

Poster Abstract: Data Acquisition Framework and Orchestration for District Management Systems in Northern Germany

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Availability of Data and Material:

The data generated and/or analyzed during the current study are confidential and cannot be made publicly available yet due to confidentiality obligations.

1 Introduction

Neighbourhoods are evolving into sector-coupled energy systems that integrate electricity, heat, and electro-mobility at the district level. The transition toward 100% renewable energy requires the efficient integration of these sectors through locally deployed technologies that enable energy sharing, local flexibility, and reduced dependence on centralized infrastructure [5, 6]. However, the installation of these technologies is not sufficient to realize their full potential. A critical obstacle is the lack of operational data from real-world deployments. While simulation studies can estimate the performance of district energy systems under idealized conditions, they cannot capture the complexity of actual resident behaviour, forecast uncertainties, or the interactions between heterogeneous components in real time. Without accurate monitoring data, operators cannot validate planning assumptions, optimize system performance, or design effective demand-shifting strategies—all of which are essential for cost-efficient and low-emission operation [2, 16].

The Helleheide district in Oldenburg (Germany) serves as a real-world laboratory. It features diverse ownership structures. Residents and building owners deploy technologies such as rooftop and balcony PV systems, heat pumps, battery storage, and thermal storage to diversify energy consumption and help reduce costs and reliance on external grid. Cross exchange between the buildings in the neighbourhood would further support self-reliance. To fully utilize existing infrastructure, stakeholders require reliable data acquisition (DAQ) and communication frameworks to understand system behaviour and enable control strategies that balance cost efficiency, regulatory compliance, and resident participation.

This study presents the data acquisition and orchestration architecture implemented in Project ENaQ *Energetisches Nachbarschaftsquartier Helleheide* phase 2 as illustrated in Figure 1. We present a multi-layered framework consisting of: (1) a secure real-time data transmission system; (2) a diverse measurement system including

utility meters, high-frequency measurement devices, weather stations, and soil temperature sensors; and (3) a district energy management system (QEMS) that orchestrates the district energy system to optimize the coordination of energy generation and consumption at neighbourhood level through intelligent system control. The collected data enables forecast-driven scheduling, multi-criteria optimization, and community engagement through participatory tools such as the "Energieampel" (energy traffic lights) to promote demand-shifting behaviours.

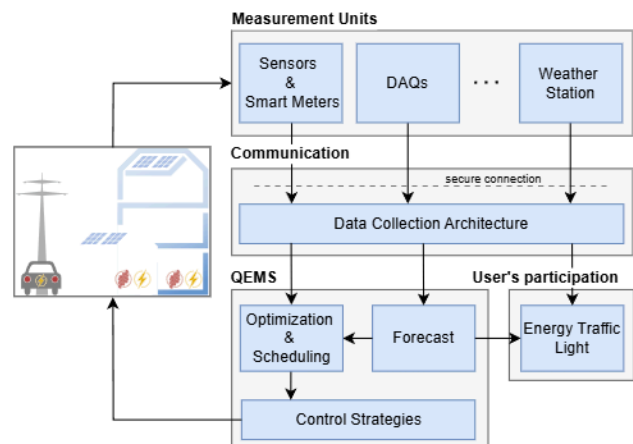


Fig. 1. Three-Layer Data Acquisition Framework: From Measurement to Optimization

2 Architecture of Data Acquisition (DAQ)

Collecting on-site research data requires a flexible and secure architecture due to the diversity of devices and data sources. The main requirements are:

- (1) Connections to the research facility must be initiated from within the facility.
- (2) Support for heterogeneous devices, including Linux systems, Windows-based commercial devices, and third-party managed equipment.
- (3) Remote maintenance (e.g., SSH, RDP, web interfaces).
- (4) Robust operation despite changing client-side IP addresses or network topologies using a single outgoing connection.
- (5) Local data caching to tolerate power or network outages.
- (6) Redundant core components for fault tolerance and uninterrupted updates.
- (7) Minimal administrative effort.

