COMP5339 Assignment 2

Electricity Sector Data Streaming and Analysis

Group Members:

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1. System Description

This project implements a **real-time data streaming and visualization system** for the Australian National Electricity Market (NEM). It retrieves electricity generation and emission metrics from the **OpenElectricity API**, processes and caches them using Python, and streams new records through an **MQTT broker** to a **Streamlit dashboard** for live visualization.

1.1 System Architecture

The overall system consists of three tightly integrated components:

1. **Backend (`a2_backend.py`)** — Fetches and transforms OpenElectricity data, maintains CSV caches, and publishes new rows to MQTT.
2. **MQTT Broker (Mosquitto)** — Serves as the lightweight message transport layer between backend and frontend.
3. **Frontend (`a2_frontend.py`)** — A Streamlit-based dashboard that subscribes to MQTT messages, visualizes live facility-level data, and supports real-time filtering.

The continuous pipeline executes as: **API → CSV Cache → MQTT Publisher → Streamlit Dashboard Subscriber.**

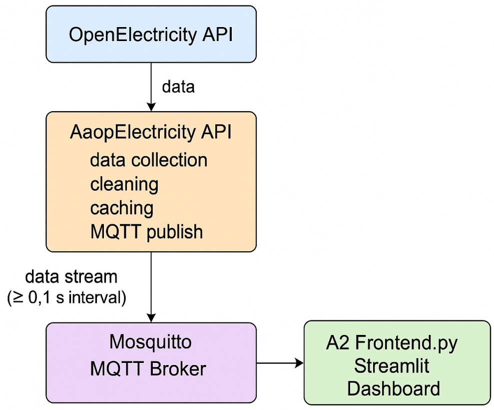


Figure 1. System architecture showing the continuous data flow from OpenElectricity API to Streamlit dashboard.

This architecture ensures that every new data point retrieved from the API is cleaned, cached, streamed, and visualized with minimal delay, achieving near-real-time monitoring.

2. Data Acquisition, Cleaning, and Transformation

2.1 Data Retrieval

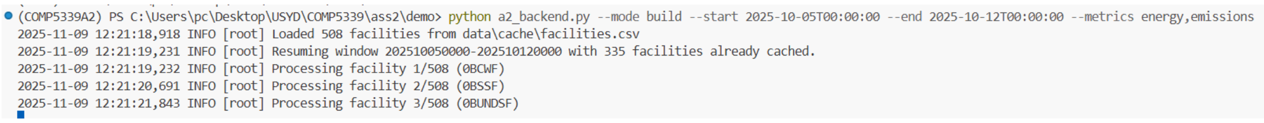
The backend fetches both **facility metadata** and **time-series metrics** using the OpenElectricity API:

- `/facilities/` — Provides metadata such as name, coordinates, fuel type, and region.
- `/data/facilities/{network}` — Provides 5-minute interval metrics for `energy` (MWh) and `emissions` (t).

Configuration is managed by the `Settings` dataclass, including network name, time range, metrics, and broker parameters. Example command:

```
python a2_backend.py --mode build \
--start 2025-10-05T00:00:00 --end 2025-10-12T00:00:00 \
--metrics energy,emissions
```

As shown in **Figure 2**, it successfully detects **508 facilities** and resumes the requested time window (2025-10-05 → 2025-10-12). The manifest file automatically skips **335 facilities** already cached, so only the remaining records are downloaded. Each uncached facility is then processed sequentially for both `energy` and `emissions` metrics, which are stored in `data/cache/nem_metrics.csv`.



```
● (COMP5339A2) PS C:\Users\pc\Desktop\USYD\COMP5339\ass2\demo> python a2_backend.py --mode build --start 2025-10-05T00:00:00 --end 2025-10-12T00:00:00 --metrics energy,emissions
2025-11-09 12:21:18,918 INFO [root] Loaded 508 facilities from data\cache\facilities.csv
2025-11-09 12:21:19,231 INFO [root] Resuming window 202510050000-202510120000 with 335 facilities already cached.
2025-11-09 12:21:19,232 INFO [root] Processing facility 1/508 (0BCWF)
2025-11-09 12:21:20,691 INFO [root] Processing facility 2/508 (0BSSF)
2025-11-09 12:21:21,843 INFO [root] Processing facility 3/508 (0BUNDSF)
```

Figure 2. Backend running in `build` mode. The log shows 508 facilities loaded from cache, 335 already cached within the selected window, and new facilities being processed sequentially.

