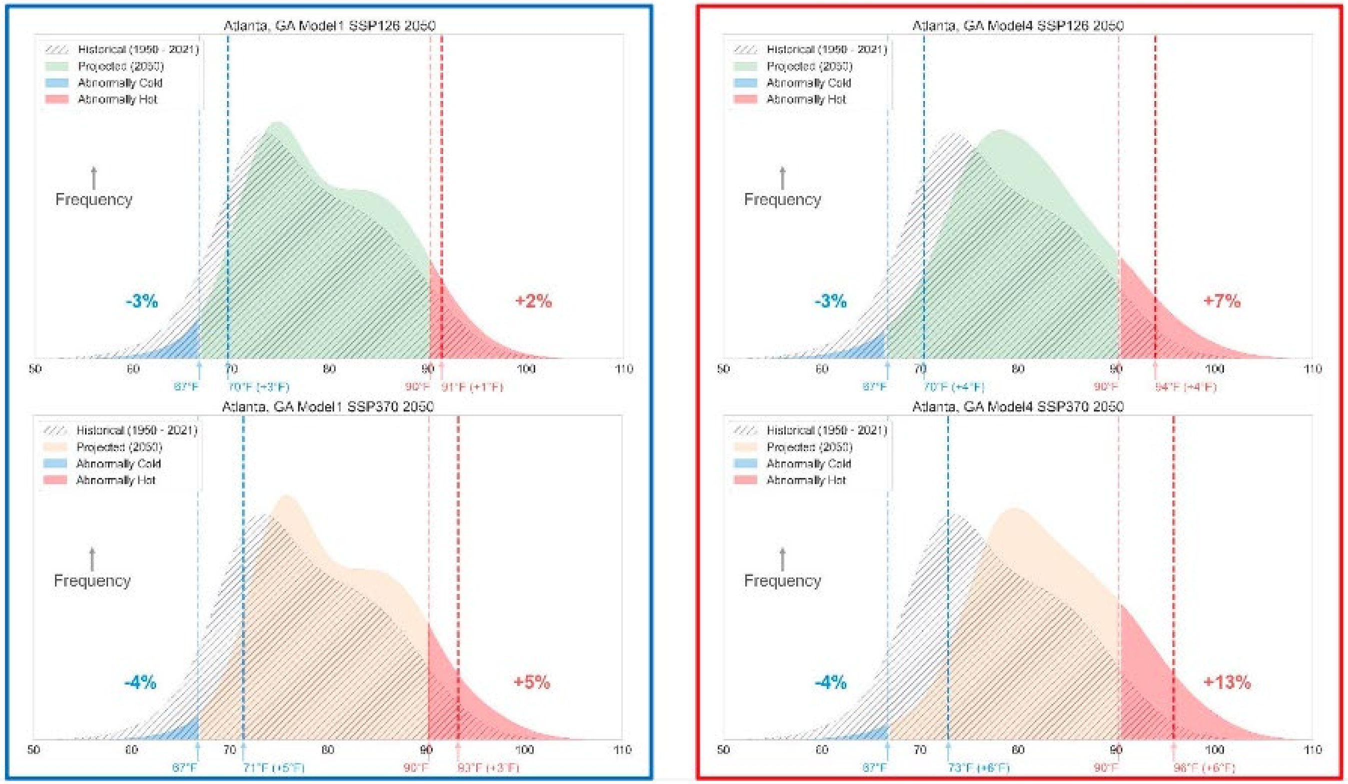


Figure1: (left) Temperature anomalies during the 2021 Pacific Northwest heatwave (NASA 2021) and (right) area-average temperatures in 2021 (red) compared to the period 1950-2020 (grey dots) in ERA5 reanalysis (plot by Erich Fischer).

