UNIVERSITY
SCHOOL OF SCIENCE & TECHNOLOGY

REPSOL

Reducing CO_2 Emissions in Industrial Plants Through Solar Self-Consumption and Battery Storage

IE Sustainability Datathon 2025

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CHALLENGE & MARKET CONTEXT

- **Energy transition in Spain:** 160 GW renewable capacity planned by 2030 (PNIEC 2023).
- **Issue:** In 2022, 3.3 TWh of renewable energy wasted.
- **Critical problem:** Industrial solar installations can't feed excess energy to the grid, causing underutilisation and waste.
- **Goal:** Enhance solar self-consumption through intelligent forecasting and storage optimisation to achieve decarbonization targets.

OUR VALUE PROPOSITION

Repsol faces a key challenge: a large share of solar energy at industrial sites goes unused. This project offers **a data-driven solution by forecasting generation, optimising storage, and measuring impact.** The result: less energy wasted, lower emissions, and a smarter, more sustainable energy future.

- **ENERGY EFFICIENCY**
- **OPERATIONAL OPTIMIZATION**
- **CO_2 REDUCTION**
- **SUSTAINABLE LEADERSHIP**

EDA & FEATURE ENGINEERING

01 EXPLORATORY DATA ANALYSIS (EDA):

- Standardized and aligned datasets (timezone Europe/Madrid).
- Missing value handling:
  - Nighttime: Zero generation assumption.
  - Daytime: Imputed hourly averages.
- Identified operational anomalies (weekend and holiday curtailments).

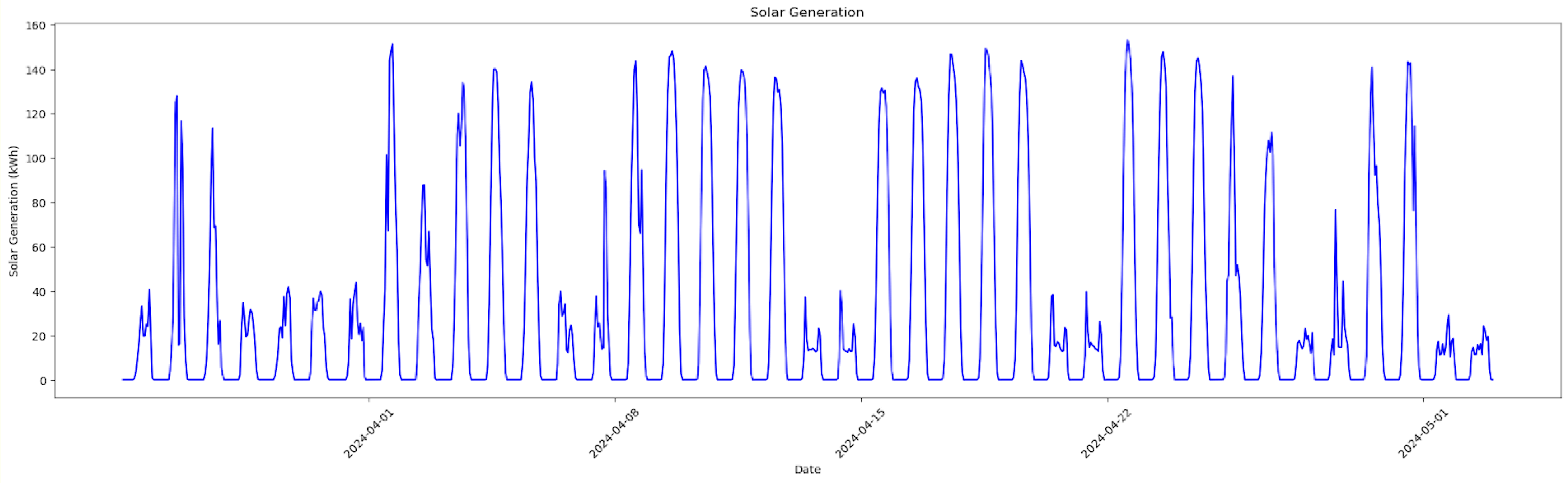
02 FEATURE ENGINEERING:

- Created temporal features (hours from maximum irradiance, days from solstice).
- Spatial averaging of meteorological data from four closest grid points.
- Selected critical predictive variables (shortwave radiation, sunshine duration, cloud cover, temperature).