This output verifies that the incremental-build logic works as intended—avoiding redundant API calls and maintaining up-to-date cached data for subsequent streaming.

2.2 Data Cleaning and Metadata Integration

The `discover_facilities()` function processes facility metadata and applies strict validation rules:

- Removes entries missing coordinates or network identifiers.
- Extracts the **primary fuel type** from the first valid `fueltech_id`.
- Standardizes columns to: `facility_id`, `name`, `fuel`, `state`, `lat`, `lon`.
- Writes cleaned results to `data/cache/facilities.csv`.

If the file already exists, it is reused, enabling incremental builds across sessions.

2.3 Data Transformation

The transformation logic, defined in `_pivot_and_enrich()`, performs several steps:

1. **Pivot to Wide Format** — Combines long-form metric rows into columns `energy_mwh` and `emissions_t`.
2. **Derive Power (MW)** — [\text{power_mw} = \frac{\text{energy_mwh}}{0.0833}] since each time step equals 5 minutes (0.0833 hours).
3. **Join Metadata** — Merges metrics with facility attributes.
4. **Add Timestamps** — Adds both `ts_event` (event time) and `ts_ingest` (ingestion time).

The final dataset is appended to `data/cache/nem_metrics.csv`.

facility_id	ts_event	ts_ingest	power_mw	energy_mwh	emissions_t	name	fuel	state	lat	lon
YSWF	2025-10-11T21:20:00	2025-11-08T02:23:34.788838	22.35	1.8625	0	Yaloak South	wind	VI	-37.71647	144.24195
MTGELWF	2025-10-05T00:15:00	2025-11-08T02:19:06.110573	29.514	2.4595	0	Mt Gellibrand	wind	VI	-38.25766	143.79865
LOYYB	2025-10-07T20:30:00	2025-11-08T02:17:52.478264	577.13	48.0938	53.9757	Loy Yang B	coal_brown	VI	-38.25362	146.58559

Table 1. Cleaned and enriched data sample from the NEM dataset.

3. Data Integration and Continuous Publishing

3.1 Cache Management and Manifest System

To avoid redundant API calls, `build_cache()` maintains a **manifest file (`manifest.csv`)** that logs:

- Date window of the current build
- Cache size and timestamp
- Processed `facility_id` entries

When the script is re-executed, previously cached facilities are skipped using `_load_checkpoint()`, ensuring efficient incremental updates.

3.2 MQTT Publishing Logic

The backend uses `paho-mqtt` to stream data rows to the topic `nem/events`. Each cache row is converted to JSON and published with a **minimum 0.1 s delay (`PUBLISH_DELAY`)** to preserve temporal order.

Example MQTT payload:

```
{
  "facility_id": "LOYYB",
  "facility_name": "Loy Yang B",
  "fuel": "coal_brown",
  "state": "VI",
  "lat": -38.25,
  "lon": 146.58,
  "ts_event": "2025-10-07T20:30:00",
  "power_mw": 577.13,
```

```
    "energy_mwh": 48.09,
    "emissions_t": 53.97
  }
```

3.3 Continuous Loop Execution

The function `loop_pipeline()` orchestrates all backend steps:

```
build_cache() → stream_cache() → sleep(60s)
```

This creates an automated real-time workflow that periodically fetches, transforms, and streams new data every 60 seconds. Extensive logging ensures reliability during long runs.

4. Data Visualization (Frontend)

4.1 Dashboard Overview

The Streamlit frontend (`a2_frontend.py`) provides an **interactive real-time dashboard**. It loads the cached CSV on startup, subscribes to the MQTT topic `nem/events`, and continuously updates the map and summary panels.

