Short-term forecasting of electricity generation, demand and market prices using machine learning

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Preface

Repository: ENSYSTRA/short-term-forecasting

Short-term forecasting of electricity generation, demand and prices using machine learning [WIP].

This work is part of Nithiya Streethran's research as Early-Stage Researcher (ESR) 9 of the ENSYSTRA - ENergy SYStems in TRAnsition Innovative Training Network, based at the University of Stavanger. ENSYSTRA is funded by the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No: 765515.

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Acronyms

AI artificial intelligence
API application programming interface
BRP balance responsible party
CAPEX capital expenditure
CO_2 carbon dioxide
DNO distribution network operator
DSM demand-side management
EIC Energy Identification Code
ENSYSTRA ENergy SYStems in TRAnsition
ENTSO-E European Network of Transmission Systems Operators for Electricity
ESR early-stage researcher
EU European Union
GHG greenhouse gas
NUTS nomenclature of territorial units for statistics
OPEX operational expenditure
PCR Price Coupling of Regions
TSO transmission system operator
VRE variable renewable energy
WP work package

Background

The transition towards a future low-carbon economy is driven globally by the Paris Agreement [1], which recognises the need for sustainable development worldwide to counter the threats of climate change. The European Union (EU) is committed to reduce greenhouse gas (GHG) emissions by 2050 to 80-90 %

below 1990 levels [2]. As the energy industry is responsible for the highest share of anthropogenic GHG emissions, importance is placed on how changes in energy systems can help achieve these GHG emission reduction targets [2].

A number of opportunities exist for the decarbonisation of the energy industry. The International Renewable Energy Agency (IRENA), in their renewable energy roadmap study, has identified renewable energy as having the highest potential in reducing energy-related carbon dioxide (CO_2) emissions globally, which is closely followed by energy efficiency and electrification with renewable energy [3]. In a 2018 political agreement, the EU member states agreed upon a target of at least 32 % of the demand being met with renewables by 2030, through national targets of the individual member states [4]. The electricity demand in the transport sector is also expected to increase due to expected petrol and diesel engine bans and subsequently the electrification of road transport [5].

The energy system is also transitioning towards a decentralised system with more consumer participation and new forms of flexibilities, including sector coupling, demand-side management (DSM), energy conversion and storage, cross-border interconnection and curtailment. This allows demand patterns to shift to better suit the generation patterns in systems with high penetration of variable renewable energy (VRE) resources, such as solar and wind [6], [7]. However, this requires cooperation involving many actors with various responsibilities and dependencies that interact within this energy system, and opens up the opportunity to perform interdisciplinary research work in the area of energy system analysis.

The ENergy SYStems in TRAnsition (ENSYSTRA) Innovative Training Network has been established to address the challenges of the energy transition with interdisciplinary collaboration and regional cooperation involving academia, government and industry [8]. ENSYSTRA is centred on the North Sea region and focusses on performing interdisciplinary modelling work involving technology, economics, social science and humanities, and combining various modelling approaches in different levels and resolutions. ENSYSTRA aims to keep an open science approach, which will allow the resulting models to be subject to full scientific scrutiny.

Energy systems models, which are tools used to project the future energy supply of a country or region [9], is the centre of ENSYSTRA. Fig. 1 explains the energy systems modelling process using a system analysis approach. This process starts with creating a model of the actual energy system by simplifying and conceptualising the present system. This conceptualised system with all assumptions is then mathematically solved to produce numerical results. These results can then be interpreted and conclusions can be drawn regarding the future energy system. Such conclusions form the evidence-base for decision makers, resulting in policy implications or operational strategies that help achieve these climate targets.

There are 15 early-stage researchers (ESRs) across four work packages (WPs) in ENSYSTRA, as shown in fig. 2. The research project entitled "Development of a real-time optimisation solution for dispatchable energy supply units" is conducted by ESR 9, who is enrolled as a PhD student at University of Stavanger (UiS) in Norway. This project is within WP 2 (technology prospects and development pathways), which focusses on technological options for the energy transition, mainly in terms of techno-economic performance over time. For this research project, the technology focus is on the digitalisation of the electricity sector. As the electricity system transitions into smart systems, the system will have an increasing amount of sensors and controllers that continuously record measurements of the system [6]. Advancements in these technologies mean that data that is fast, heterogeneous and high in volume from the electricity system will be generated. Data with these characteristics must be managed and analysed effectively to gain insights on the electricity system, which can then be converted to strategies that optimise the system [11]. This project will specifically investigate how artificial intelligence (AI) can play a role in the transition to a low-carbon electricity system by utilising high resolution data of the system. The next section will investigate this, as well as explain what is meant by "real-time" and "dispatchable" in the context of electricity systems in this project.

