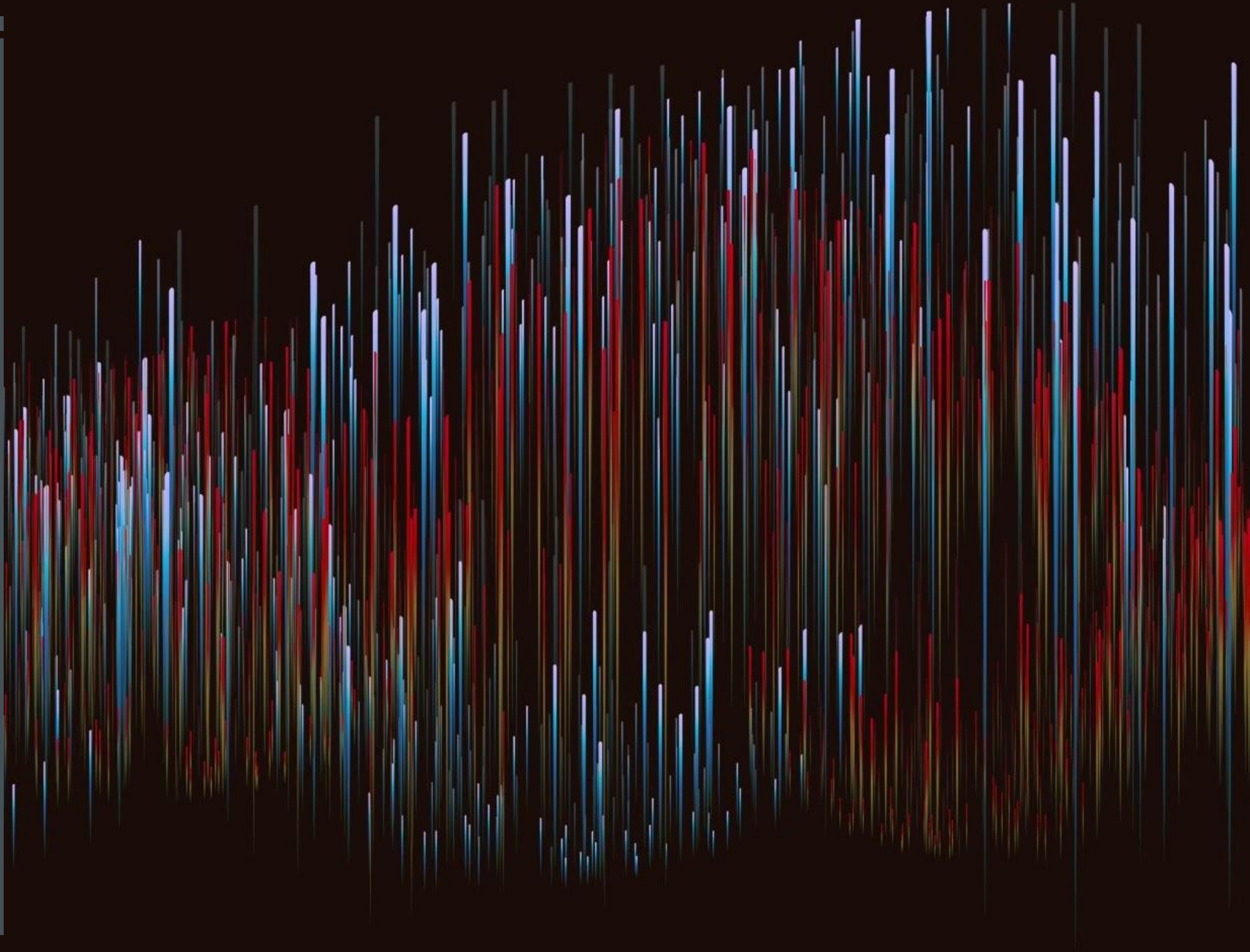


# **ANALYSIS AND FORECASTING OF ELECTRICITY DAY-AHEAD PRICES IN GERMANY USING DEEP LEARNING**

IBM ADVANCED DATA SCIENCE CAPSTONE  
PROJECT

BY DAVE SIRCAR



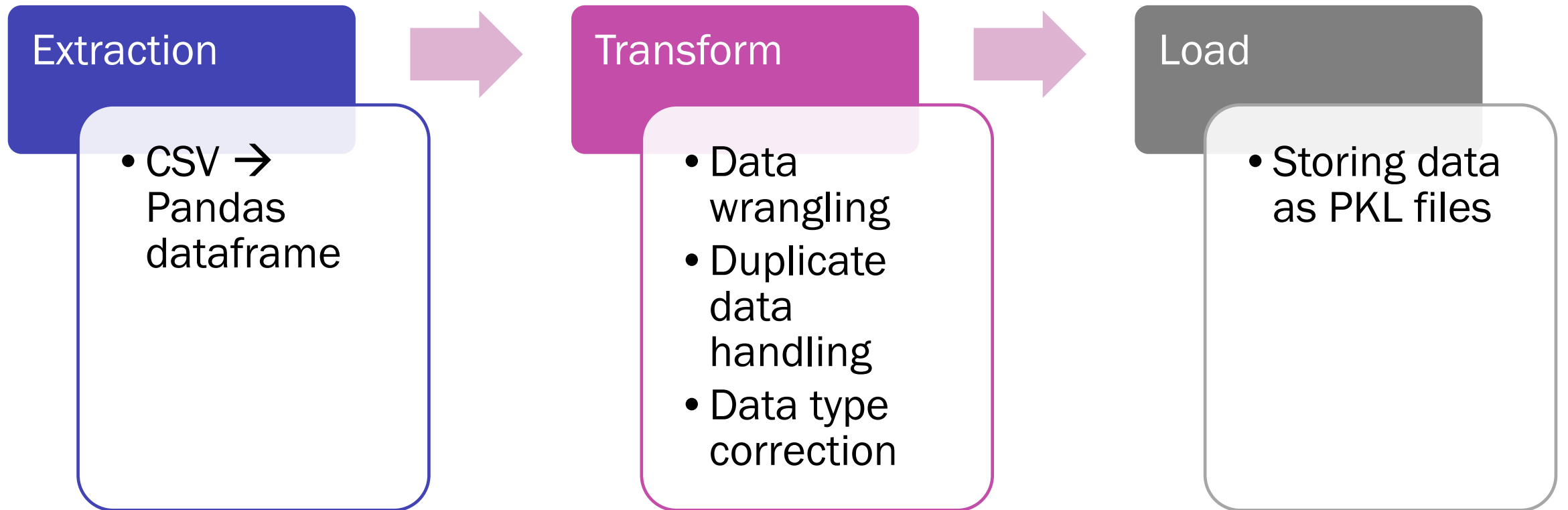
# INTRODUCTION

- Goal: Predict the Day-Ahead prices in advance
- Background / Energy market context
  - EU energy market uses 3 different ways for trading
    - Fixed contracts between generating companies and wholesalers / communal suppliers / large scale consumers
    - Day-Ahead trading: Obtain energy 1-day ahead for accommodating flux in actual consumption (Spot Market)
