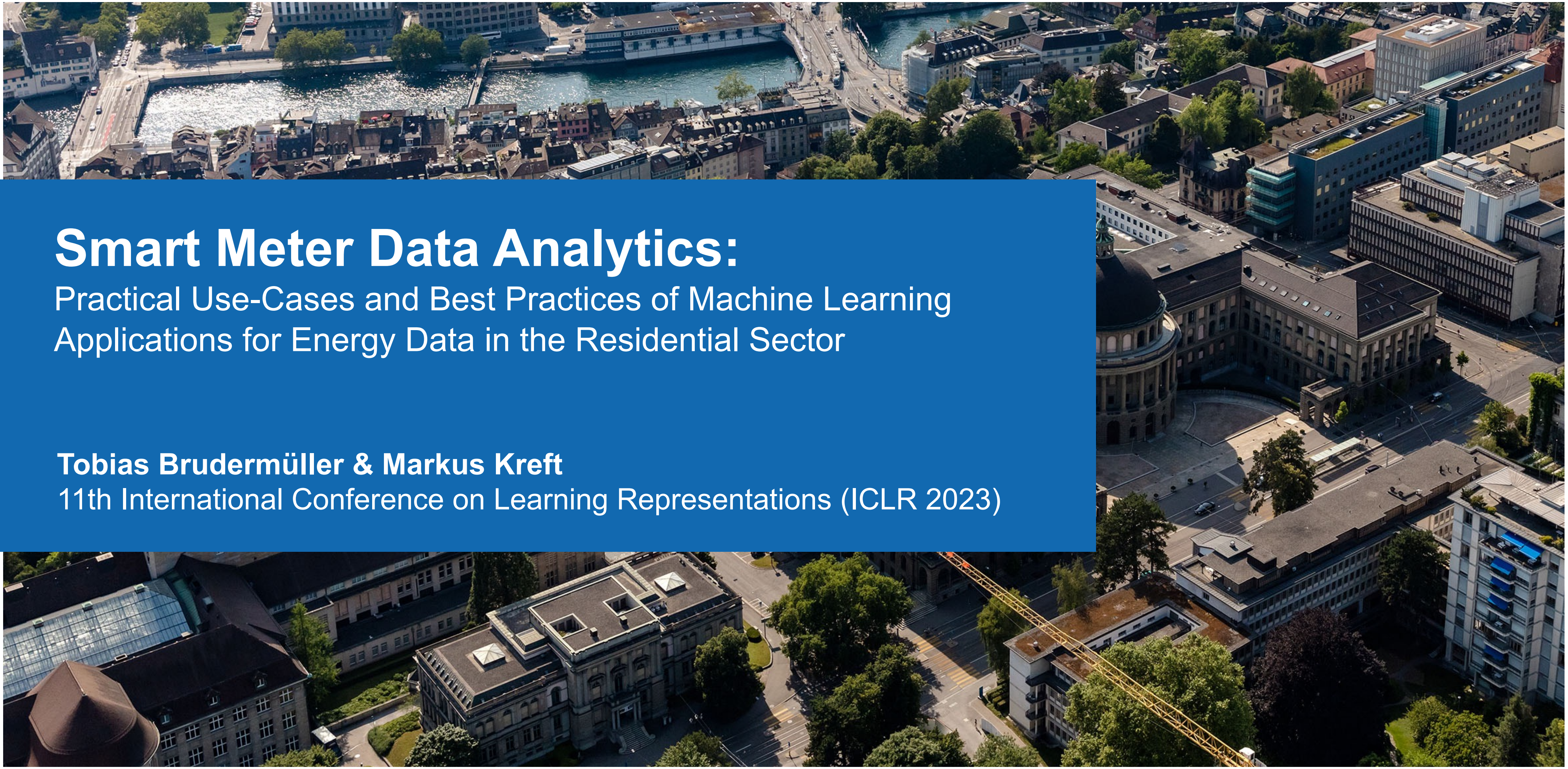
ETH zürich

BITS TO ENERGY LAB



Smart Meter Data Analytics:

Practical Use-Cases and Best Practices of Machine Learning Applications for Energy Data in the Residential Sector

