Cloud-Native Renewable Energy Forecst via Automated Machine Learning and Cloud Pipelines

Team Number: 06

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Area of Project

- Renewable Energy Forecasting (Solar Wind)
- Machine Learning for Weather and Energy Prediction
- Cloud-Based Environmental Monitoring Systems
- Real-Time Data Visualization and Analytics
- Smart Cities and Sustainable Infrastructure
- Contributing to United Nations SDG 7: Affordable and Clean Energy

Motivation

- Growing global demand for clean and sustainable energy
- Need for accurate forecasting to optimize solar and wind energy utilization
- Real-time environmental monitoring is essential for smart city development
- Lack of integrated systems combining prediction, visualization, and cloud deployment
- Supports United Nations SDG 7: Ensure access to affordable, reliable, sustainable, and modern energy for all

Problem Statement

- Develop an end-to-end system for predicting and visualizing solar irradiation and wind parameters.
- Integrate machine learning models and real-time weather APIs to enable accurate, location-based predictions.
- Build interactive dashboards to visualize trends, patterns, and forecasts for decision support.
- Ensure the system is cloud-deployed, scalable, and accessible via a user-friendly web interface.
- Address the need for clean energy forecasting to support efficient renewable energy utilization and planning.

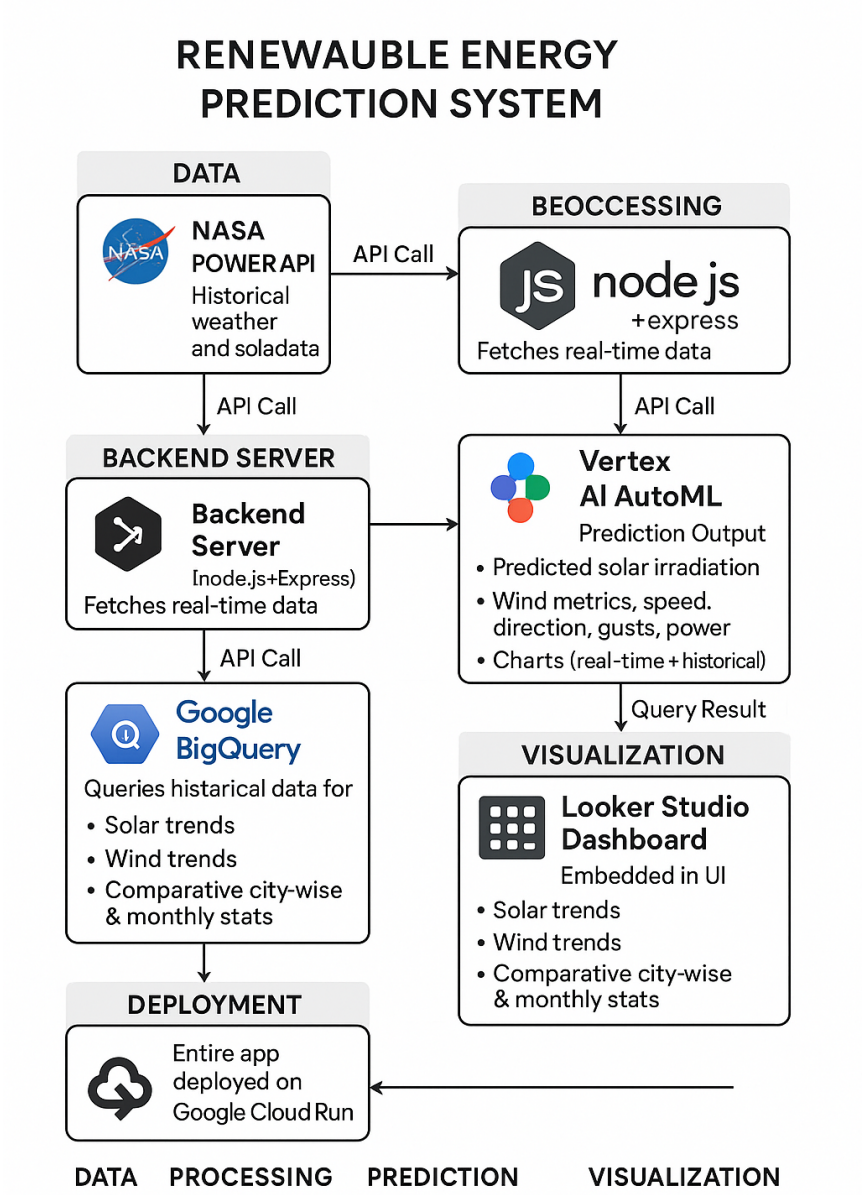
Solution Approach

- **Data Collection:**
  - Historical weather data from CSV files stored on Google Cloud Storage
  - Real-time weather inputs using Tomorrow.io API (temperature, humidity, wind, etc.)
- **Model Development:**
  - Solar irradiation prediction using AutoML Regression model in Vertex AI
  - Feature engineering with parameters like temperature, dew point gap, wind speed, etc.
  - Wind forecasting handled through real-time data analytics and trend analysis