    - Intra-day trading: Accommodate short-time flux within a day (Spot Market)
  - Energy can't be stored → must be consumed immediately for grid stability
  - Spot market prices: Merit-Order-Model
    - Energy generators bid on the unmet need
    - Bids are stacked in ascending order from cheap to expensive until the entire market's demand is covered. Bids which are more expensive are not bought
    - The costliest accepted bid sets the sales price for all other (cheaper) bids

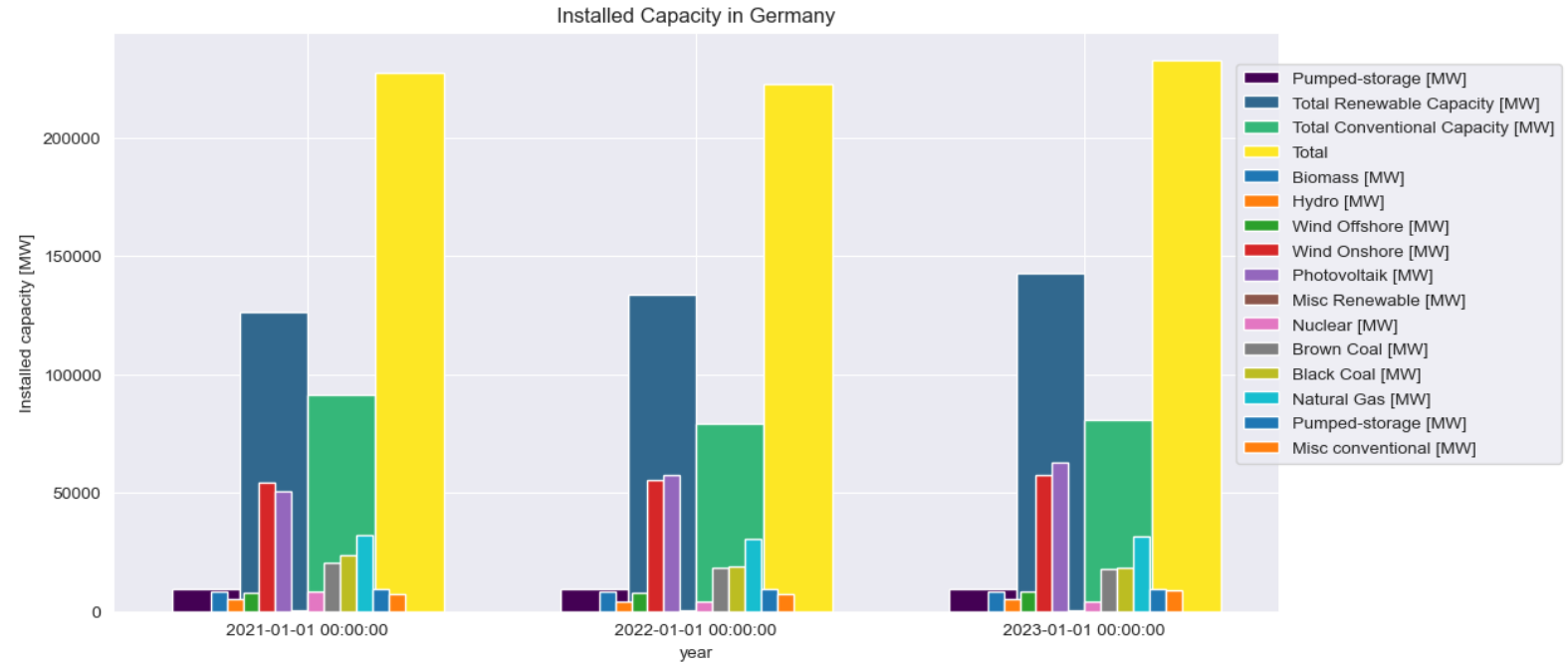
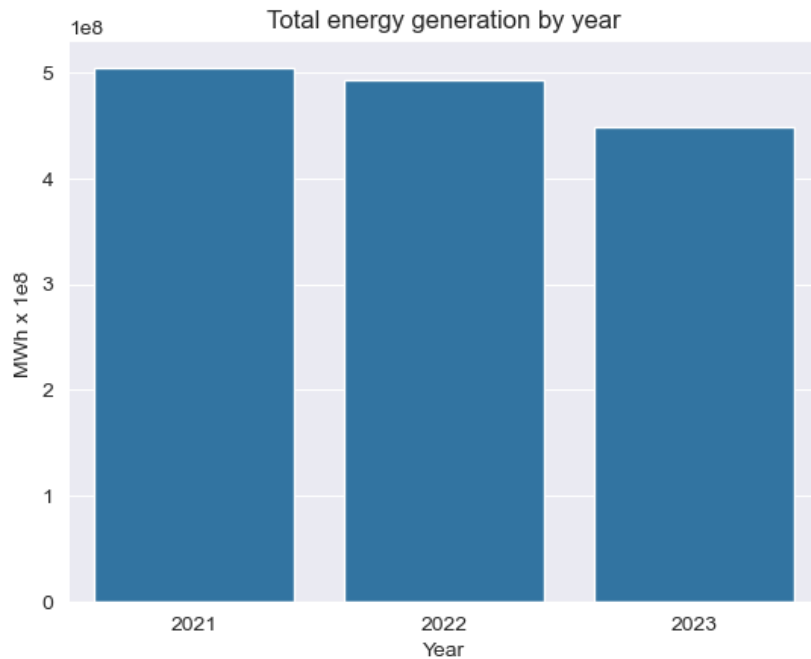
# INTRODUCTION - DATASETS

