A Generative Framework of Creating Synthetic Residential Demand Response Data

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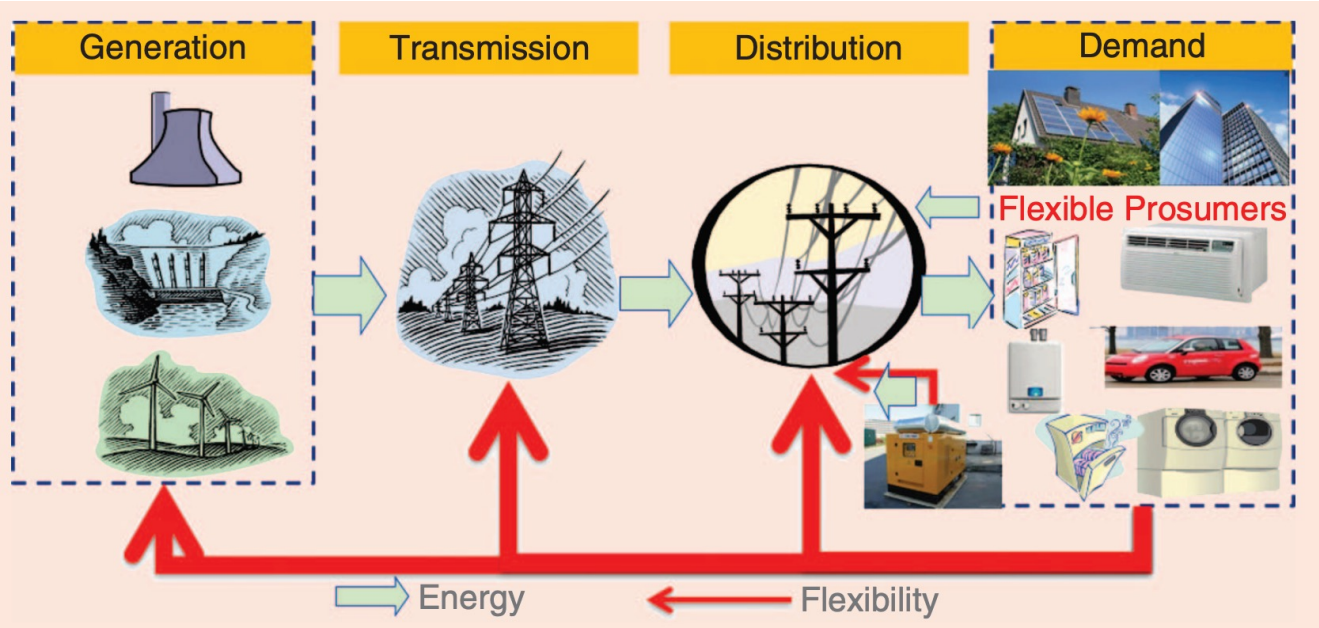
Lee, Shi, Xie, Working Paper 2023