Problem definition

Electricity system

The electricity system can be seen as having two components; the physical grid consisting of generators and transmission and distribution systems, and the electricity market consisting of a number of actors

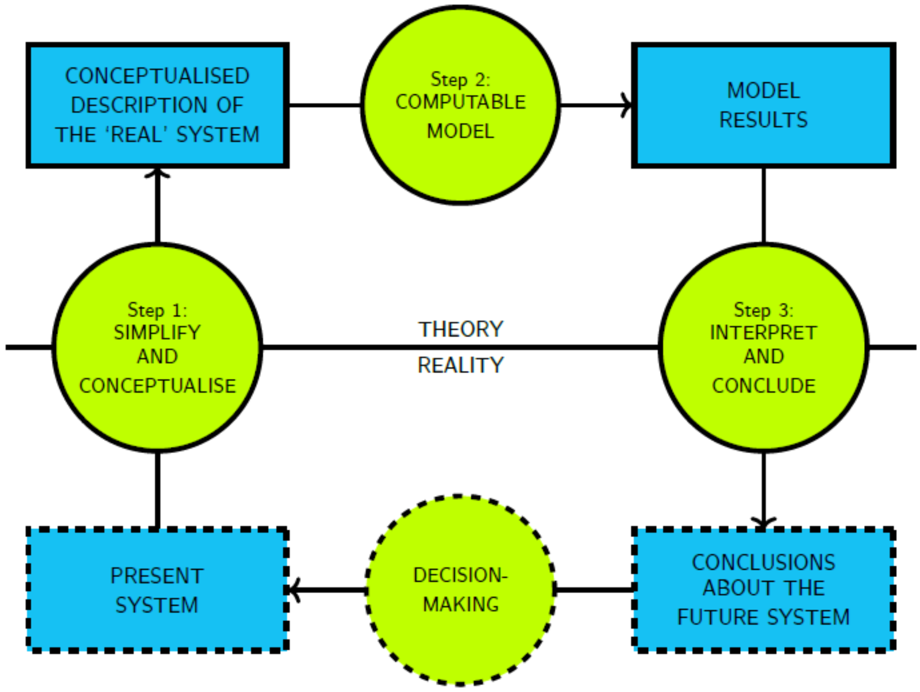

Figure 1: The system analysis approach applied on the energy system modelling process, adapted from Krook-Riekkola 2015 [10].

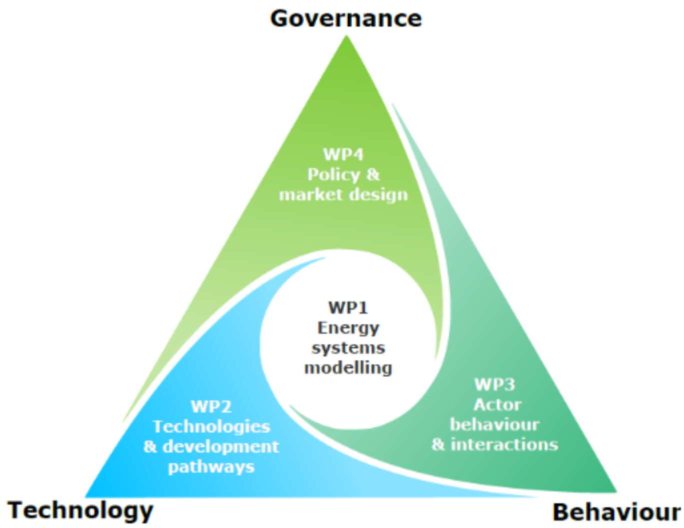

Figure 2: Interactions between the four WPs of the ENSYSTRA project. Source: ENSYSTRA [8].

[12].