Solution Approach

- **Backend System:**
  - Built using Node.js and Express.js
  - Handles prediction requests, API integration, and serves data to the frontend
- **Frontend Interface:**
  - HTML + Tailwind CSS for UI
  - Chart.js for dynamic visualizations (time series, bar, pie, wind rose, etc.)
  - Embedded Looker Studio dashboards for historical trend analysis
- **Deployment:**
  - Deployed on Google Cloud Run for a serverless, scalable architecture
  - API endpoints for ML predictions and real-time weather insights

Model Architecture



Explanation

- **1. Data Module:**
  - Historical weather data retrieved from **NASA POWER API**.
  - Real-time weather data fetched using **Tomorrow.io** via backend integration.
- **2. Machine Learning Module:**
  - Trained a solar irradiation prediction model using **Vertex AI AutoML**.
  - Features include temperature, humidity, wind speed, dew-point gap, and more.
  - Wind metrics analyzed in real-time for forecasting trends (direction, speed, gust).
- **3. Backend Module:**
  - Built using **Node.js + Express**.
  - Handles:
    - API calls to NASA and Tomorrow.io
    - Requests to Vertex AI for solar predictions
    - Data serving to the frontend

Explanation

- **4. Frontend Visualization:**
  - Built using **HTML, Tailwind CSS**, and **Chart.js**.
  - Visualizes:
    - Time-series of solar wind parameters
    - Wind rose, bar, and pie charts
  - Embedded **Looker Studio** for historical data analytics.
  - Live app: `https://temp-589768796668.us-central1.run.app`
- **5. Deployment Status:**
  - Entire system deployed on **Google Cloud Run**.
  - Fully functional:
    - Real-time API data
    - ML predictions
    - Interactive UI and dashboards

Results & Dashboard Overview

- **Solar Irradiation Prediction:**
  - Displays predicted solar irradiation in kWh/m².
  - Shows a confidence interval to indicate model certainty.
- **Wind Prediction:**
  - Wind speed prediction in meters per second (m/s).
  - Wind direction shown in degrees with compass orientation.
  - Gust speed and turbulence level provided.
  - Estimated wind power output calculated in kilowatts (kW).
- **Embedded Analytics Dashboard:**
  - Integrated Looker Studio dashboard for historical data insights.
  - Charts include:
    - Time-series of solar and wind parameters.
    - Bar and pie charts for city-based and monthly trends.
    - Wind rose for direction analysis.
    - Scatter plots for feature correlation.
- **Web Application:**
  - Fully deployed on Google Cloud Run with live predictions and interactive visualizations.

Technologies & Services Used

- **Data Sources:**
  - NASA POWER API (historical weather data)
  - Tomorrow.io API (real-time weather conditions)
- **Machine Learning:**
  - Google Vertex AI AutoML (solar irradiation prediction)
- **Cloud Services:**
  - Google Cloud Run (web app hosting)
  - Google Cloud Storage (dataset storage)
  - Google BigQuery (data querying & aggregation)
- **Visualization Tools:**
  - Google Looker Studio (interactive dashboards)
  - Chart.js (real-time graphs in frontend)
- **Web Application:**
  - Frontend: HTML, Tailwind CSS, JavaScript
  - Backend: Node.js, Express.js, Axios
- **Deployment:**
  - Deployed on Google Cloud Run with integrated APIs and dashboards

Comparison with Forecasting Methods

Traditional vs. ML Pipelines vs. Our Model

Aspect	**Traditional**	**Manual ML**	**Our Model**
Prediction Time	Slow	Moderate	**Real-time**
Expertise Needed	High	Moderate	**Low**
Scalability	Low	Medium	**High**
Automation	None	Partial	**Fully Automated**
Real-time Data	No	Rarely	**Yes**
Deployment	Offline Tools	Local APIs	**Cloud Dashboard**

Key Advantage: Our model combines accuracy, automation, and real-time capabilities with cloud scalability.

Our Novel and Efficient Cloud-Native Approach

Core Advantages

- Achieved **93% prediction accuracy (R^2)** using Vertex AI AutoML.
- Fully automated end-to-end ML pipeline: from data ingestion to live deployment.
- **Real-time prediction latency:** results generated in just a few seconds.

Key Differentiators & Novelty

- Seamless integration of ML, real-time APIs, cloud infrastructure, and visualization.
- Fully cloud-native, real-time, and accessible via a responsive web interface.
- Directly contributes to **UN SDG 7** — promoting affordable and clean energy through smart digital forecasting.

Conclusion

- Developed an end-to-end system that predicts solar irradiation and analyzes wind parameters using machine learning and real-time data.
- Integrated multiple cloud-based services including **Vertex AI**, **BigQuery**, and **Looker Studio** for intelligent prediction, data handling, and visualization.
- Enabled real-time insights with a fully deployed web application on **Google Cloud Run**, accessible from any device.
- Dashboard provides dynamic charts and analytics to assist in energy planning, weather monitoring, and environmental decision-making.
- Contributes to **UN SDG 7 (Affordable and Clean Energy)** by enabling data-driven renewable energy solutions.
- Future enhancements can include:
  - Long-term forecasting
  - Integration with IoT-based weather stations
  - Turbine efficiency analytics

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Thank You!

Questions or Feedback?

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