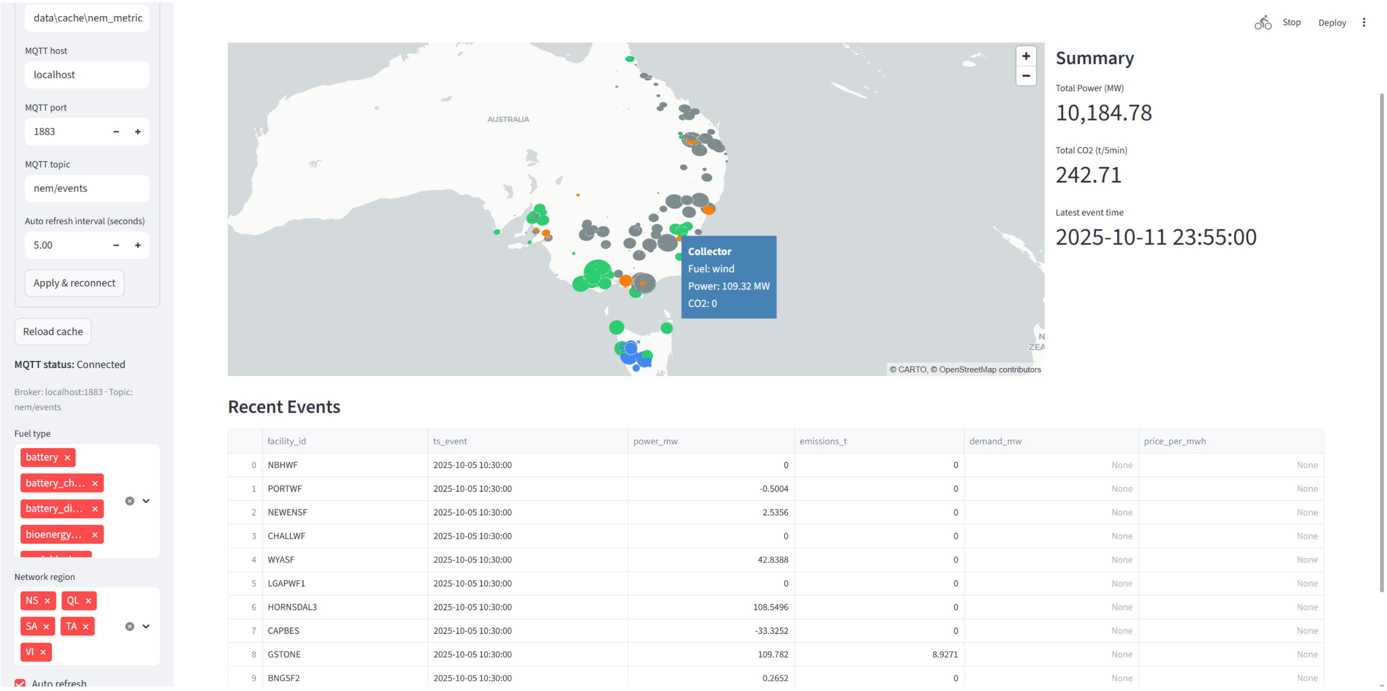


Figure 3. dashboard overview.

4.2 MQTT Subscriber Implementation

The `MQTTSubscriber` class runs in a background thread to maintain live data flow:

- Connects to `localhost:1883`
- Subscribes to `nem/events`
- Parses and validates incoming JSON messages
- Merges new records into the active DataFrame via `apply_event()`

Invalid messages are logged but skipped, ensuring consistent performance.

4.3 Visualization and Interactivity

- **Color coding by fuel type:** Coal = dark gray, Gas = salmon, Hydro = blue, Solar = gold, Wind = green.
- **Marker scaling:** Radius ∝ √(power_mw), bounded within [800 m, 120 km].
- **Sidebar controls:** Adjust broker settings, filter by fuel or region, reload cache, toggle auto-refresh (default = 5 s).
- **Summary panel:** Displays total active power (MW), total CO_2 emissions (t/5min), and the timestamp of the latest event.