KEY INSIGHTS

- **Solar generation (kWh) from March 25th to May 2nd 2024**
  We observed consistent anomalies that prompted a critical hypothesis: PV installation might be curtailed or intentionally disconnected from the grid during periods of no industrial demand (weekends/holidays).

- Consequently, we developed our models under **two scenarios:**
  1. **Including weekends and holidays** to simulate potential under full sun exposure.
  2. **Excluding those periods** to reflect likely operational constraints in industrial environments.



PREDICTIVE ML MODELS

01 MODEL DEVELOPMENT & VALIDATION

- **Chosen algorithms:**
  - Random Forest: robust to noise, handles nonlinearities well.
  - XGBoost: high-performance gradient boosting, better at capturing complex patterns.
- **Two Scenarios tested:**
  - Full dataset (including weekends/holidays).
  - Filtered dataset (excluding weekends/holidays due to identified operational curtailments).
- Performed rigorous **3-fold cross-validation** with **grid-search** hyperparameter optimization.
- Ensured model robustness and prevented overfitting.

PREDICTIVE ML MODELS

02 MODEL SELECTION

- **Best <u>internal validation</u> MAE achieved by XGBoost** (weekday dataset): **5.69 kWh**

INTERNAL VALIDATION			
Model	**Scenario**	**Training MAE**	**Test MAE**
Random Forest	All Days	6.91 kWh	6.55 kWh
	Weekdays Only	6.62 kWh	6.23 kWh
XGBoost	All Days	5.79 kWh	5.39 kWh
	Weekdays Only	**5.69 kWh**	**5.12 kWh**

PREDICTIVE ML MODELS

02 MODEL SELECTION

- **External (Real-World) Evaluation based on Repsol's official calculator:**
  - Final model chosen: **XGBoost trained on weekdays-only data.**
  - Weekend/holiday curtailments validated through analysis.
  - Excluding weekends/holidays leads to more realistic and accurate predictions.

REPSOL'S CALCULATOR VALIDATION		
Model	**Scenario**	**Official MAE**
Random Forest	All Days	11.1126 kWh
	Weekdays Only	5.3524 kWh
XGBoost	All Days	10.0190 kWh
	Weekdays Only	**4.9056 kWh**

OPTIMIZATION OF BATTERY USAGE

- **Objective:** Maximise the self-consumption ratio (Ra) by optimising daily battery usage.
- **Tool:** Python-based optimisation model using *scipy.optimize*, applied to each day in September.
- **Inputs:** Predicted hourly solar generation and real consumption data from the facility.
- **Constraints:**
  - Battery capacity: 100 kWh maximum.
  - Daily energy flow limit: Max 100 kWh charge/discharge per day.
  - Hourly limits: Aligned with surplus solar and consumption needs.
  - State of Charge (SoC): Must remain between 0–100 kWh.
  - End-of-day rule: Encourage battery to discharge before midnight.
- **Results:**
  - Ra improved from 82.36% to 85.26%.
  - Avoided 88,994 gCO_2 in direct emissions—even without explicit carbon optimisation.

ENVIRONMENTAL IMPACT ANALYSIS

- **Goal:**
  Reduce CO_2 emissions by optimising battery discharge based on grid carbon intensity.

- **Emissions Metrics:**
  Compared both direct emissions (generation only) and lifecycle emissions (including upstream impacts).

- **CO_2-Optimised Strategy:**
  Discharged battery during high-emission hours, achieving the same Ra (85.26%) as the Ra-optimised case, but avoiding 94,158 gCO_2eq (vs. 88,994 gCO_2eq) direct emissions.