Tobias Brudermüller & Markus Kreft

11th International Conference on Learning Representations (ICLR 2023)

The Bits to Energy Lab

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Otto-Friedrich-Universität Bamberg

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

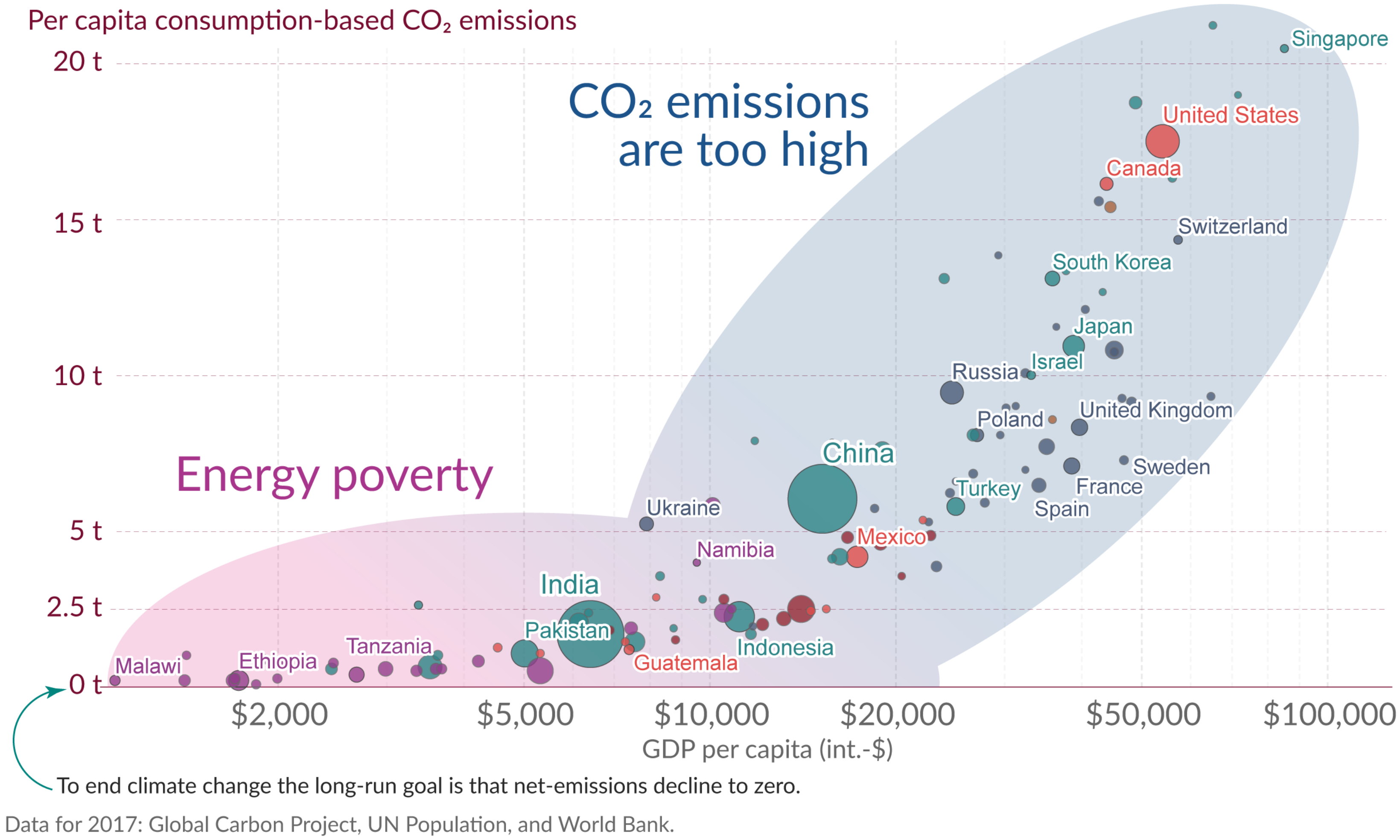
University of St.Gallen

- **Team:** ~20 researchers with different professional backgrounds at 4 institutions (Germany & Switzerland)
- **Goal:** Leverage technology to foster sustainability
- **Focus:** Machine learning, energy applications, and digital behavioral interventions
- **Web:** www.bitstoenergy.com / www.im.ethz.ch