- Source: SMARD website ([smard.de](https://smard.de))
- Sets
  - Actual Generation (Germany)
  - Installed Generation Capacity (Germany)
  - Actual Consumption (Germany)
  - Gross Day-Ahead prices (EU)
- Train and Validation sets: 01/01/2021 – 31/12/2023
- Test sets: 01/01/2024 – 04/03/2024
- File Format Data: CSV

# ETL

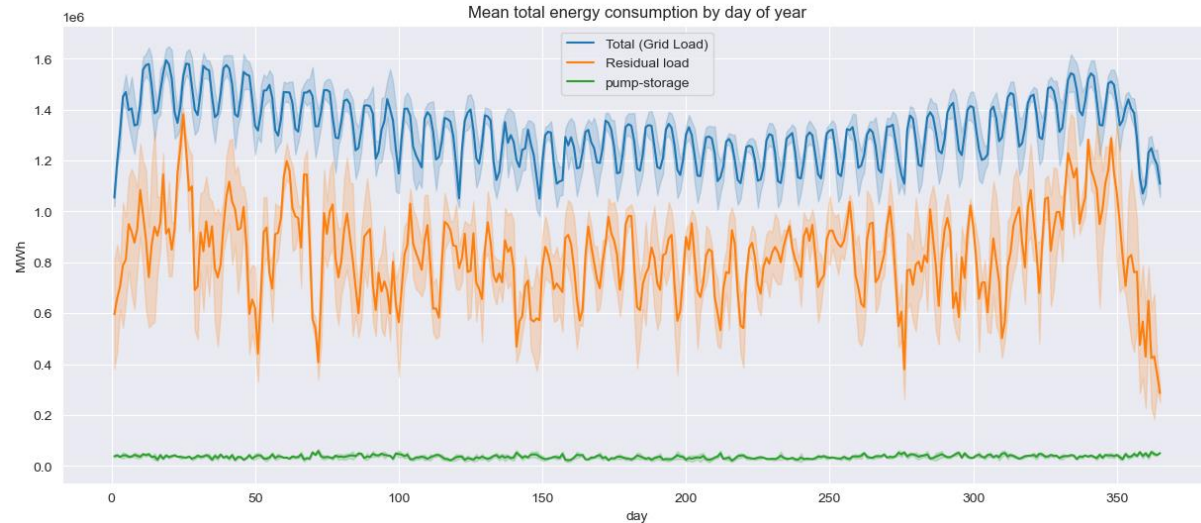
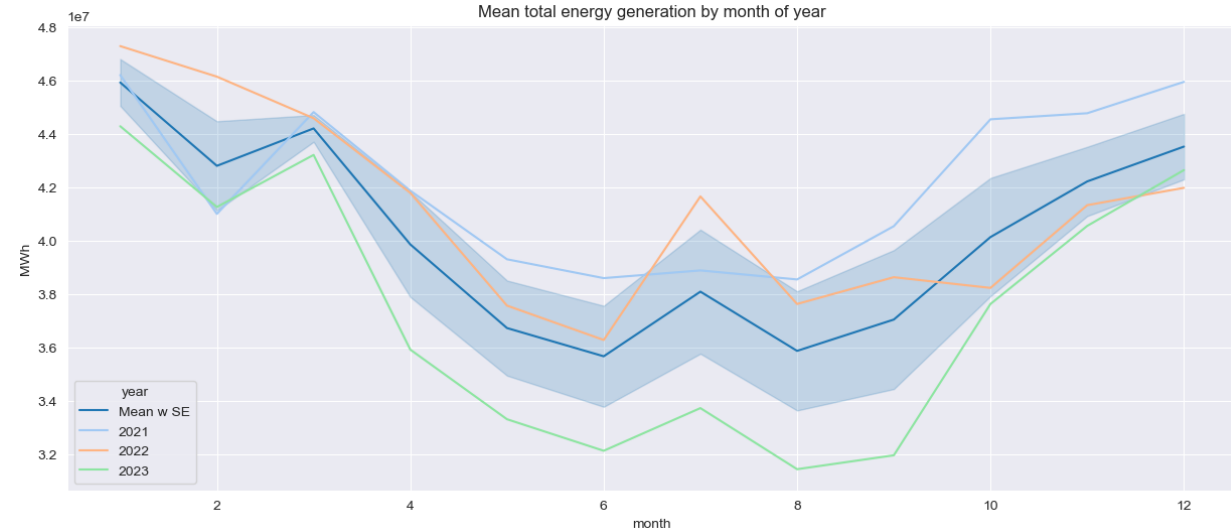
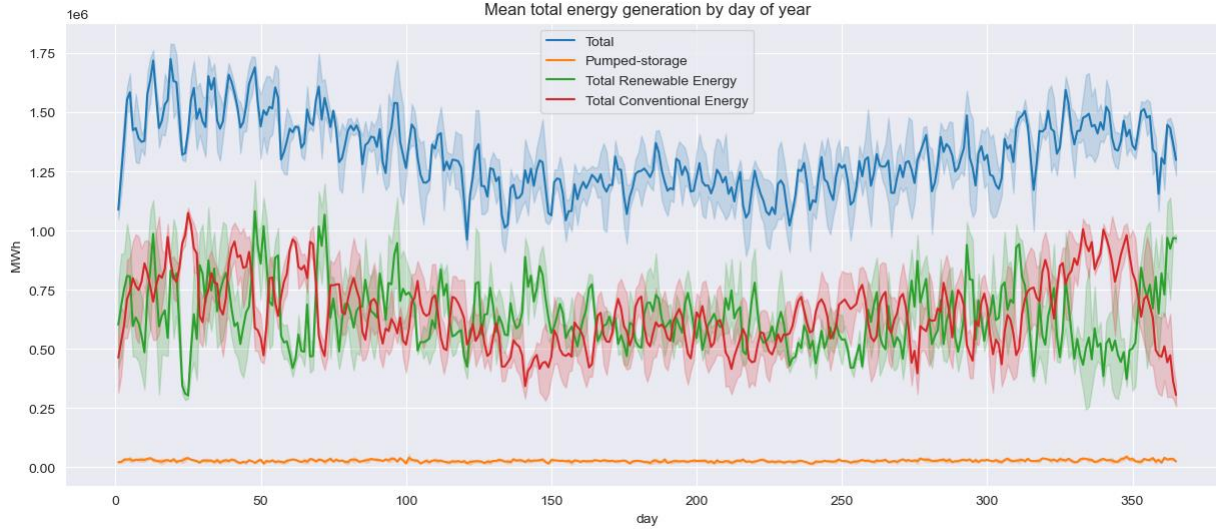


