

# Non-Intrusive Load Disaggregation for Smart Meters

## What It's About: Exploring Non-Intrusive Load Disaggregation

As energy utilities adopt smart metering, the ability to extract granular insights from consumption data has expanded significantly. For a major electricity distribution company in the Middle East, understanding how individual appliances contribute to overall energy consumption at the consumer level has become a key priority. Non-Intrusive Load Disaggregation (NILM) offers an innovative solution to achieve this without the need for additional hardware installations.

This project utilizes the company's existing smart meter infrastructure to break down total energy consumption into appliance-level insights. By analyzing patterns in voltage, current, and harmonic profiles, NILM accurately identifies the energy contribution of specific appliances. This data-driven approach not only advances the company's operational objectives but also empowers consumers with actionable insights to optimize their energy usage.

## How It Was Done: The Journey from Data to Insights

In collaboration with the utility company, we leveraged advanced signal processing, Non-Intrusive Load Monitoring (NILM), and machine learning to redefine energy consumption analysis. This cutting-edge solution disaggregates total energy usage into appliance-level insights without requiring additional hardware, enabling greater visibility into consumption patterns and inefficiencies.

At the core of this innovation is signal processing, where raw electrical data is analyzed to detect frequency variations, transient changes, and harmonic distortions. These insights allow the system to accurately differentiate between appliances, providing both utilities and consumers with valuable data. By integrating AI-driven analytics, the company enhances grid management while empowering consumers to optimize their energy use, driving efficiency and sustainability.

## Frequency Analysis

- By decomposing the electrical signal into its frequency components, we identified unique appliance characteristics—such as the cycling patterns of HVAC systems or the steady consumption of entertainment devices.

## Transient Detection

- Momentary power changes, such as when an appliance is switched on or off, were captured to precisely detect usage events.

## Harmonic Distortions:

- Subtle distortions in the electrical signal helped distinguish appliances with similar consumption profiles.

This signal processing layer powered the NILM engine, providing a robust and accurate foundation for energy disaggregation.

Non-Intrusive Load Monitoring (NILM) enabled the decomposition of total energy consumption into appliance-level insights—without the need for invasive hardware. By analyzing historical and real-time data, NILM identified unique appliance signatures based on power cycles, load shapes, and temporal usage patterns.

## The AI/ML models classified consumption into five key categories:

- HVAC:** High-frequency cycles reflecting heating and cooling patterns.
- Cooking:** Short bursts of power during meal preparation.
- Cleaning:** Intermittent spikes from devices like dishwashers and washing machines.
- Entertainment:** Steady yet fluctuating usage of TVs, audio systems, and gaming devices.
- Others:** Miscellaneous loads identified through residual analysis.