United Nations - Sustainable Development Goals (SDGs)

Source: United Nations

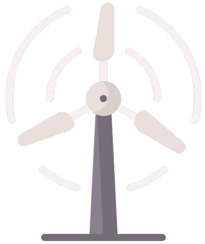
Reality: CO_2 Emissions per Capita vs. GDP per Capita



Source: Our World in Data (2020): https://ourworldindata.org/worlds-energy-problem - Last accessed: 2023 April 05

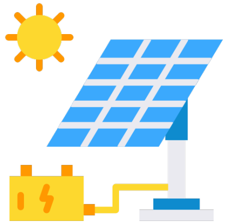
Energy System - Electrification & Transformation (1)

Generation



+ 55 %

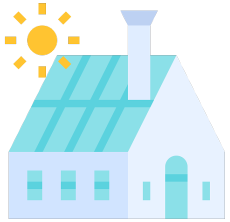
Wind electricity generation (2021 vs. 2020) [1]



+ 22 %

Solar PV generation (2021 vs. 2020) [2]

Distribution



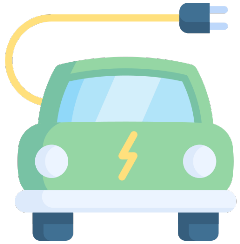
70 %

Of power transformers & transmission lines in the U.S. at least 25 years old (2015)

+ 88 %

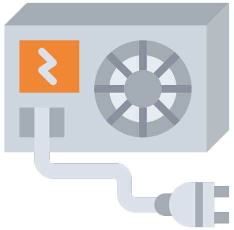
Global annual grid-scale battery storage additions (2021 vs. 2020) [4]

Consumption



13 %

Of new cars sold are electric (2022) [5]



+ 11 %

Global annual growth of heat pump sales (2021 & 2022) [6]

[1] IEA (2022) https://www.iea.org/reports/wind-electricity, Last accessed: 2023 April 05
[2] IEA (2000-2021) https://www.iea.org/data-and-statistics/charts/evolution-of-annual-solar-pv-installations-and-share-by-segmentation-2000-2021, Last accessed: 2023 April 05
[3] IEA (2022) https://www.iea.org/reports/unlocking-the-potential-of-distributed-energy-resources, Last accessed: 2023 April 05
[4] IEA (2016-2021) https://www.iea.org/data-and-statistics/charts/annual-grid-scale-battery-storage-additions-2016-2021, Last accessed: 2023 April 05
[5] IEA (2022) https://www.iea.org/reports/electric-vehicles, Last accessed: 2023 April 05
[6] IEA (2021-2022) https://www.iea.org/data-and-statistics/charts/annual-growth-in-sales-of-heat-pumps-in-buildings-worldwide-and-in-selected-markets-2021-and-2022, Last accessed: 2023 April 05

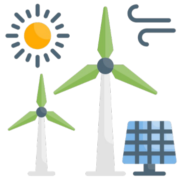
Energy System - Electrification & Transformation (2)

- Population growth
- Increasing access to electricity
- Electrification in all sectors

Higher electricity demand

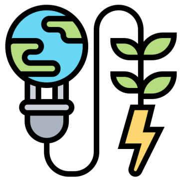
- Increasing share of renewables
- Higher degree of decentralization

Larger fluctuations in electricity production



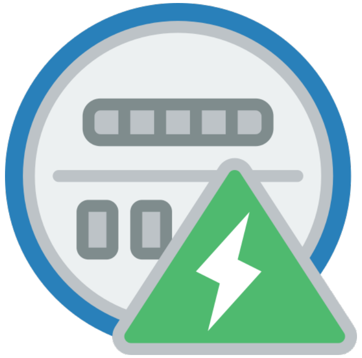
Need for ....

...smart control, energy storage, energy efficiency, etc...