Electricity systems exist in different resolutions and levels of uncertainty. Fig. 3 represents the different scales of electricity systems, mainly in terms of temporal resolution, but also uncertainty and spatial resolution [13], [14]. Temporally, "real-time" is referred to as the time of dispatch. It can be observed that the operational planning scale has high spatial and temporal resolution, and relatively low uncertainty. Operational planning includes dispatch planning and plant scheduling (i.e., unit commitment), which ranges from a few minutes to a week before dispatch. Maintenance planning can take a few weeks to years, as it involves upgrade and maintenance work which may require shut-down of units or assets, in turn affecting the availability of generation units and grid infrastructure. Adequacy assessments, which takes years, involve assessing the existing generation and storage capacities and planning for new installations based on demand projections, to ensure this demand will be met in the future. Finally, grid investment decisions, including planning transmission and distribution grid networks, cross-border and regional interconnections and grid capacity expansions, take many years to decades and have very high uncertainty as a result.

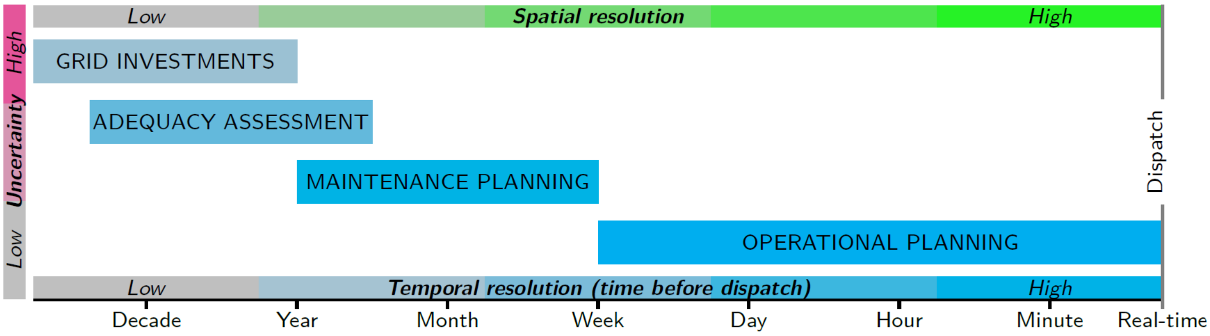

Figure 3: The various scales of electricity systems in terms of their approximate temporal resolution, as well as spatial resolution and uncertainty, adapted from Glismann 2018 and Pfenninger, et al. 2014 [13], [14].

Generation technologies

Tbl. 1 shows the characteristics of the main energy generation technologies, including their costs. These generation sources have different variabilities, fuel types, flexibilities, costs and carbon emissions. According to the EU reference scenario 2016 [15], wind and solar energy resources, which are VRE resources, are expected to generate a total of 35 % of EU's electricity by 2050, which is a significant increase (23 %) from 2015 levels. Conversely, generation from nuclear and solids, which are not variable and provide base load generation, are expected to decrease significantly. Unlike conventional generators, VRE are intermittent as they are dependent on atmospheric conditions, such as wind speed and cloud cover, and they vary both spatially (i.e., location-dependent) and temporally [16]. Therefore, VRE generation cannot be controlled to meet the demand patterns and needs of the energy system [16], which is a challenge to electricity and energy system operators in general. The costs listed in tbl. 1 are derived based on National Renewable Energy Laboratory (NREL)'s NREL-SEAC 2008 Data Set [17]. VRE generation technologies have high capital expenditure (CAPEX) compared to conventional fossil-powered and biomass generation. Conversely, the operational expenditure (OPEX), which includes fuel and fixed operational and maintenance (O&M) costs, is low for VRE generation technologies, as they have no fuel costs unlike conventional generators.

Table 1: Characteristics of the main energy generation technologies, adapted from Erbach 2016 [12] and Tidball, et al. 2010 [17]

Type[1]	**Variable**	**Fuel type**	**Flexibility**	**Low carbon**	**CAPEX**	**OPEX**	**LCOE**[2]
Coal	no	fossil	medium	no	low	high	very low
Natural gas	no	fossil	high	no	very low	very high	low
Biomass	no	renewable	medium	yes[3]	low	very high	very high
Nuclear	no	nuclear	low	zero-emission	medium	medium	medium
Hydro	no	renewable	very high	zero-emission			
Solar	yes	renewable	very low	zero-emission	very high	very low	very high
Wind	yes	renewable	very low	zero-emission			
Onshore wind					high	very low	very low
Offshore wind					very high	low	high
Geothermal	no	renewable	high	zero-emission	high	medium	high

Electricity market

The actors in the electricity market include generators, retailers, large and small consumers, transmission system operators (TSOs), distribution network operators (DNOs), balance responsible parties (BRPs), aggregators, regulators, and market operators [12], [18], [19].