Key Gaps and Needs in Distribution Planning Load Forecasting

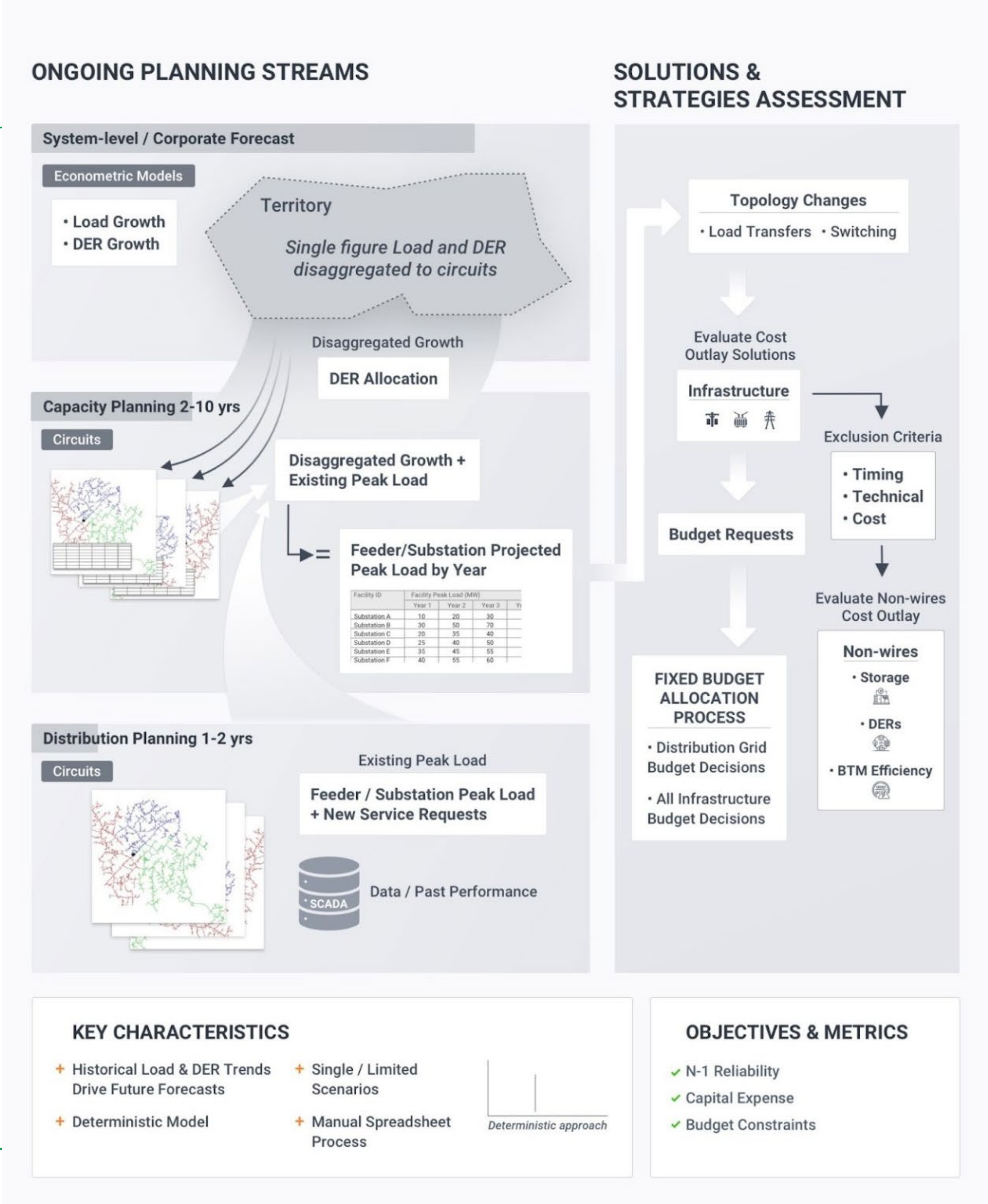
- **Statistical load forecasting based on historical load and weather events will miss extreme weather events**
  - Hourly climate model projections are currently being developed