# EDA – INSTALLED CAPACITY AND GENERATED ENERGY



- Installed Capacity is about 4x of average consumption per year

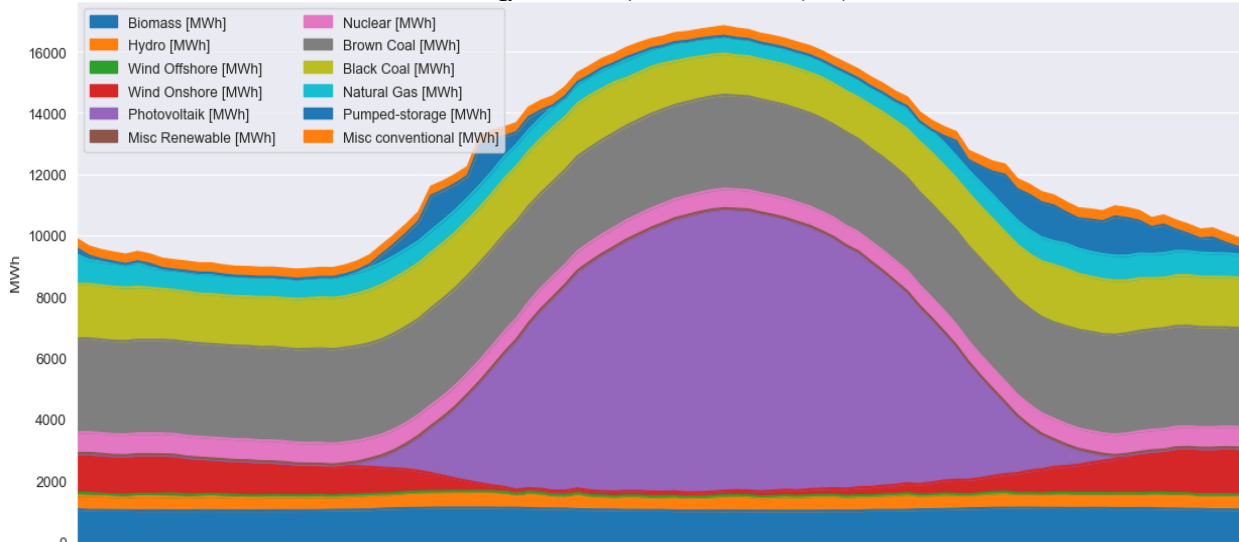
# EDA – GENERATION AND CONSUMPTION IN A YEAR



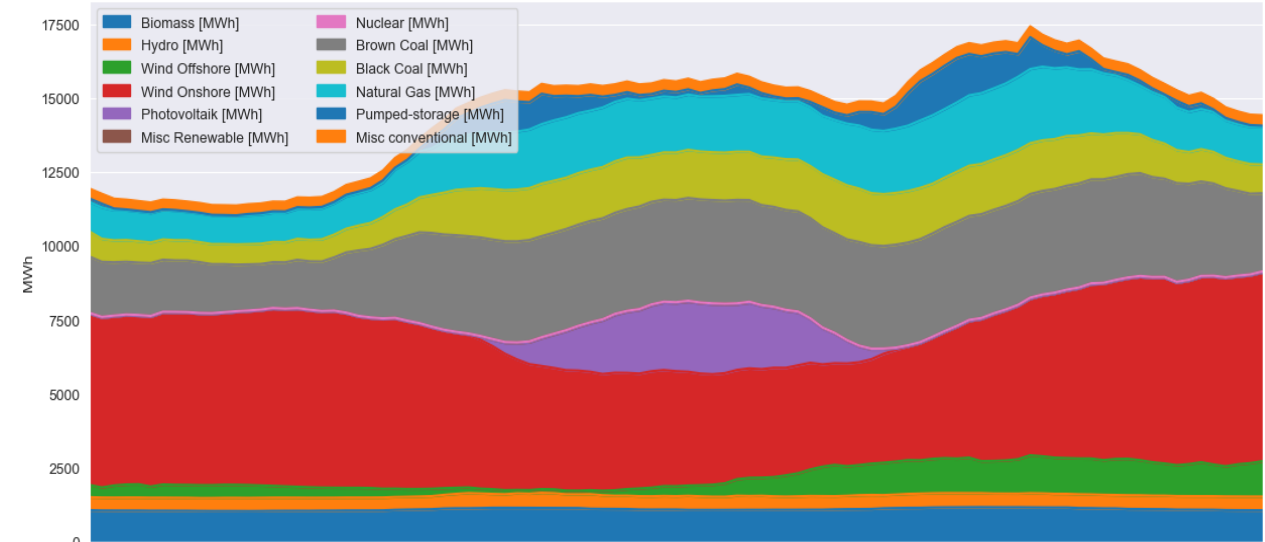
- Energy Generation in Jan highest at  $46 \cdot 10^6$  MWh
- June + August generation lowest at  $36 \cdot 10^6$  MWh
- Consumption is cyclic
  - drop off Fridays to Sundays
  - rapid return on Mondays to plateau
- Note: Residual Load := Consumption of conventionally generated energy