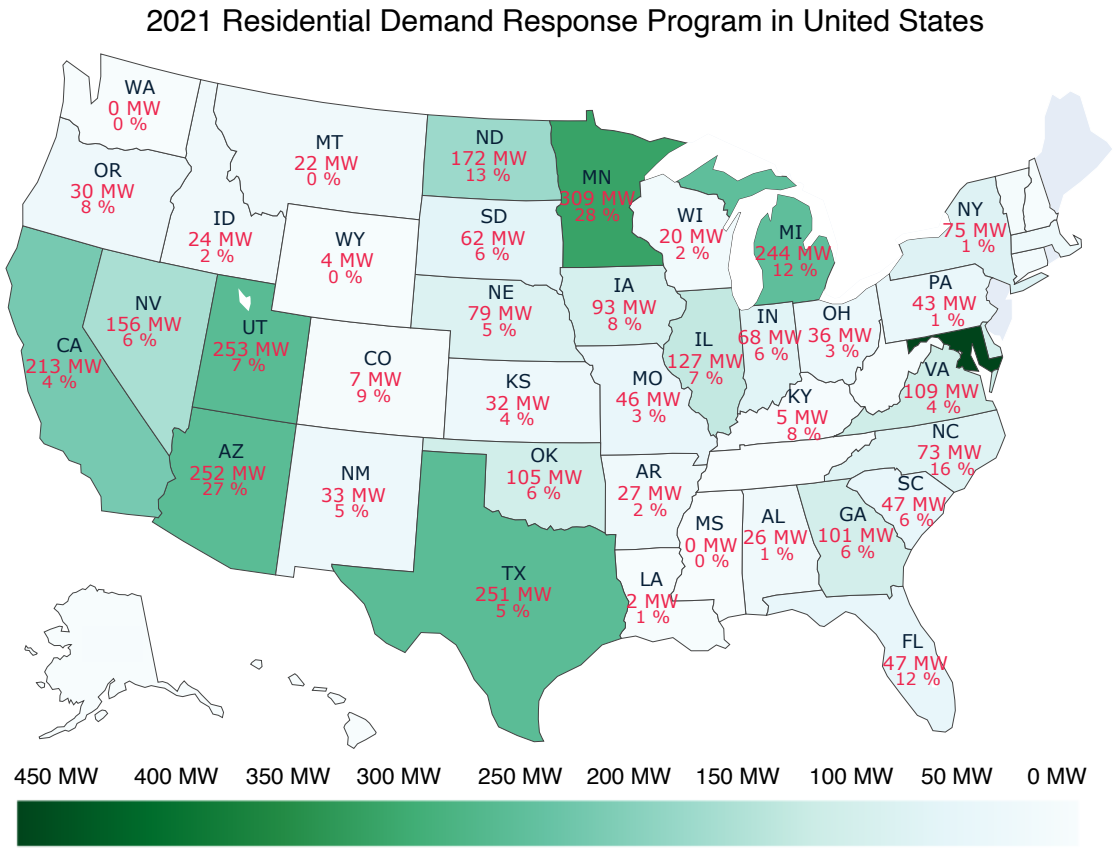
Motivation: Demand Response (DR)



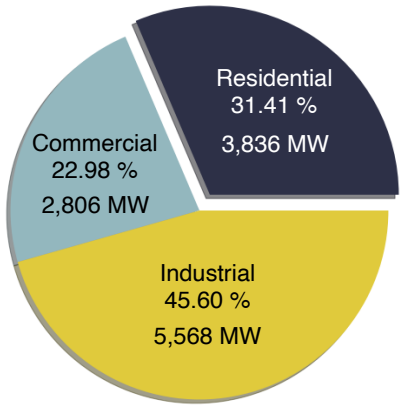
- Flexibility such as demand response (DR) enables higher penetration of renewable resources
- Economic efficiency

Strbac, Goran, et al. "Cost-effective decarbonization in a decentralized market: The benefits of using flexible technologies and resources." *IEEE Power and Energy Magazine* 17.2 (2019): 25-36.

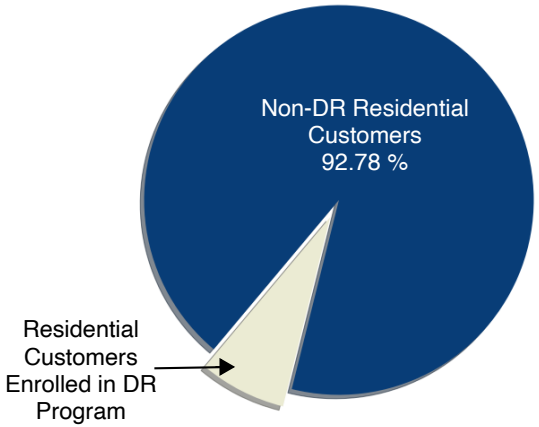
Today's Demand Response in U.S.



Total U.S. Actual Peak Demand Saving per Sector



Total U.S. Percentage of Customers Enrolled in DR



- Residential DR largely remains untapped and has huge potential

Data source is from U.S Energy Information Administration (EIA)