Colder Model



Warmer Model

Source: EPRI



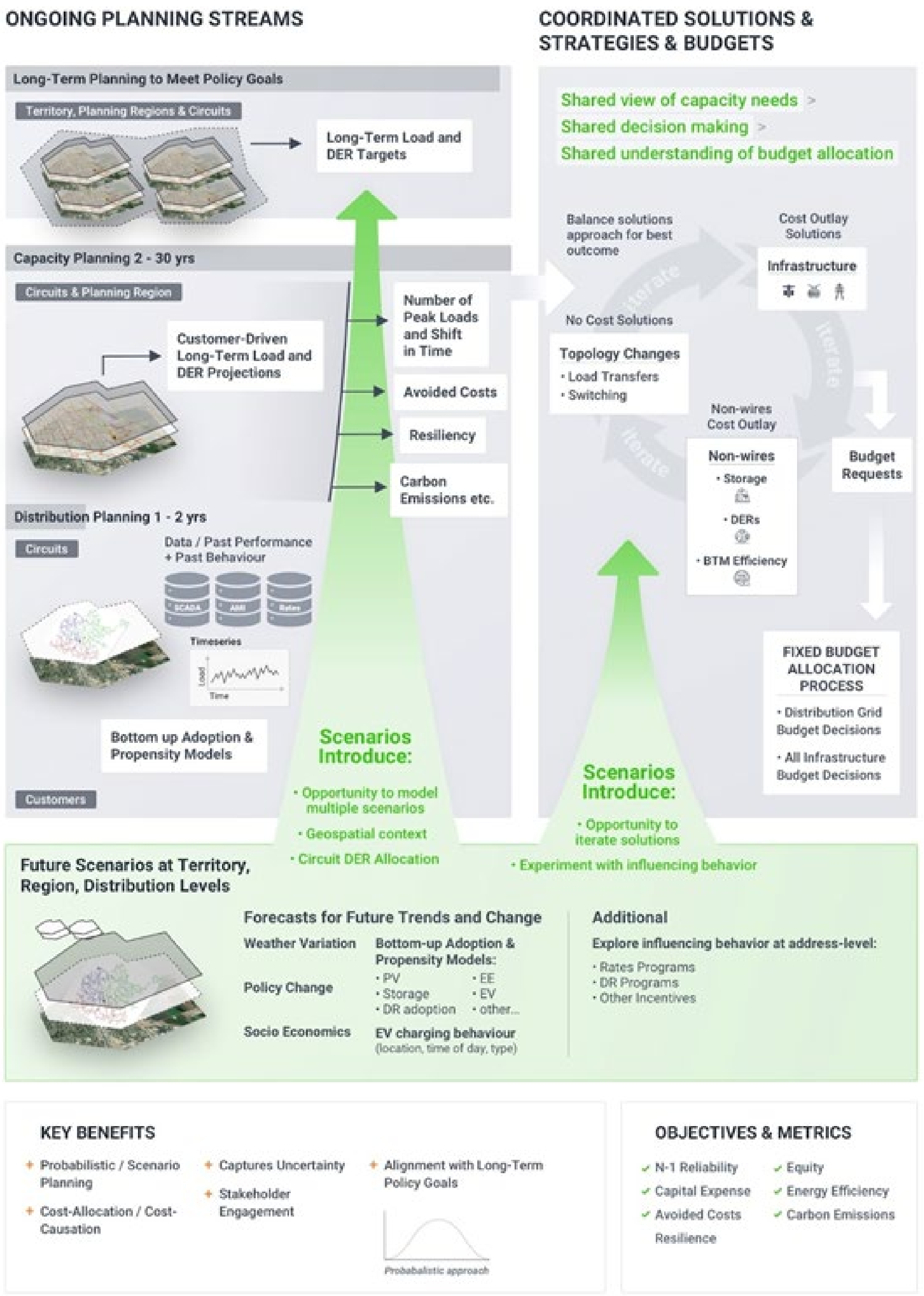
Existing Load Forecasting for Capacity Planning

- Capacity planning mismatch with long-term changing policy goals
- Historical trends (load, weather, etc.) are used to predict the future
- Allocation/forecasts not aligned with electrical infrastructure and meters

Source: NREL/Kevala

Future Load Forecasting for Capacity Planning

- High spatial and temporal resolution for load and DER forecasting
- Longer term forecast
- Scenario and probabilistic methods
- Include climate change models and extreme weather events



Source: NREL/Kevala

Questions to Ask

- Does **distribution planning coordinate** with or take inputs from the **load forecasting department**?
- Do you forecast **peak load** or some form of **timeseries**?
- What **DERs** are **explicitly forecasted** and modeled in your distribution planning forecast?
- What **weather data** is used in your distribution planning load forecast? Does it include the **effects of climate change**?
- Do you perform a **single point load forecast**, or do you consider a range of **scenarios** and **probabilistic methods** to determine infrastructure needs?

Questions?

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