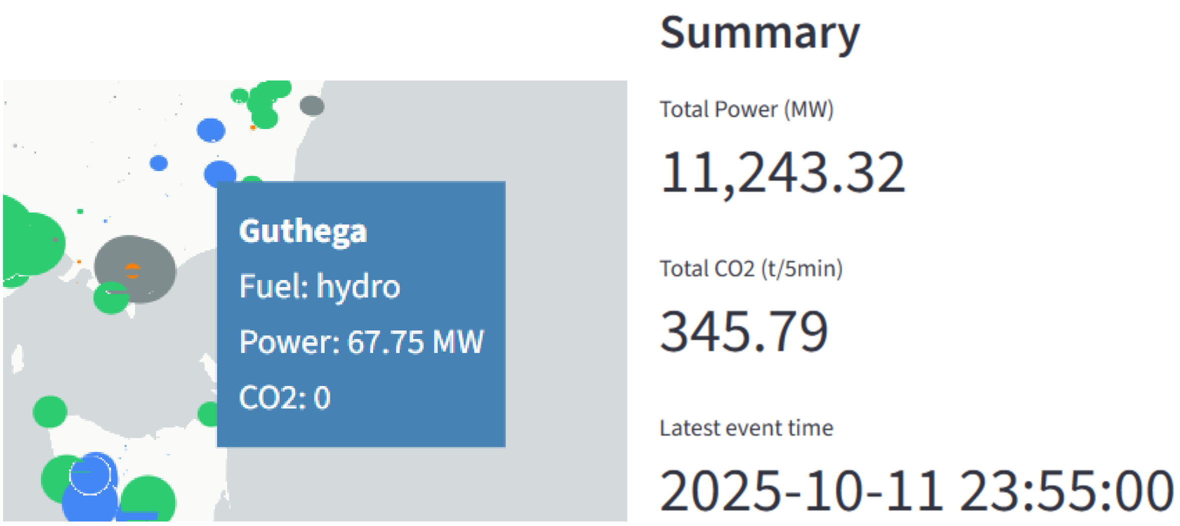


Figure 4. facilities detail(left) and dynamic summary metrics(right).

5. Findings, Challenges, and Future Improvements

5.1 Key Findings

- **Coal and gas plants** (e.g., LOYYB) dominate total energy output and emissions.
- **Wind and solar facilities** (e.g., YSWF, MTGELWF) produce clean energy but with higher variability.
- The system consistently achieved **1–2 s end-to-end latency**, validating the real-time streaming design.

5.2 Challenges and Solutions

Challenge	Description	Solution
API Rate Limit	OpenElectricity free-tier limited to 500 calls/day	Introduced caching and manifest checkpointing
Multi-unit Facilities	Several plants have multiple sub-units	Aggregated metrics within `_pivot_and_enrich()`
MQTT Stability	Occasional broker disconnections	Implemented auto-reconnect and buffered queue
Map Scaling	High MW values distorted marker sizes	Applied square-root scaling with bounds

5.3 Future Improvements

- Incorporate **market price** and **demand** data to extend analysis scope.
- Add **historical charts** and **trend visualizations** for long-term insights.
- Deploy on a **cloud-based MQTT broker** for multi-user access.
- Integrate **InfluxDB and Grafana** for scalable, persistent time-series analytics.

6. Individual Contributions

- **Shilong Wu (540406973):** Developed the Streamlit frontend (`a2_frontend.py`), implemented MQTT subscription, Pydeck-based visualization, filtering system, and overall dashboard layout. Conducted integration testing.
- **Yunan Zhang (540597499):** Developed the backend module (`a2_backend.py`), including data retrieval, caching, transformation, and MQTT streaming. Implemented manifest tracking and continuous loop logic.

7. Repository Access

All source code for this project, including the backend (`a2_backend.py`), frontend (`a2_frontend.py`), and configuration files, is publicly available at:

🔗 **GitHub Repository:** https://github.com/Richu-725/demo

The repository contains:

- Complete Python source files (`a2_backend.py`, `a2_frontend.py`)
- Configuration and requirements files (`requirements.txt`, `API_key.txt`)
- Cached data samples under `/data/cache/`
- Instructions for running the backend (`build`, `stream`, and `loop` modes)
- Streamlit dashboard implementation and screenshots

This ensures full reproducibility of the system and allows independent verification of functionality.