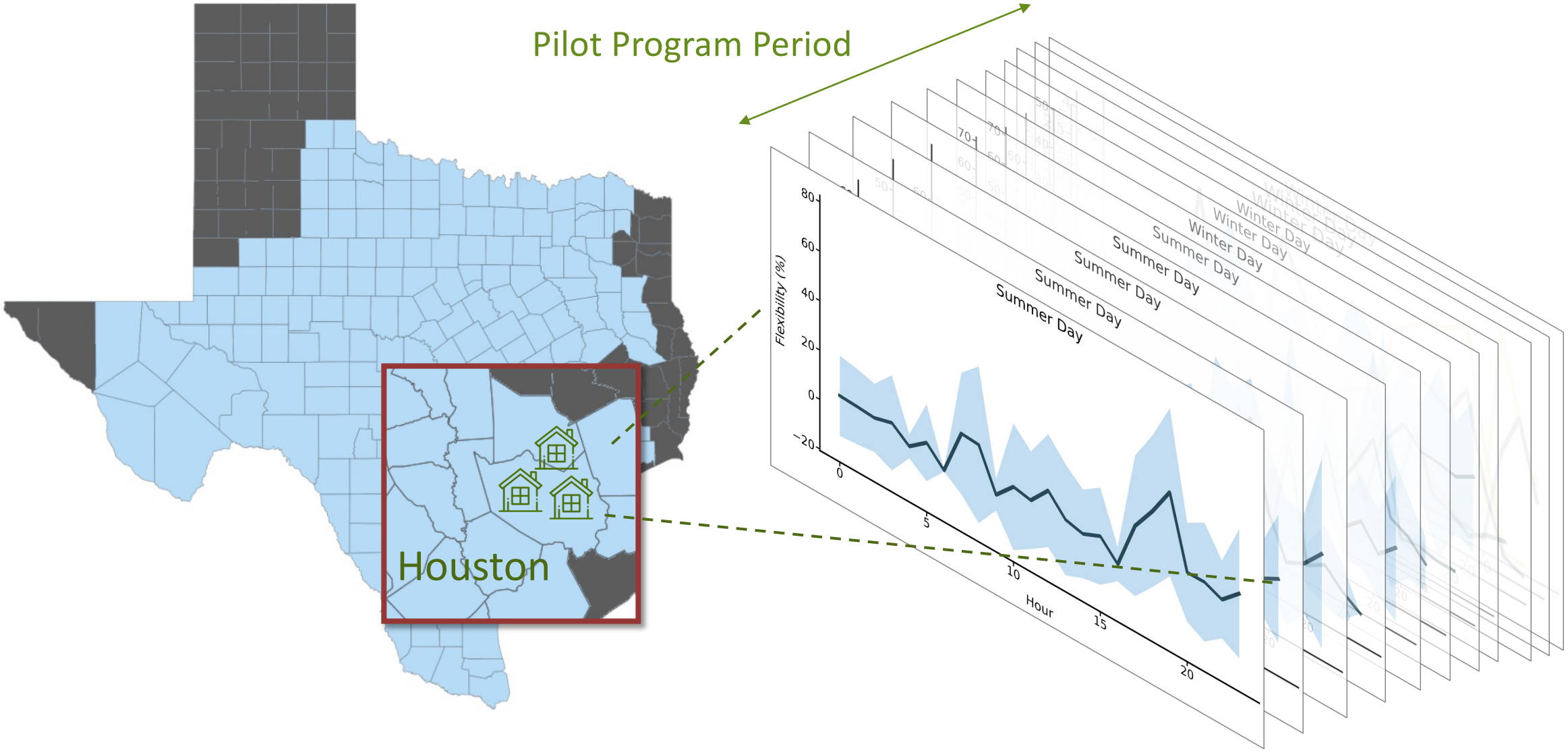
Past Residential DR Pilots

- There are numerous DR Pilot programs
  - California's Statewide Pricing Pilot (2003-2004, 2016-2017)
  - Low Carbon London (2011-2014)
  - EnergyCoupon (2016 Summer, 2017 Summer)
  - …