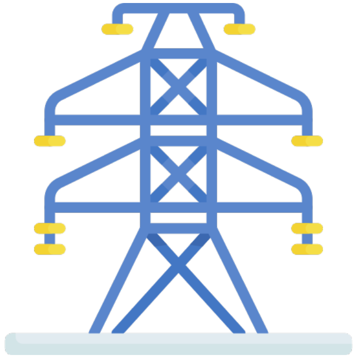
Part of Solution: The Advanced Metering Infrastructure (AMI)

Smart Electricity Meters



- High penetration, e.g.:
  - U.S.: 50% (2016) [1]
  - China, India, Japan, South Korea: 69% (2019) [2]
  - E.U.: 80% (2020-2025) [3]

Smart Grid



- Monitoring activities on the grid
- Decentralized control
- Demand response programs
- Planning & forecasting
- Dynamic tariff design
- etc.

Digital Services

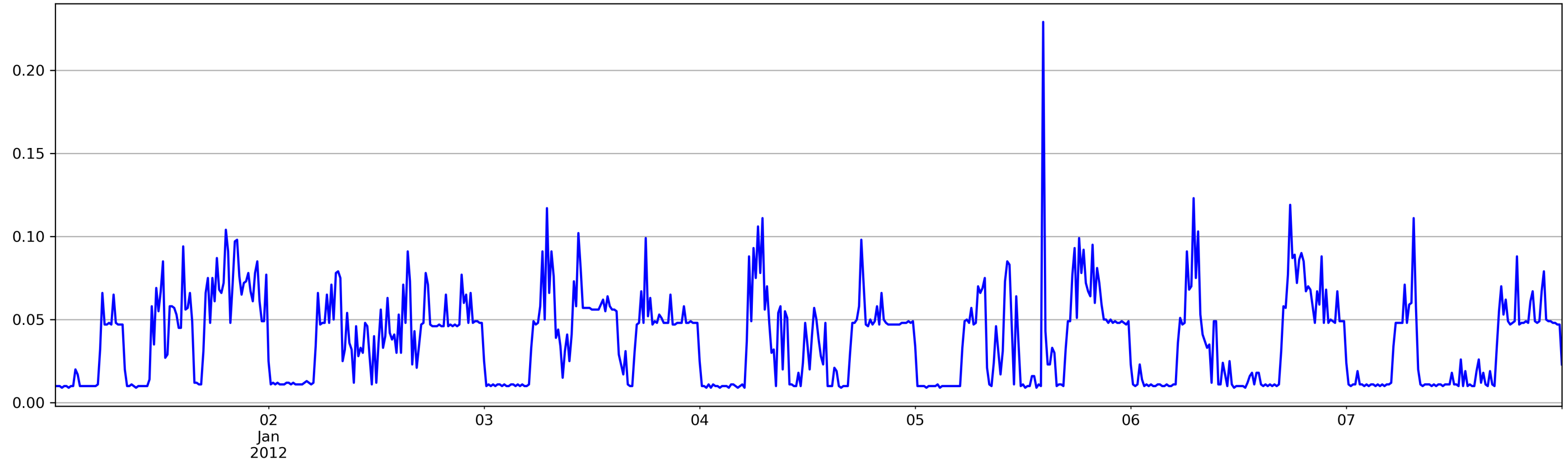
- Energy efficiency insights
- Smart buildings & retrofits
- Electric vehicles charging
- Heat pump operation
- etc.

[1] U.S. Energy Information Administration (2027) https://www.eia.gov/todayinenergy/detail.php?id=34012, Last accessed: 2023 April 06
[2] Smart Energy International (2021) https://www.smart-energy.com/industry-sectors/smart-meters/smart-electricity-meters-rollout-in-china-india-japan-and-south-korea/, Last accessed: 2023 April 06
[3] Efkarpidis, N., Geidl, M., Wache, H., Peter, M., & Adam, M. (2022). Smart Metering Applications. In Smart Metering Applications: Main Concepts and Business Models (pp. 13-124). Cham: Springer International Publishing.

