Detailed Project Plan

Modelling of European Interconnectors for Sustainable Energy Integration

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1 Background

1.1 Nature of this Project

This project takes an experimental and research approach. It aims to generate knowledge, and verify existing claims on European interconnectors. A focus is set on the theme of sustainability and energy integration, in the heated context of Net Zero initiatives by various nations.

This project places particular emphasis on the financial aspects of interconnectors and their correlation with wind energy generation within a carefully selected group of European nations.

1.2 Sustainability, Energy Transition, and Net Zero

In the current landscape, sustainability is paramount. The need to transition towards sustainable energy sources and practices has never been more urgent. As nations grapple with the challenges of climate change, the reduction of carbon emissions has become a central tenet of energy policies worldwide. Achieving Net Zero emissions is a shared goal, and interconnectors are a crucial component of this endeavor.

1.3 Interconnectors

Interconnectors are cross border, high voltage cables linking national power grids. They allow electricity to flow according to patterns of supply and demand.

Interconnectors play a pivotal role in advancing sustainability and Net Zero objectives. By facilitating the efficient sharing of electricity across borders, interconnectors enable the integration of renewable energy sources into the grid. This integration reduces reliance on fossil fuels and enhances the capacity for clean energy generation. It also helps balance supply and demand, reducing the need for backup power sources that may produce emissions.

2 Objective

This research project is to be focused on understanding the multifaceted dynamics of European interconnectors with the following key objectives.

2.1 Development of Comprehensive Models

To construct software models that encompass the technical specifications, operational characteristics, and capacity constraints of European interconnectors, providing a foundation for comprehensive analysis. These models shall highlight the relationships between market-economics and sustainable energy generations with particular focus on wind.

2.2 Evaluation of Interconnector Efficiency

To assess the current state of European interconnectors, identifying operational bottlenecks, vulnerabilities, and opportunities for enhanced sustainability. Emphasis will be placed on analysing the price difference (zero in ideal conditions) between two domains of a interconnectors. Moreover, outages and maintenance work events will be made more predictable, and be scheduled in more optimal windows of time.

2.3 Role in Sustainable Energy Integration

To investigate the pivotal role of interconnectors in supporting the integration of renewable energy sources across Europe, with an emphasis on reducing high-carbon generations.

2.4 Recommendations for Enhanced Integration

To propose strategies and recommendations for optimising the utilisation of European interconnectors in the context of sustainable energy integration.

3 Methodology

3.1 Energy Data

Historical Energy Production: Energy generation over past years, including information on fossil fuels, nuclear, renewable energy sources, and their respective contributions to the energy mix.

Real-time Energy Production: Real-time data on energy production from sources such as wind farms, solar installations, hydroelectric plants, and conventional power stations is essential for modelling the behaviours of the grid.

This data is available from the country's electricity suppliers/ national regulatory body. For instance, Elexon is one in the UK.

3.2 Climate and Weather Data

Given the project's focus on sustainable energy integration, climate and weather data are of paramount importance. These datasets aid in understanding the influence of weather conditions on energy generation and demand. The following types of climate and weather data will be utilized:

Historical Weather Data: Temperature, wind speed, solar radiation, and precipitation, will provide insights into long-term climate trends.

Real-time Weather Data: Current weather conditions are crucial for assessing the immediate impact on renewable energy sources, such as wind and solar power generation.

The above data can be gather via Open-Meteo.

3.3 Interconnector Data

Specific data related to interconnectors will be instrumental in the modeling and analysis process. This includes:

Interconnector Specifications: Technical specifications of existing and planned interconnectors, such as capacity, location, and operational details.

Operational Data: Real-time operation of interconnectors, including power flow, past and future maintenance/outages, and day-ahead prices.

Economic and Regulatory Data: Pricing mechanisms, tariffs, and regulatory frameworks that influence their use and development.

Financial Market Data: Prices of electricity, capacity, and various related securities, derivatives, and commodities.

The above data can be accessed via the Transparency Platform of The European Network of Transmission System Operators for Electricity.

3.4 Quantitative Analysis

Given the experimental nature of this project, it is difficult to select in advance and promise on certain methodology. However still, this text provides a list of potential candidates worthy of explorations, and their respective use.

- Regression analysis with Support Vector Machines and Decision Trees: to predict interconnector flows given domestic generations by fuel type and other information.
- Time-series forecasting of prices.
- Signal processing to extract market signals.
- Stochastic simulations of prices for analysing scenarios related to security securities.
- Ensemble learning.
- Clustering analysis to identify markets with similar energy patterns.
- Neural networks of various degree of deepness for complex pattern recognition.
- Transformers. In particular Self-Attention Transformers.

- Statistical and probabilistic approach to computing future contracts with the goal of predicting fair prices.
- Deep Reinforcement Learning to simulate electricity bidding with a multi-agents system.

3.5 Software Tools and Technologies

R will be used to conduct some statistical analyses.

Python will be the primary technology for building models. Industry-standard packages like Pandas, Numpy, Scikit-learn, Keras, Matplotlib will be used for modelling and data visualisation.

Distributed and cloud computing might be used when required. HKU's resources would be of first considerations due to limited budget, then commercial tools such as Microsoft Databricks and Google Colab.

Git and GitHub will be used for version control.

3.6 Case Studies and Areas of Focus

There are many countries in Europe with vastly different energy market dynamics. Due to limited time and manpower, this project will narrow its scope to focus on several countries and areas of the energy market.

Onshore & offshore wind generations are rapidly growing. They provide large amount of cheap energy, and seem to be significant factors on how interconectors behave.

Wind generations couple highly with weather conditions. Such nature provides an interesting opportunity to conduct quantitative research and modelling with computing in the area of Big Data and Machine Learning.

The energy market, as the name suggests, is fundamentally a financial market. Within this dynamic environment, one crucial component is the capacity market, ensuring a reliable supply of electricity. Additionally, interconnectors day-ahead future trading allows for cross-border electricity trading, contributing to market efficiency and energy security. These trading activities demand this project's attention as they play directly into how supply and demand of electricity behave. The quantitative and probabilistic nature of trading also introduce modelling opportunities that require advanced understandings in mathematics and computing.

With the reasons above, this projects will focus on the aspects of the energy markets related to interconnectors of several leading wind power nations: Denmark, UK, Netherlands, and Germany. The list is tentative.

4 Schedule and Milestones

Early Oct.	Seek and evaluate various data sources.
Late Oct. to mid Nov.	Basic data infrastructure ready. API clients are well boiler-plated. Some amount of clean data is available. Work will continue.
Mid Nov. and onward	Rapid modelling and experimentation: • Simple statistical analysis: market volatility, demand patterns, correlation analysis. • Simple machine learning models: SVMs, Random Forests, Gradient Boosting, etc. Further researches on the project scope: • Principles and regulations of electricity trading in the selected countries. • Understanding of the Capacity Market and Futures trading.
Late Dec. to early Jan.	Insights generated, and verifiable models are ready. Evaluate the need for more advanced modelling techniques both in terms of infrastructures (local vs distributed computing and etc), and more sophisticated models.
Mid Jan.	Interim report write-up.
Mid Jan. to Apr.	Deep modelling, experimentation with advanced and complex model architectures in one or two selected topics from the followings: • Time Series analysis with Long Short-Term Memory. • Transformer with Self-Attention. • Multi-agent simulation of hourly electricity bidding.

The schedule is tentative.