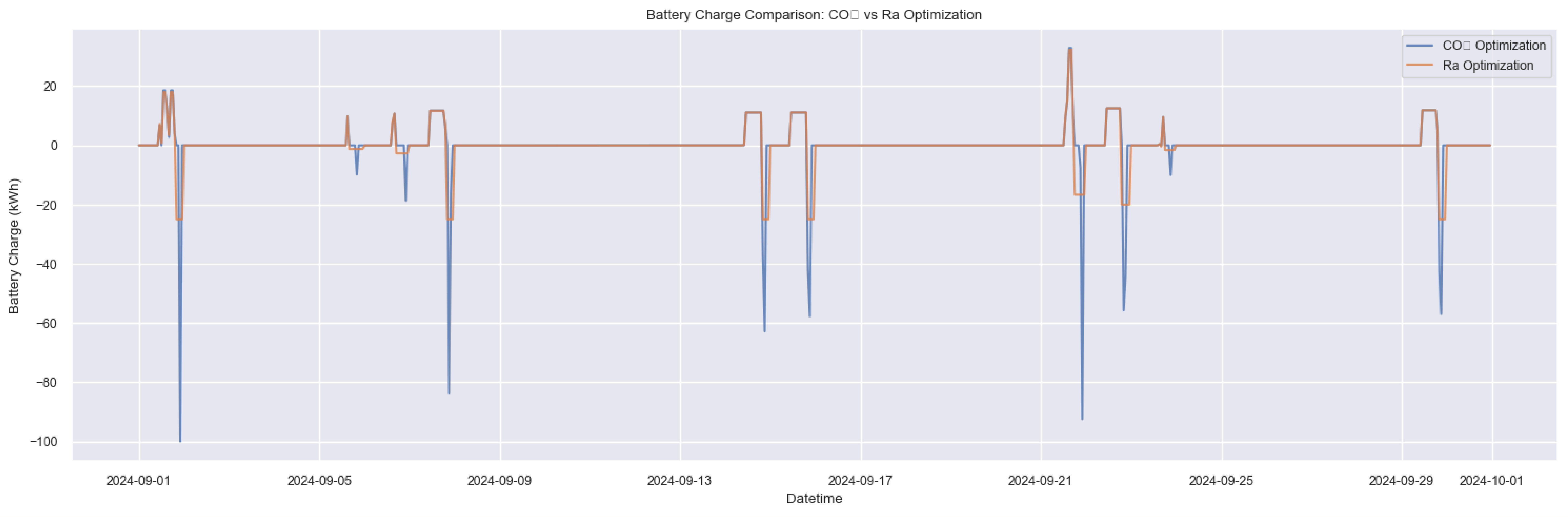
- **Operational Insight:**
  CO_2-optimised cycles were sharper and timed to grid intensity; Ra-optimised cycles were smoother and evenly distributed.

- **Lifecycle Impact:**
  Using lifecycle emissions didn’t change battery behavior but increased avoided emissions to 124,028 gCO_2eq, showing a greater systemic benefit.

KEY FINDINGS

Battery discharge differs between strategies:

CO_2 optimization concentrates discharges during high-emission hours to maximize impact, while Ra optimization spreads usage evenly to maximize self-consumption.



CONCLUSIONS & BUSINESS IMPLICATIONS FOR REPSOL

- **Data-driven solar forecasting adds real value**
- **Weekday-focused modelling improves accuracy**
- **Battery optimisation raises self-consumption** and, when CO_2 is prioritised, boosts emissions savings by ~5,000 gCO_2eq.
- **Lifecycle emissions analysis reveals even greater environmental gains,** strengthening Repsol's ESG positioning.
- **Optimisation strategies support both cost efficiency and carbon reduction**, with potential access to carbon credits and EU taxonomy benefits.
- **Hybrid control systems** offer dynamic flexibility between economic and environmental goals.
- **System reliability is essential**, maximising uptime ensures full value from solar and storage assets.