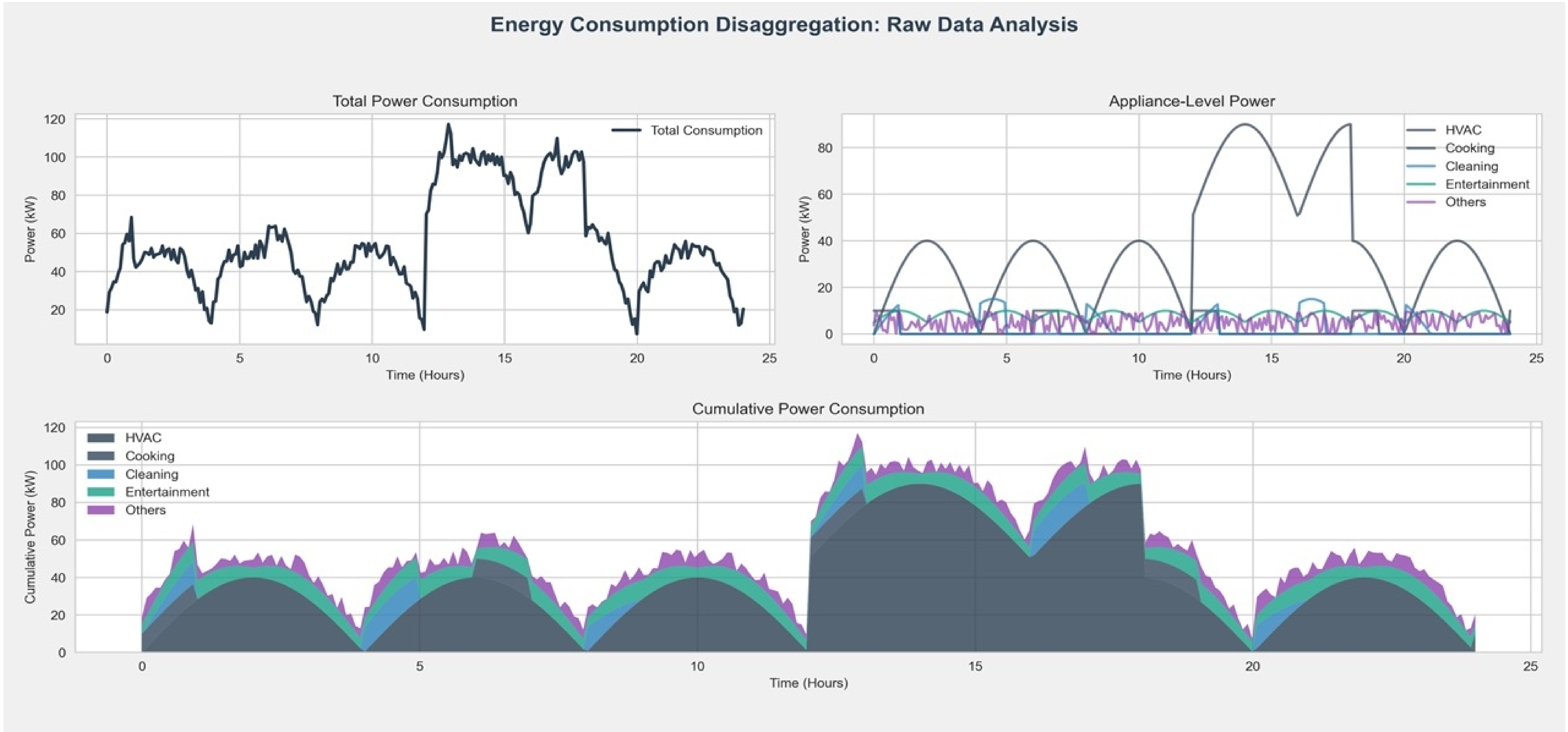
## Impresa Solutions:

- Impresa Insights Data Platform
- Energy Disaggregation

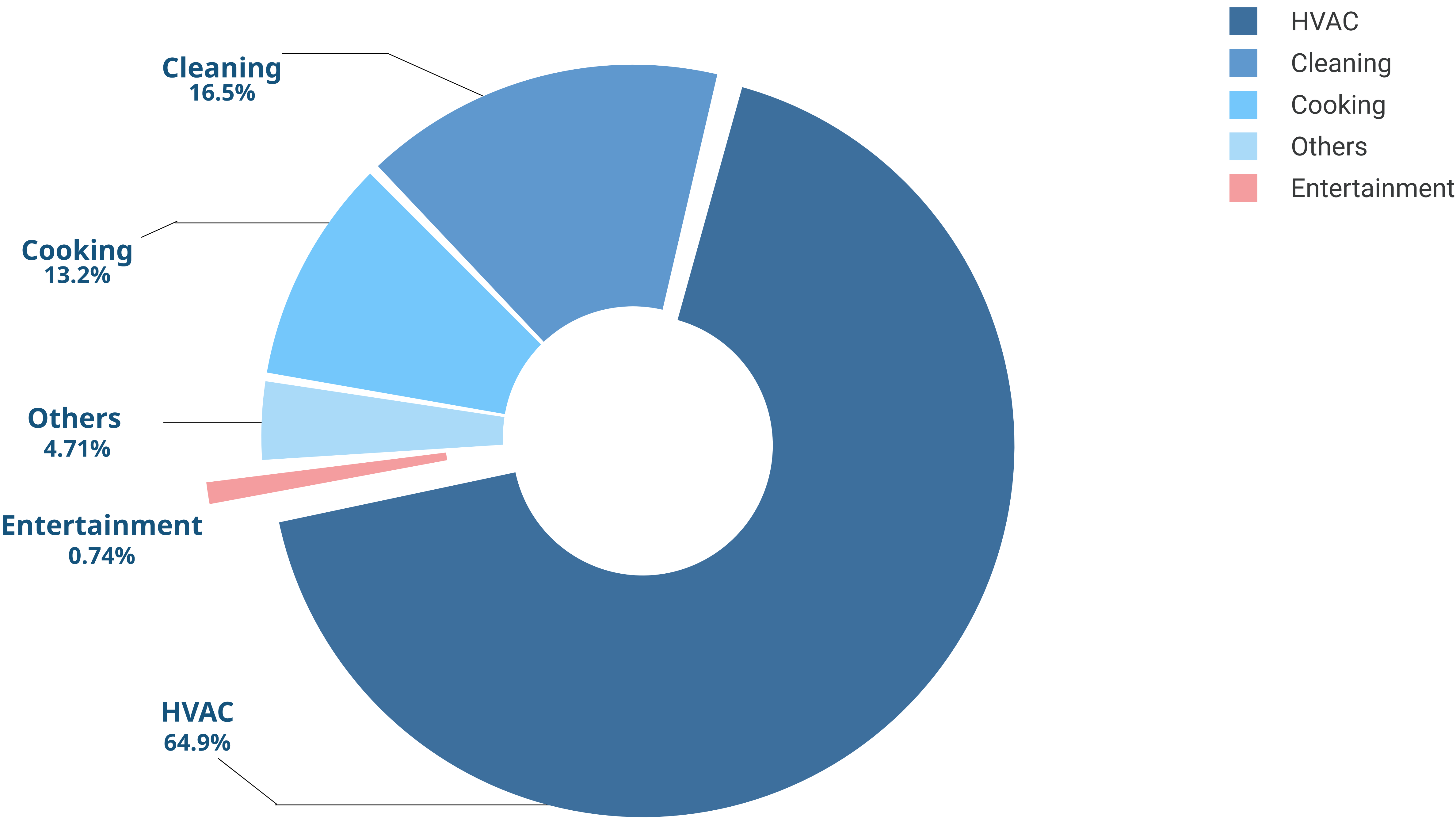


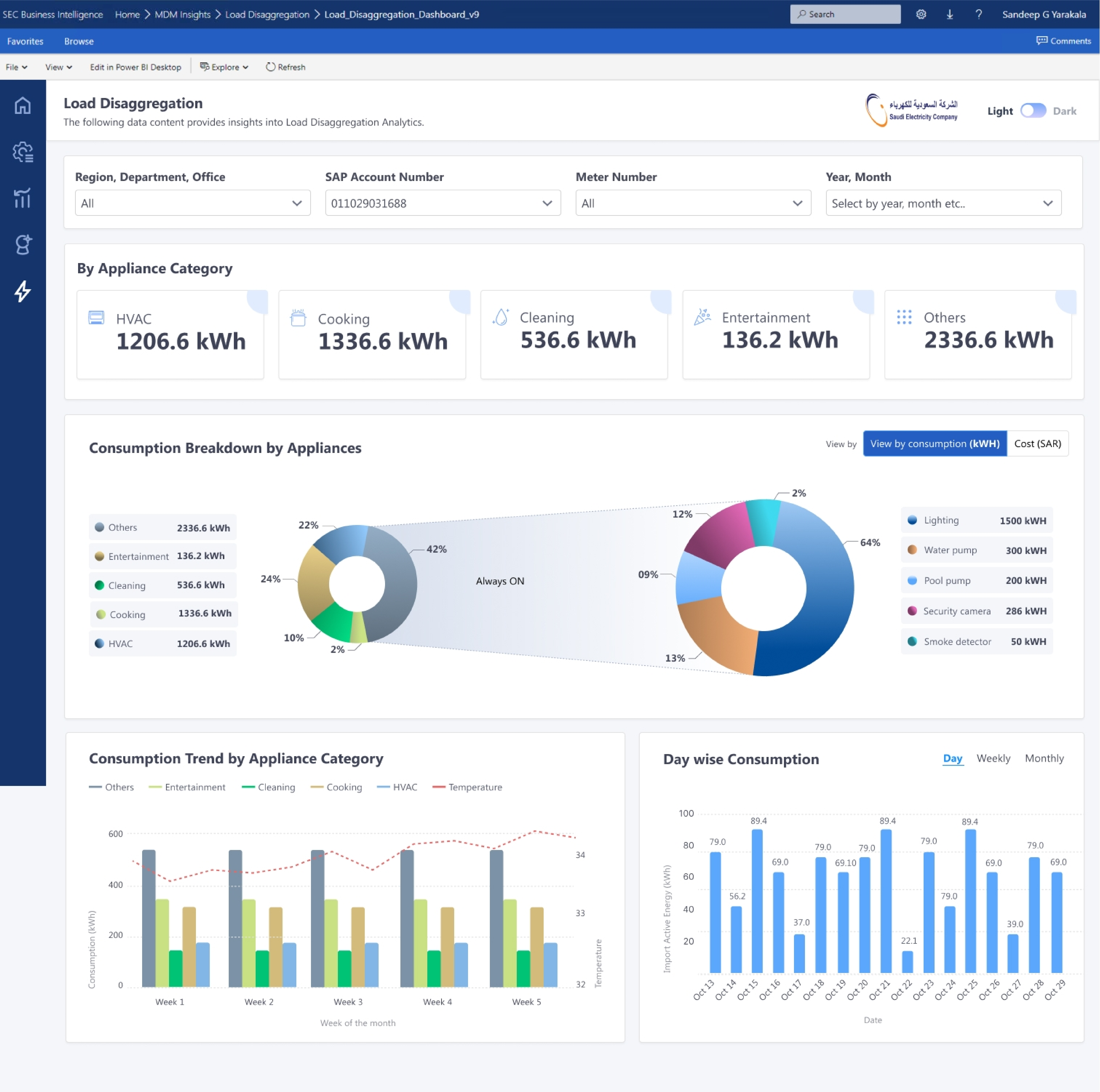
- The AI/ML layer leveraged signal processing outputs and deep learning to enhance accuracy and adaptability.**
- **Feature Engineering:** Advanced features such as peak load trends, weather-driven usage patterns, and appliance runtime were extracted to enhance model inputs.
  - **Model Training and Validation:** Historical data spanning several months was used to train the models, validated against real-world data to ensure adaptability.

- **Adaptive Learning:** The system evolved dynamically by incorporating feedback loops from real-world data, ensuring it stayed relevant in the face of changing consumer behaviours.
- The insights generated by the system were visualized on interactive dashboards within the Impresa Insights platform. Operational teams gained a granular view of energy usage, while consumers received tailored predictions and reports integrated seamlessly through APIs into the company’s customer-facing systems.



**Consumption Distribution by Appliance Category**





How It Benefitted the company?  
Strengthening GIS Accuracy and Utility Operations

The benefits of the NILM project extend across the company’s operational landscape and its customer base. For the company, the disaggregated insights provided a robust foundation for optimizing energy efficiency programs and crafting data-driven tariff structures. By understanding the dominant categories of energy consumption, the company gained valuable inputs for demand-side management strategies, further supporting grid stability and sustainability goals.

Consumers, empowered with category-specific data gained actionable insights into their energy usage.

This transparency fostered better energy management practices, enabling households to reduce costs and align their consumption habits with sustainability objectives. In future consumers can expect even greater value through detailed appliance-specific insights, promoting deeper engagement and smarter energy usage.

Conclusion: Driving Energy Intelligence Beyond Categories

The Non-Intrusive Load Disaggregation project showcased the company’s commitment to leveraging data for operational and consumer benefits.