Example: Smart Meter Data (SMD)

Smart Meter Data:
Time series of power or energy measurements at different resolutions (~1s to 1h)

Electrical Energy (kWh)



Time (15 min resolution)

The Goal of our Tutorial

Insights Into Energy Domain

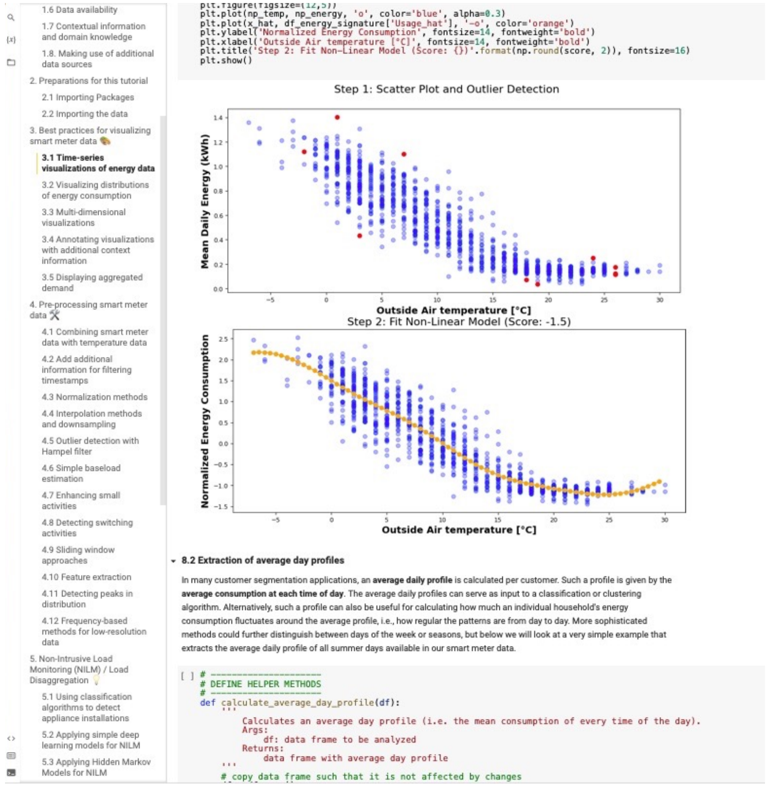
- Current trends & use-cases in energy space
- Typical & atypical energy use in residential buildings
- Value of smart meter data & smart grids

Educating About Data Analysis

- Practical, self-paced learning in a “hands-on” manner
- Applying best practices, ML & data mining to real-world energy data
- Provide starting point for analyzing own energy data

Creating Awareness

- For energy efficiency, own energy use and climate change
- For novel data sets, methods, and applications in ML community
- For necessity for exchange between research communities



Topics Covered (1)

Introduction to smart meter data
1. What is smart meter data?
2. Relevance for tackling climate change
3. Chances and limitations
4. Power vs. energy measurements
5. Data resolution
6. Data availability
7. Contextual information and domain knowledge
8. Making use of additional data sources

Best practices for visualizing smart meter data
1. Time-series visualizations of energy data
2. Visualizing distributions of energy consumption
3. Multi-dimensional visualizations
4. Annotating visualizations with additional context information
5. Displaying aggregated demand

Pre-processing smart meter data
1. Combining smart meter data with temperature data
2. Add additional information for filtering timestamps
3. Normalization methods
4. Interpolation methods and downsampling
5. Outlier detection with Hampel filter
6. Simple baseload estimation
7. Enhancing small activities
8. Detecting switching activities
9. Sliding window approaches
10. Feature extraction
11. Detecting peaks in distribution
12. Frequency-based methods for low-resolution data

Topics Covered (2)

Non-Intrusive Load Monitoring (NILM)

1. Using classification algorithms to detect appliance installations
2. Applying simple deep learning models for NILM
3. Applying Hidden Markov Models for NILM
4. Correctly evaluating NILM approaches
5. Rule-based heuristics for pattern isolations

Anomaly Detection

1. Introduction to online vs. offline change point detection
2. Finding state changes with offline change point detection
3. Finding anomalies with sliding window
4. Applying Symbolic Aggregate ApproXimation
5. Finding discords and motifs