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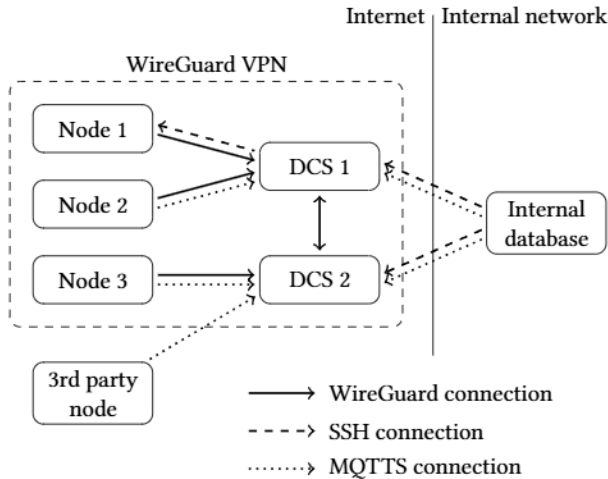


Fig. 2. Communication architecture

Based on these requirements, a redundant hub-and-spoke communication architecture was implemented as shown in Figure 2. Two central servers (DCS 1 and 2) provide fixed WireGuard VPN endpoints for field nodes. Each node consists of a router connected to the local network, optionally with a cellular backup link, and establishes VPN connections to both servers. Measurement devices connected to the router can be accessed remotely via SSH or RDP. Self-managed devices inside the VPN and externally managed devices transmit continuous data to the central servers via MQTT. Internal servers retrieve data continuously through MQTT and periodically via SSH/SFTP for large event-based data files.

3 Measurement Units

A wide range of measurement data at the district, building, and device levels are being collected, stored, and monitored. These operational data are used to develop, test, and validate novel simulation models, methods, and control strategies for both building-specific and district-level energy management via QEMS. Furthermore, high resolution data enables detailed analysis of device operation under specific events.

3.1 High Frequency DAQ

To measure electrical data at higher resolution, multiple Dewesoft IOLITE R8 units [4] will be installed across the district. The units record electromagnetic transient (EMT) waveforms at up to 40 kHz during trigger events. They also continuously measure RMS voltage and current, frequency, power (P, Q, S), power factor, and harmonics. RMS data are transmitted via MQTT at sub-second resolution, while EMT data are stored locally and transferred via SSH/SFTP for long-term storage and event analysis.

3.2 Eye2Sky: Solar irradiance nowcast

Ground observations are provided by a single station located on the ENaQ quarter garage rooftop (Lat: 53.17192, Lon: 8.18004) as part of the broad Eye2Sky network, operated by the DLR Institute

of Networked Energy Systems [10]. The meteorological station provides 360° field of view images from an All-Sky-Imager (ASI) and global horizontal irradiance (GHI) measurements, which are combined with Satellite data (cloud-index) and future clear-sky values. A CNN-ML model then generates an in-situ, point-timeseries of solar irradiance forecasts both deterministic and probabilistic [9]. Intra-hour nowcasts together with satellite and NWP forecasts assist the district energy management system regarding the challenge of highly variable cloud cover that leads to volatile PV production [1, 8]. The operational ML nowcast, as well as the complementary long-term forecasts and all other measured weather data are transmitted via MQTTS for data collection and integration into district energy system optimization.

3.3 Soil Temperature DAQ

To assess heat losses in the district heating network, seven soil temperature sensors were installed. The DAQ system as shown in Figure 3 uses PT1000 resistance temperature sensors whose signals are converted to 0–10 V, digitized by an MCC 118 DAQ HAT, and acquired by a Raspberry Pi. A Python script processes the measurements and transmits the temperature data via MQTTS for storage and visualization.