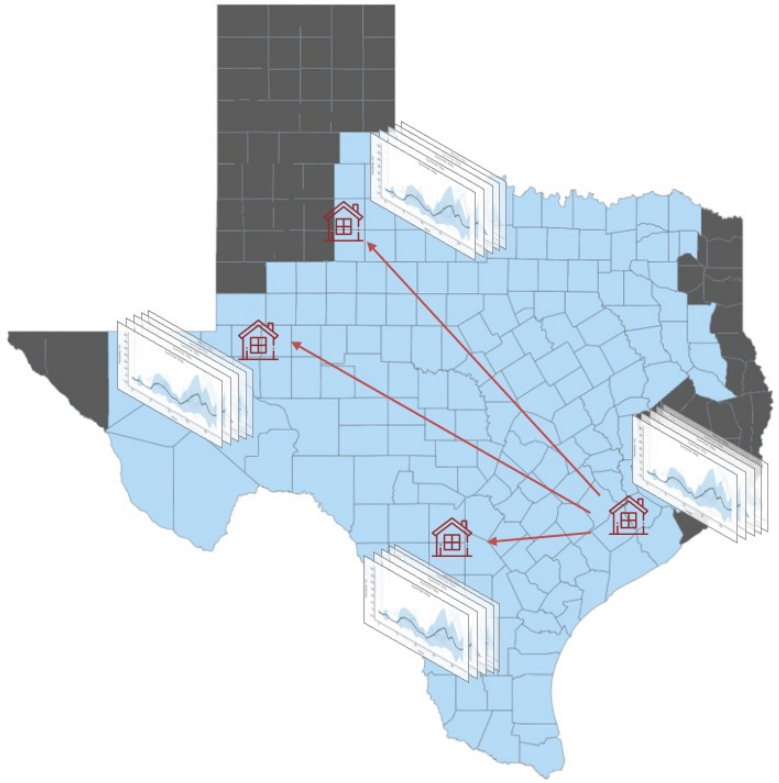
- Residential DR data is private and inaccessible
- Can we scale up existing data (small and limited) and make a prediction?

Bainan Xia, et al. "EnergyCoupon: A Case Study on Incentive-based Demand Response in Smart Grid", *ACM e-Energy* 2017

Question and Scope of This Work



Question and Scope of This Work



- What does it mean by Creating Synthetic Residential DR data?
- Is it useful to generate statistically identical DR customer?

- Can we infer/predict what non-DR customers would do?
- The answer to the question has no ground truth because it has not happened, i.e., the answer is synthetic or counterfactual

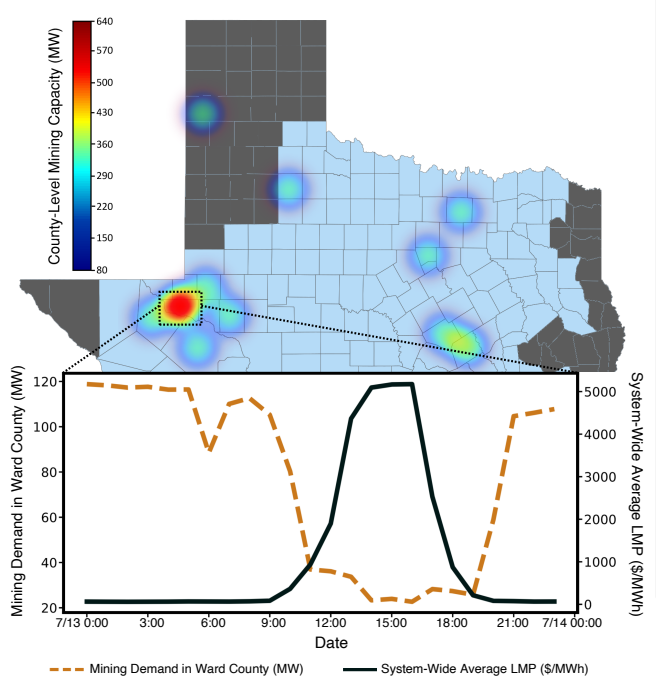
Challenges in DR

- DR depends on multiple factors
  - Usage, Duration, Weather
  - Information and Time provided, and other Externalities
  - Residential DR: Individual Characteristics
- Responsiveness is conditional to multiple factors

- Two notable DR examples: Bitcoin Mining Facilities, Data Centers
  - Rational Inattention (RI): Consider Power Flow vs Network Flow
  - RI: Inability to process all information, but process pieces of information