# EDA

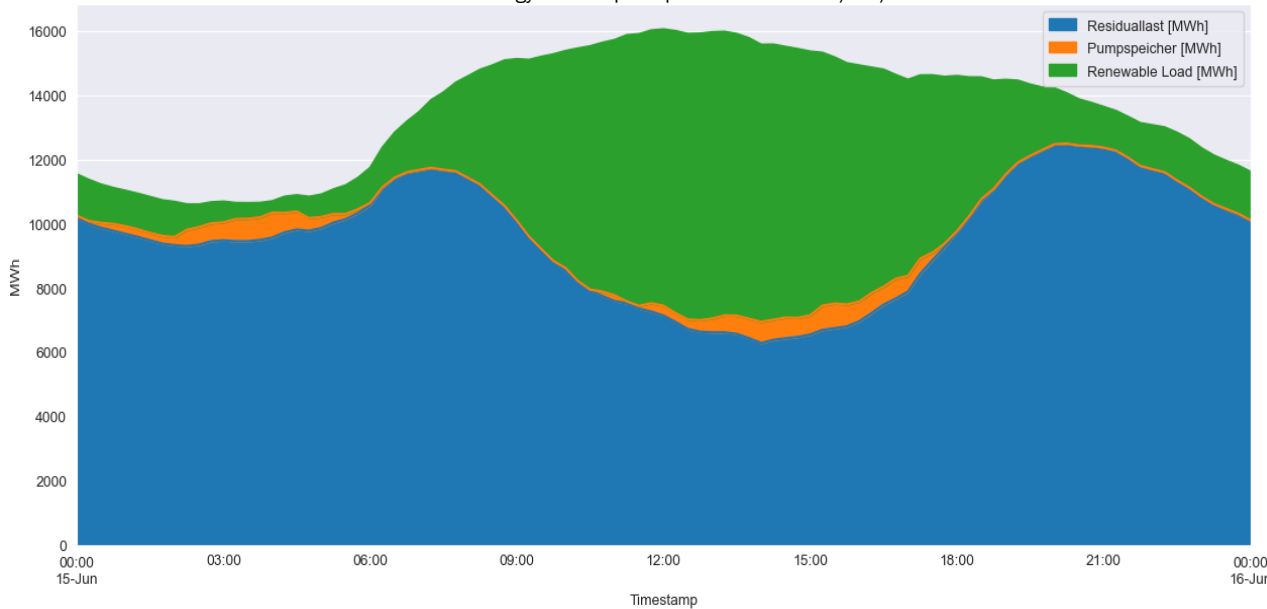
Energy Generation per 15 Min on 15th/Jun/2022



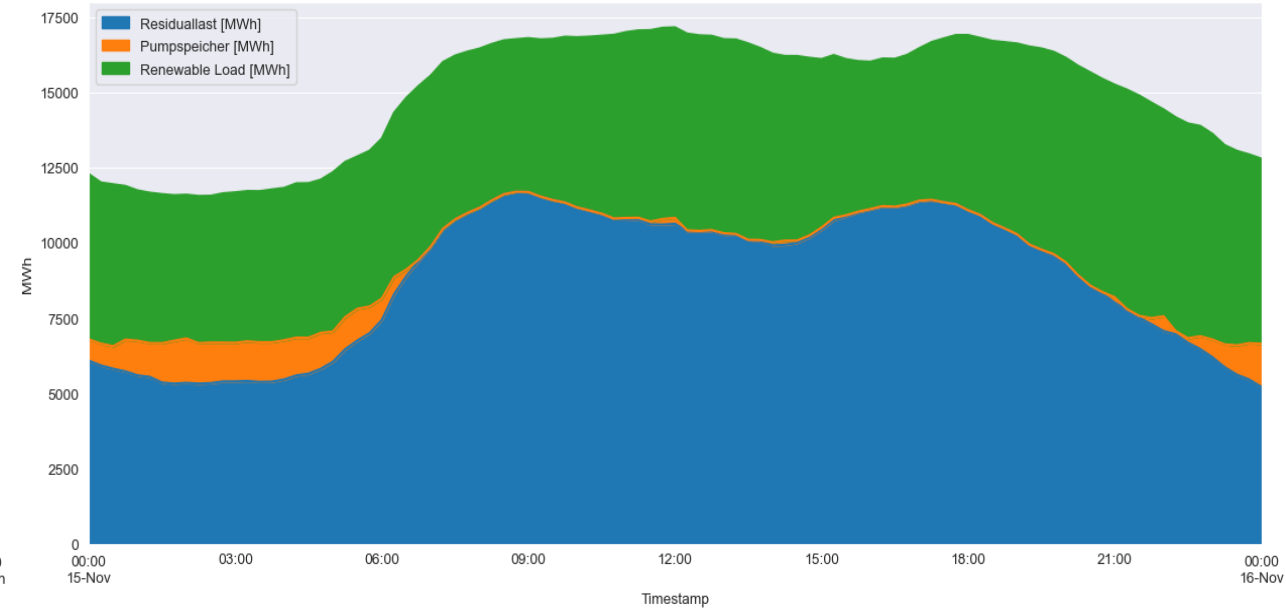
Energy Generation per 15 Min on 15th/Nov/2023