Flexibility Estimation

1. Estimating load shifting potential of disaggregated appliances

Load Forecasting

1. Brief and short introduction

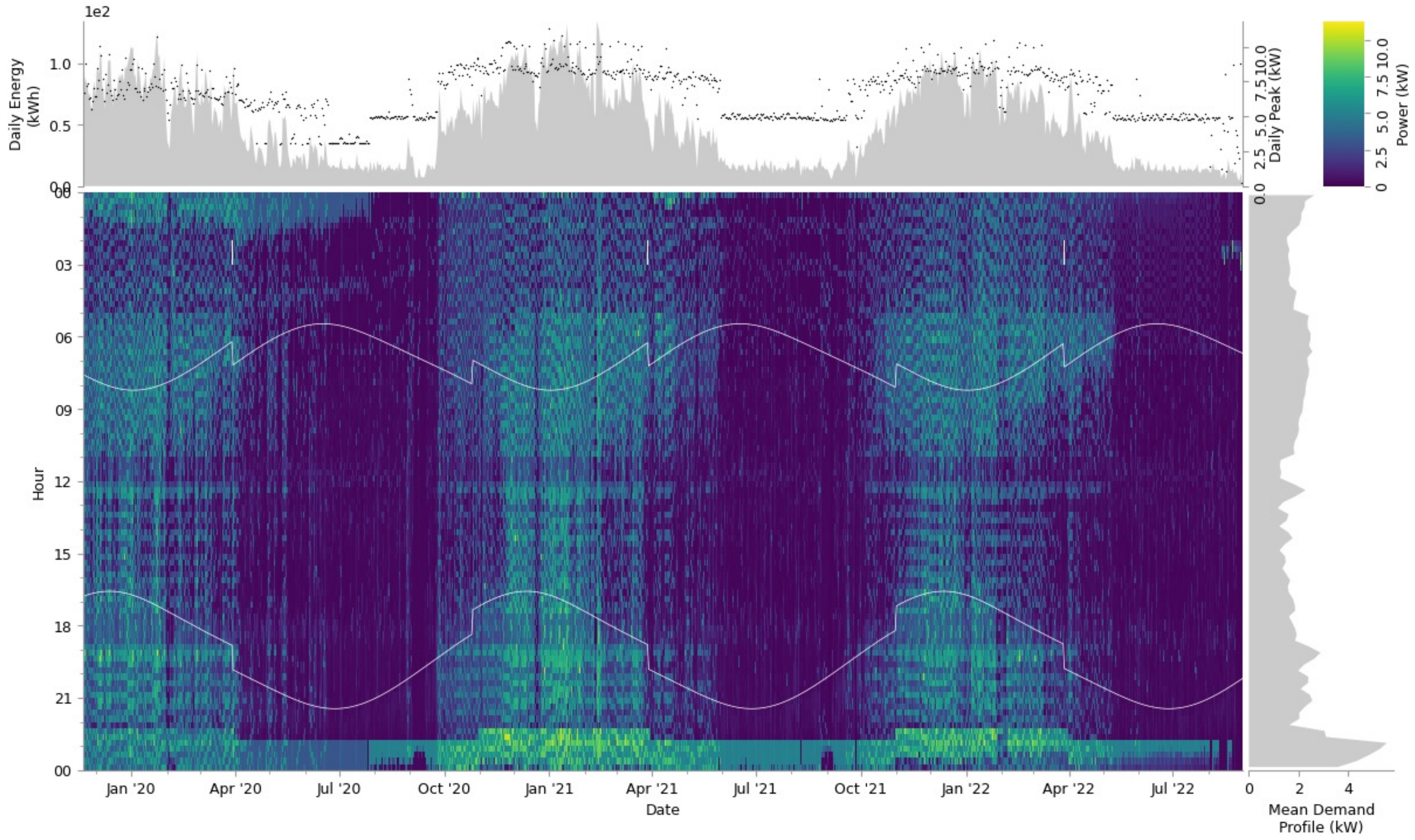
Customer segmentation

1. Extraction of energy signatures through regression
2. Extraction of average day profiles
3. Applying clustering algorithms