Rational Inattention on Customers

- Rational inattention plays less on mining facilities



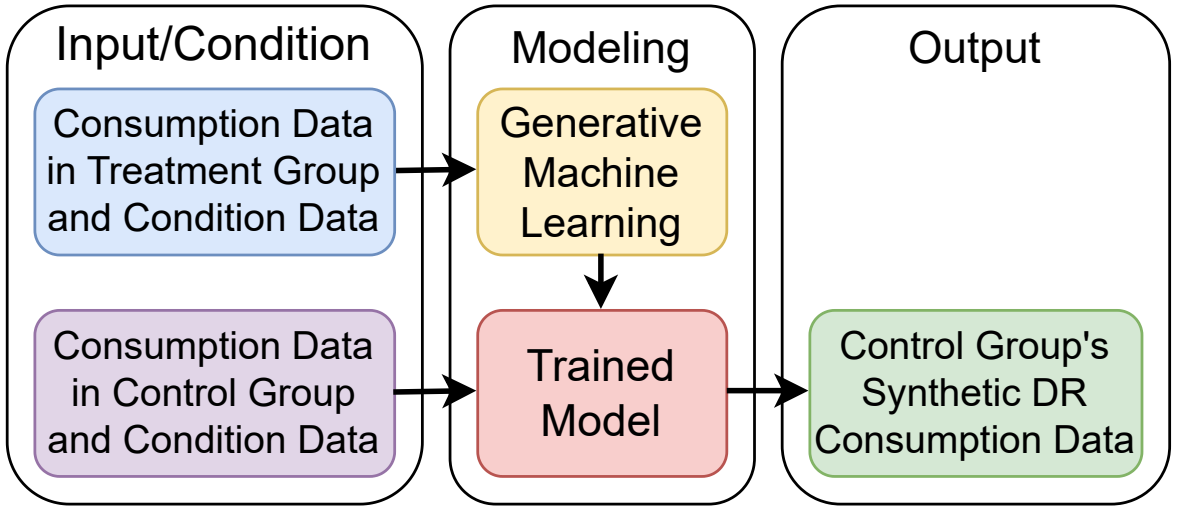
- Can residential customers do the same as mining facilities?
- Do they have economic incentives to do the same as mining facilities?

- RI is more significant on residential sector

Menati, Ali, et al. "High resolution modeling and analysis of cryptocurrency mining's impact on power grids: Carbon footprint, reliability, and electricity price." Advances in Applied Energy 10 (2023): 100136.

Proposition: Generative Framework

1) Input/Conditions: DR customer data, multiple factors
2) Modeling: Train a generative model for conditional responsiveness of DR customers
   - Conditional to details of DR (price, duration, etc), weather, etc
3) Output: Generate Synthetic DR data
   - Assume non-DR customers have the same conditional responsiveness



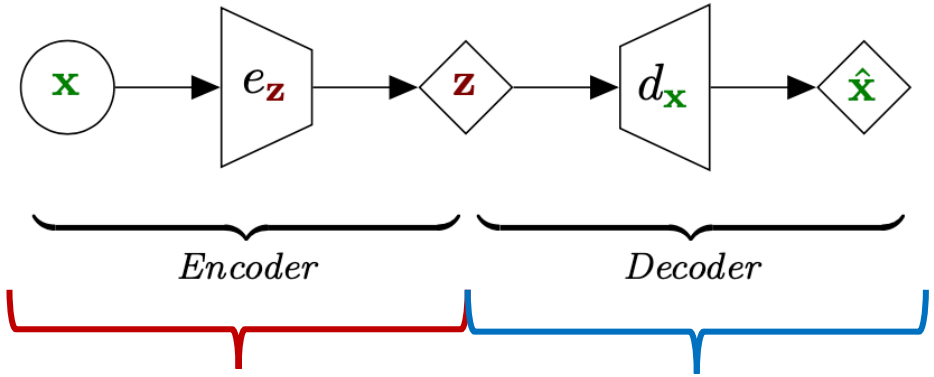
Inputs/Conditions to the Framework

- Input (time series): responsiveness = $\frac{Consumption\ during\ DR}{Baseline\ Consumption}$
- Conditions (categorical): Responsiveness, Temperature, Price
  - Responsiveness: High, Medium, Low
  - Temperature: High, Medium, Low (peak-hour annual percentile)
  - Price: High, Medium, Low
- Conditions are arbitrary in computer vision and natural language processing
  - They are limited to categorical values in this work (Why?)