Energy Consumption per 15 Min on 15th/Jun/2022

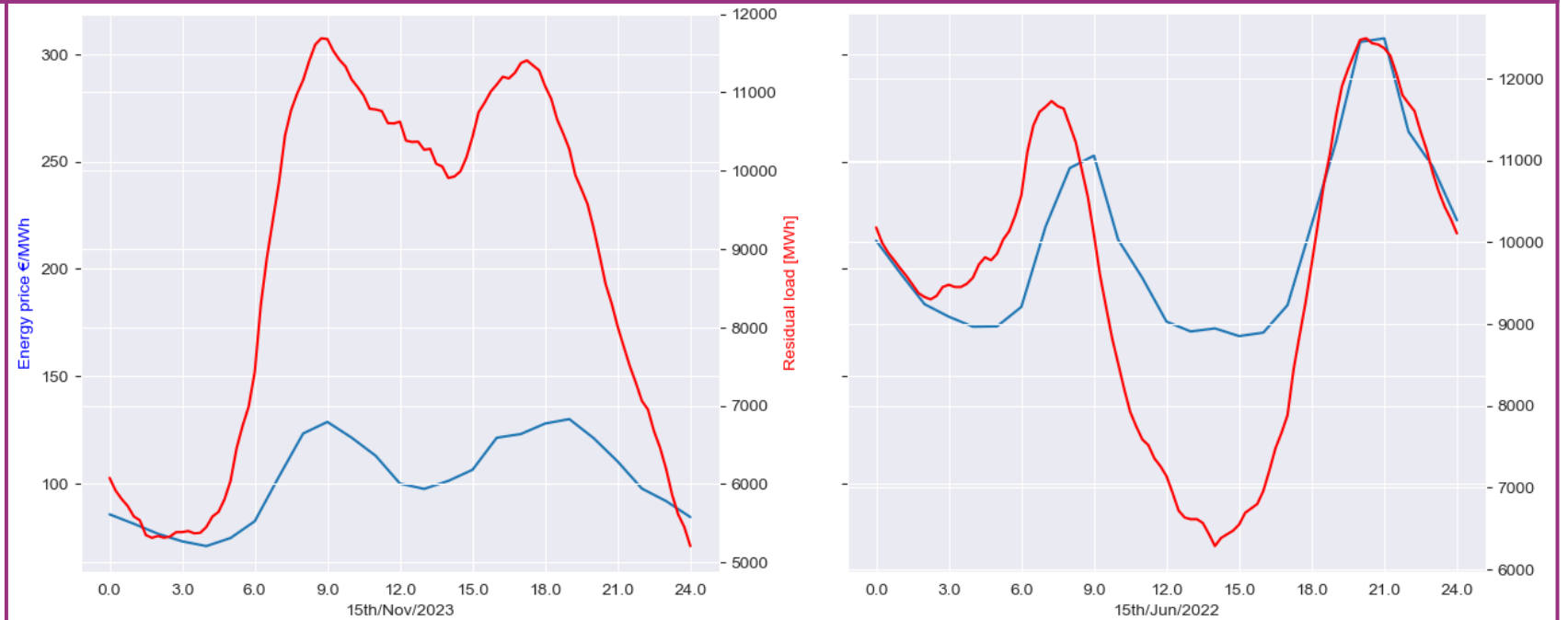
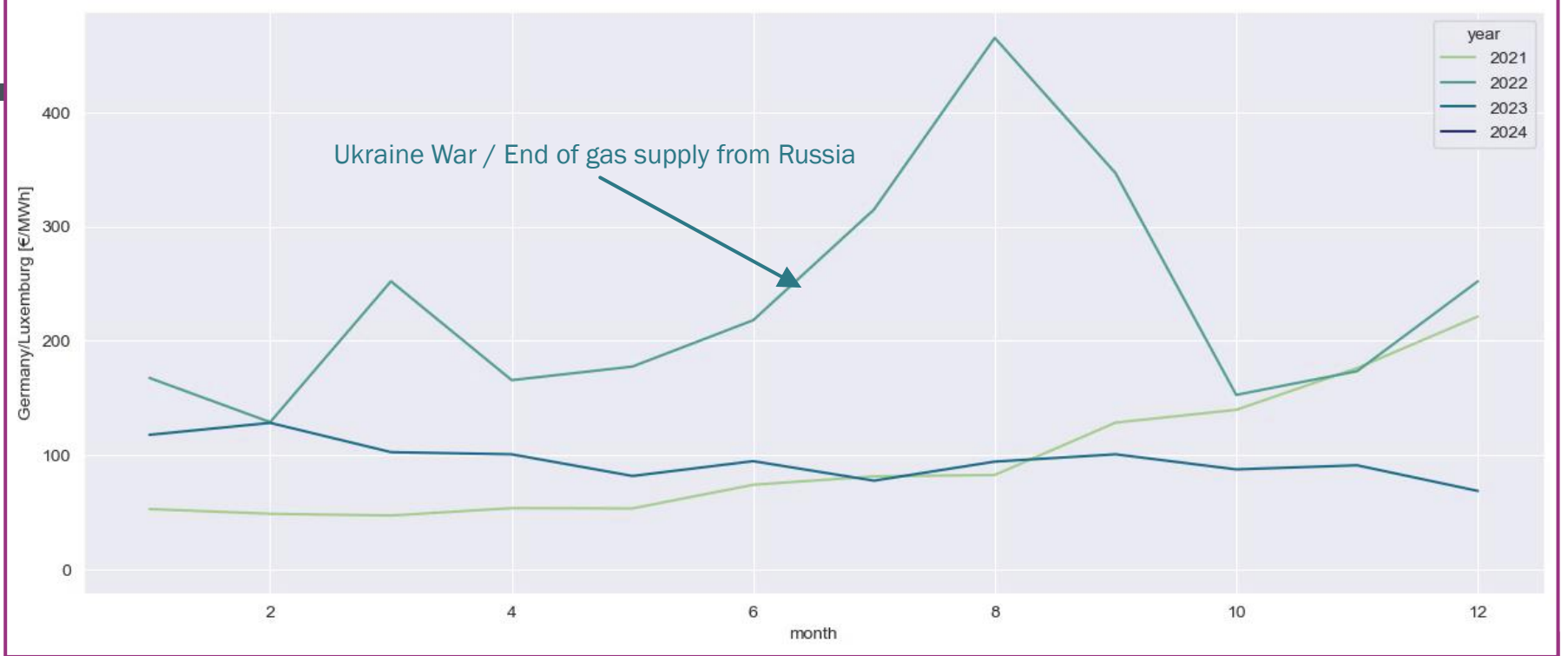