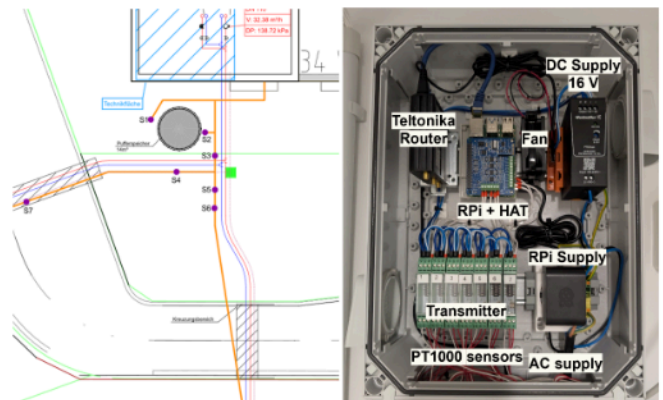


Fig. 3. DAQ system for soil temperature measurement. Sensor locations (left) and DAQ setup (right).

3.4 Building Management System

The Building Management System is used to monitor and control the buildings' technical services. The system was implemented by a third-party engineering firm, utilizing a standardized approach to ensure a precise data exchange across the heterogeneous infrastructure. The system adheres to the VDI 3814 standard for data point documentation [15].

The data points architecture focuses on four levels: central heating infrastructure, distribution networks, individual component monitoring, and renewable energy integration. These level consider the entire operational scope, from the central heat pump plant and buffer storage to the substation-level regulation of individual building blocks.

4 Orchestration of District Energy Systems

To translate the collected monitoring data into actionable operational strategies, we utilize a district energy management system (QEMS). It is based on Mango [12], which is an agent-based framework featuring a role system. Agents represent either a device or a service. A “Service Agent” example would be the weather agent, which provides the current and forecasted weather data. Behind the data acquisition role, data can be extracted from sources such as the Eye2Sky system. These forecasts can then be subscribed to by other agents, for example, the PV agent, uses them to forecast its own production. A “Control Agent” then gathers all necessary device and service data to calculate a schedule, which is sent to the device agents to execute the schedule and monitor the control. This control agent integrates for example, MTRESS [13] for operational optimization. Initially, the role is based on simulation, which can also be exchanged by real devices.

The modular approach of QEMS enables dynamic modelling of device and service entities, where inter-device communication is independent of the structure of the incoming data, and role exchange supports both simulation and real device control. In this work, we are testing the orchestration via QEMS to identify potential improvements in both structure and optimization.

4.1 Forecasting

Since forecasting constitutes a key component of district energy management, various models including statistical and machine learning approaches are being implemented and compared. For demand prediction, PSLP model [14] and machine learning methods such as XGBoost [3] and Long Short-Term Memory (LSTM) [11] are considered for optimization. On the other hand, residents are expected to participate in demand-side management through “Energy Traffic Light” signals, which encourage load shifting based on day-ahead PV forecasts. A study will be carried out to evaluate resident’s behaviour due to “Energy Traffic Light” [previous study [7]].

5 Conclusion and Outlook

This paper presented the monitoring and orchestration framework deployed in Project ENaQ2 at the Helleheide district in Oldenburg, Germany. A secure and modular data acquisition architecture based on a WireGuard VPN, MQTTS, and SSH/SFTP enables reliable integration of heterogeneous measurement systems. The monitoring infrastructure combines electrical, weather, soil temperature, and building management data to provide a comprehensive view of district energy system operation.

The collected data feeds into the QEMS, an agent-based orchestration framework built on Mango and MTRESS that enables dynamic device modelling, forecast-dependent scheduling, and seamless switching between simulation and real-hardware control. Machine learning-based forecasting models for weather, PV generation, and electricity demand support both operational optimization and participatory intensive load-shifting through the Energy Traffic Light system, which communicates recommended load-shifting periods to residents.

Future work will use the collected data to validate forecasting and control strategies, publish datasets as open-source resources, and further develop decentralized district energy management. Owing to its modular design, the framework can be readily transferred to other district energy systems.

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