Generative Machine Learning

- Suppose responsiveness x_{data} is drawn from $\mathbb{P}_{data}(x)$
- Generative models aim to learn $\mathbb{P}_{data}(x)$ and produce $\hat{x}$

- Two popular generative models
  - Variational Autoencoder (VAE)
  - Generative Adversarial Networks (GANs)



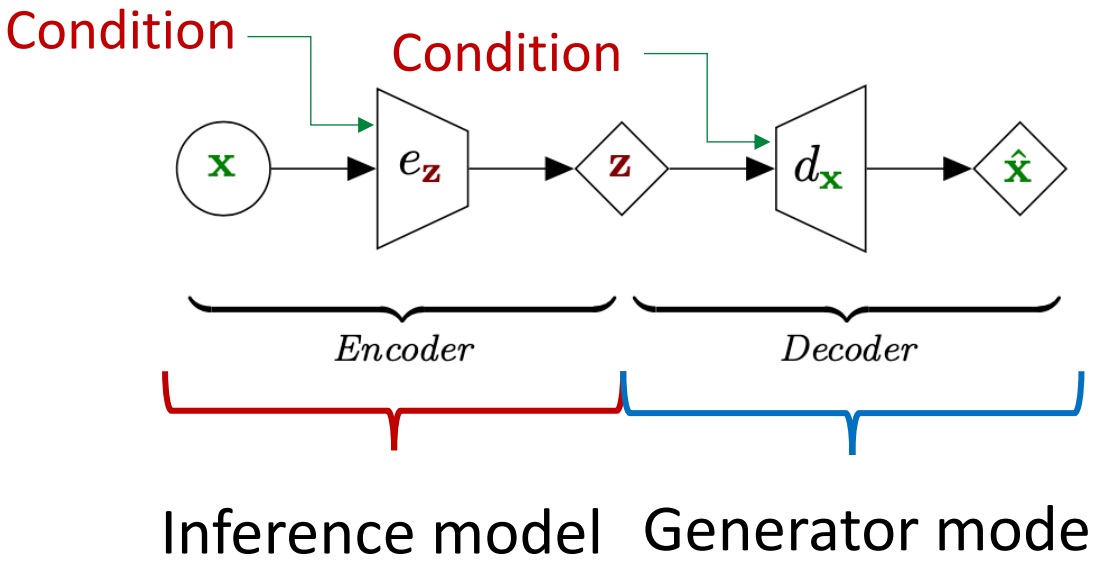
- Input: x_{data} and output: $\hat{x}_{data}$
  - x_{data} and $\hat{x}_{data}$ are statistically identical

- What does $\hat{x}_{data}$ mean in residential sector?

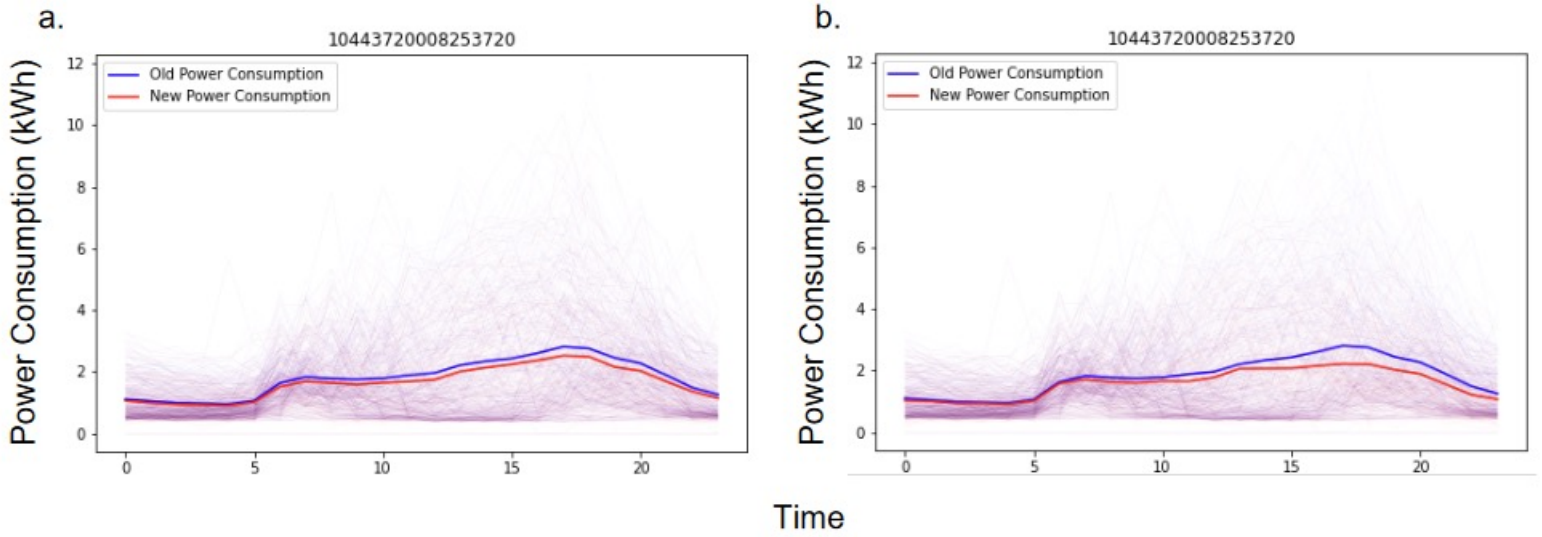
G, Laurent et al. “Dynamical variational autoencoders: A comprehensive review”, Foundations and Trends® in Machine Learning, 2021