Energy Consumption per 15 Min on 15th/Nov/2023





# EDA





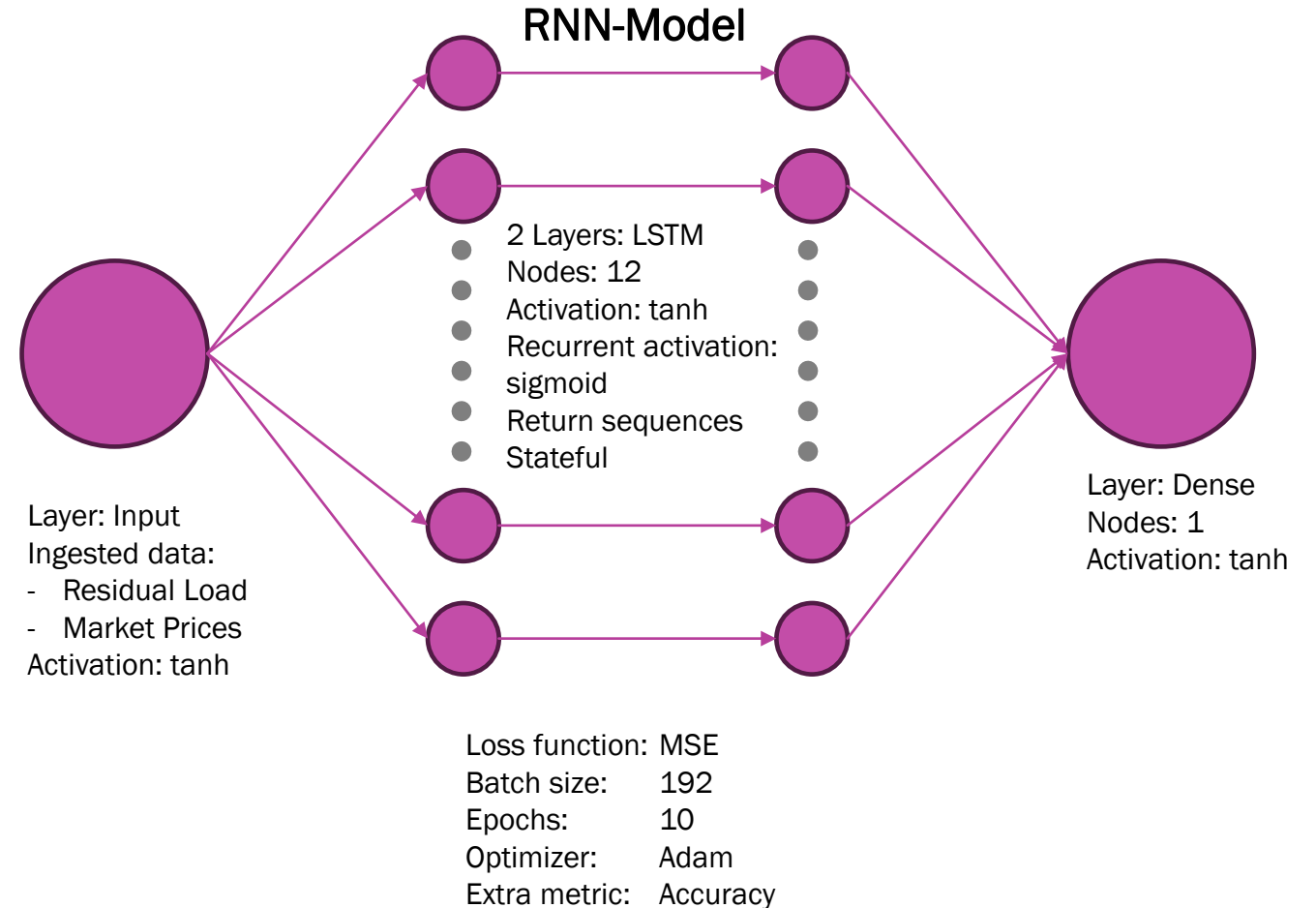
# INSIGHTS EDA

- The total installed capacity is far greater than the generated energy
- In summer PV energy is a major contributor. Peak contribution is nearly 10,000 MWh
- Brown coal and on-shore wind power are also large contributors
- Installed on-shore wind power is about 57.000 MW and 7.13x of off-shore capacity
- Energy Generation in Jan is highest with  $46 \cdot 10^6$  MWh while in June and August generation is lowest with  $36 \cdot 10^6$  MWh
- More conventional energy is produced in the first and last quarter of a year.
- Renewable energy generation is more constant throughout the year
- Renewable + conventional energy in sum produce similar amounts of energy. Pump storage is a marginal appearance
- There is a weekly cycle. Sundays the consumption is lowest and gets reduced from Friday. Monday it's back on plateau level.
- Renewable Energy is consumed first and therefore more completely.
- The market prices are connected with the residual load. This can be explained by the merit-order-model imposed. Traditionally the conventional means of generating energy, i.e. fossil fuels and fission are most expensive.