Additional Resources

1. Data Sets
2. Software Packages
3. Other

Example: Visualization of Energy Consumption



Visualization as Heat Map:
Observe regular energy consumption patterns over time

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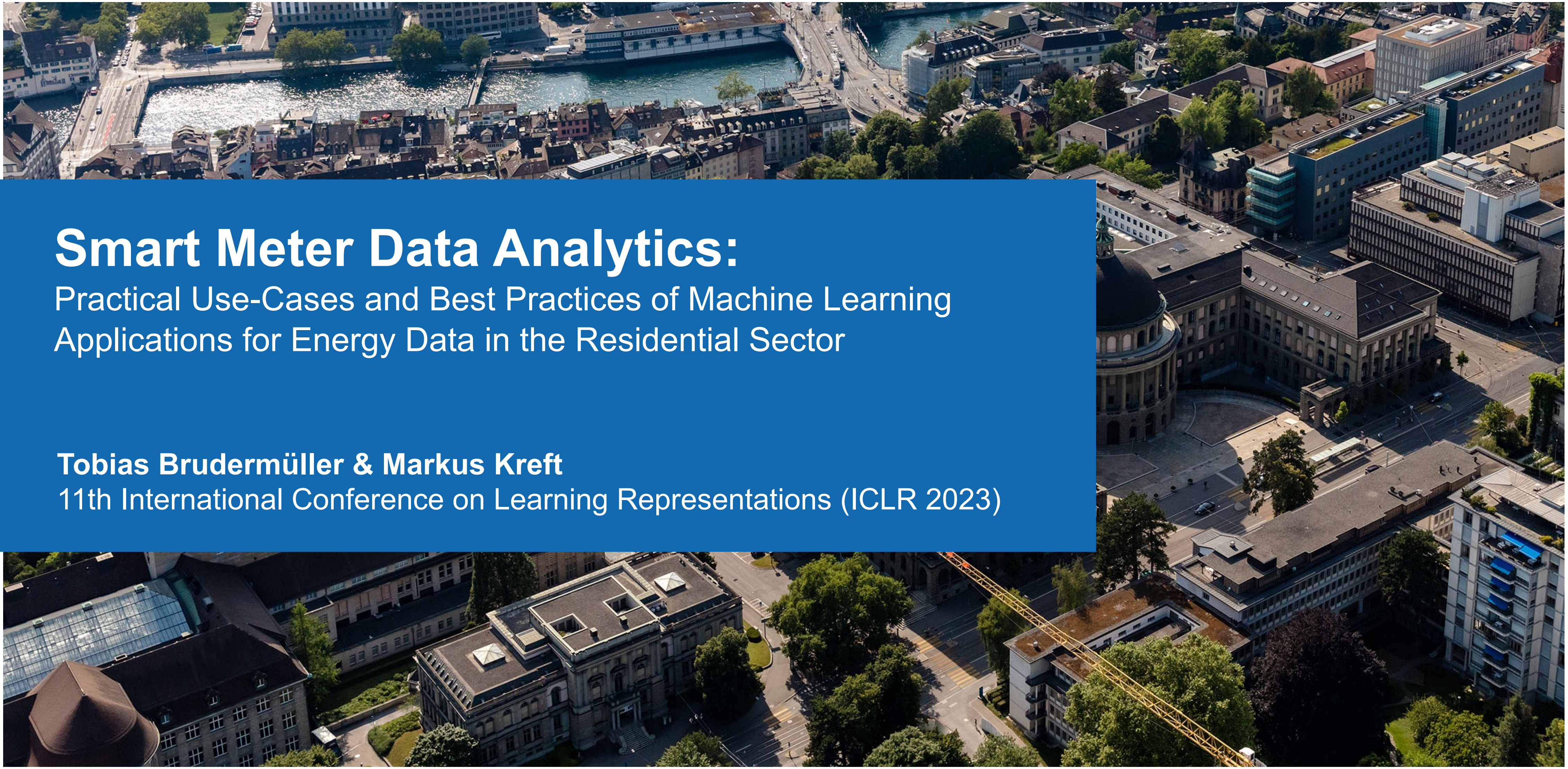

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