Generative Machine Learning

- DR is conditional to price, weather, duration, information, etc
  - Conditional VAE and Conditional GANs

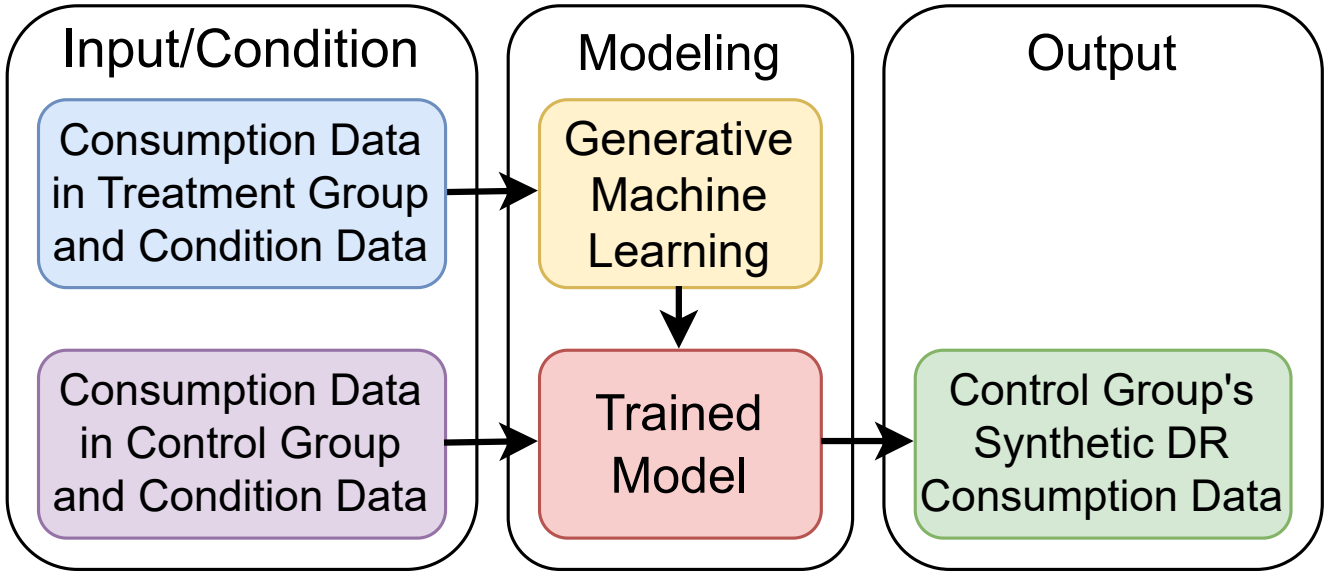


Output: Conditional Synthetic Data



- Inputs (time series): Responsiveness
- Conditions (categorical): Responsiveness, Temperature, Price
- Generated Data: Conditional Responsiveness

To sum up: Generative Framework



- Learn conditional responsiveness from existing DR data
- Generate statistically identical responsiveness (not consumption)
  - Conditioned on details of DR (User can choose conditions)
- Apply conditional responsiveness to non-DR customers

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Concluding Remarks

- We developed a generative framework for residential DR
  - Learn responsiveness from existing DR data
  - Apply conditional responsiveness to non-DR customers

- Residential DR is still data-hungry - size of original data is still limited compared to applications such as computer vision and natural language processing
  - In these two applications, data is almost infinite
  - Conditions could be as large as input sizes in these two applications
  - In this study, conditions are categorical (compressed) due to lack of data