- In the market price data, specially for 2022 it's obvious, that while the pattern of the curve of the residual load is followed, it has a rapid increase in value. This is the result of the post-COVID world and the Russian-Ukraine war.

# FEATURE GENERATION AND RNN-MODEL

## Features

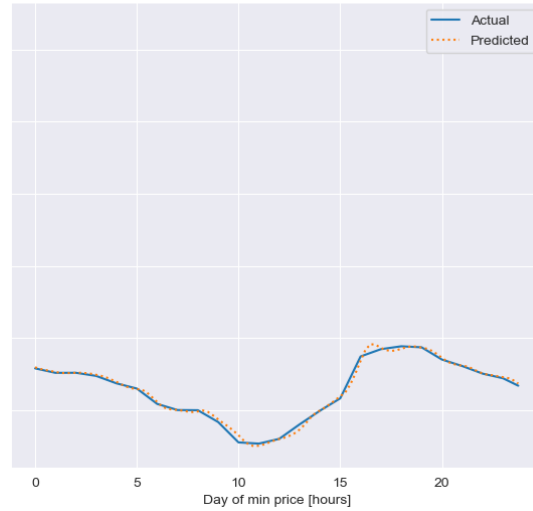
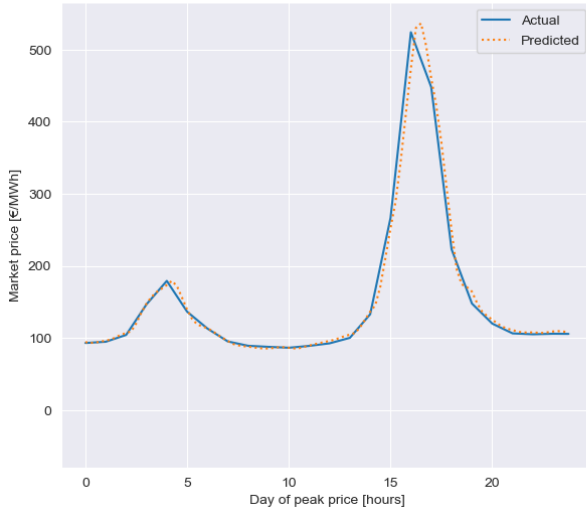
- Market price data has been resampled to 15 min
- Linear interpolation has been applied to fill the missing price values
- Last 15% of the train data was used for validation (15,729 data points)



# MODEL EVALUATION

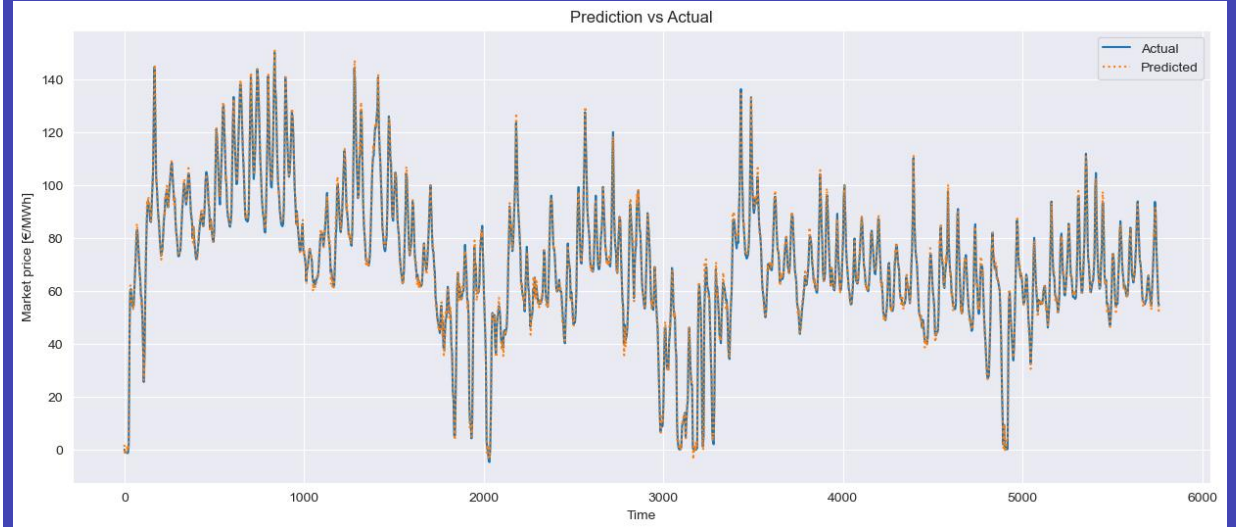
Model after 10 epochs

Prediction of the day with peak and min prices



	Loss	Accuracy
Train	3.53e-05	3.58e-04
Validation	1.89e-05	7.07e-04

Fit with Test Data (Jan/2024 till Mar/2024)



Predicted values fit closely  
to actual values 🏆

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## SUMMARY

- EDA revealed a correlation between Residual Load and Market Prices
- A Recursive Neural Network Model has been built to predict Market Prices 2 days ahead
- Ingested data are Market Prices and Residual load