[1] *Costs for natural gas, biomass, solar and geothermal are that of advanced combustion turbine, biomass gasification plant, utility-scale photovoltaic and hydrothermal plant respectively.*
[2] *LCOE - levelised cost of electricity.*
[3] *Regrowth of biomass compensates emissions.*

There are two types of electricity markets; the retail market and the wholesale market [12]. The retail market involves the retailers buying electricity from generators and selling it to consumers. The wholesale market involves generators, retailers and (large) consumers, who buy and sell electricity. Energy-only transactions in the wholesale market have different temporal resolutions [18], [19] and take place before dispatch, shown in green in fig. 4. Balancing markets, shown in pink in fig. 4, which involve both energy and services, operate both before and after dispatch [19]. The energy-only markets are operated by the market operator or power exchanges, while the balancing market is operated by the system operator. The day-ahead and intra-day markets can be considered short-term electricity markets, as the former takes place 24 hours in advance of dispatch, while the latter takes place continuously after the day-ahead market, up to minutes before dispatch [20].

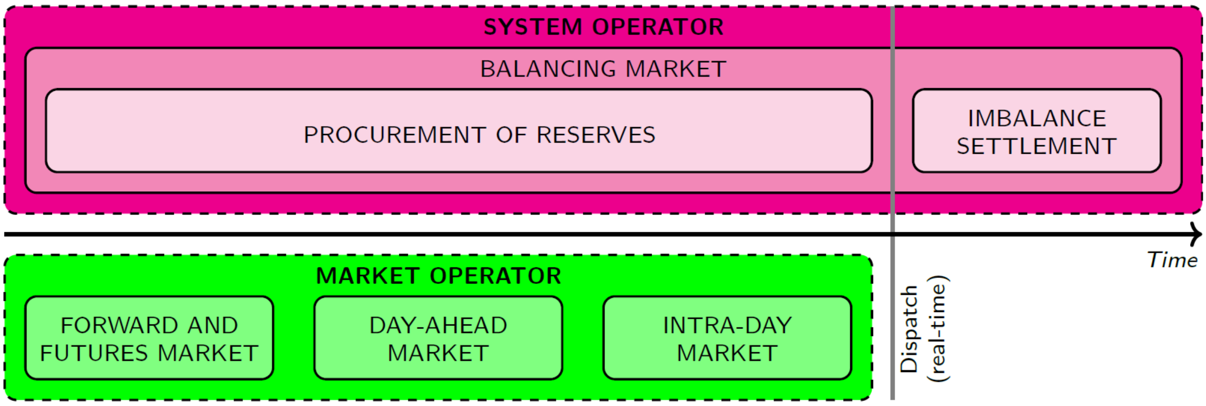

Figure 4: The various electricity markets in terms of operator and temporal resolution, before and after dispatch, adapted from KU Leuven Energy Institute 2015 and Pinson 2018 [18], [19].

In short-term electricity market auctions, such as the day-ahead market auction, generating companies have the incentive to bid as low as possible, as the supply bids are ranked in ascending order of price. Conversely, on the demand side, consumers have the incentive to bid as high as possible, as the demand bids are ranked in descending order of price. These two curves form a so called merit order, and the intersection between these two curves is the equilibrium point. The price at this equilibrium point is the market clearing price, which is what all accepted bids will receive, regardless of their initial bid. All supply and demand bids to the left of the equilibrium point will be accepted, and those to the right are rejected.

In the case of generating companies, the OPEX of their generators determine the price at which it is bid. For conventional power plants, this OPEX includes fuel costs and carbon costs (except nuclear power plants). For solar and wind power plants, the OPEX is close to zero, as they do not require fuel to run. The revenue received by generating companies in the day-ahead market for each power plant contributes towards their CAPEX. Since conventional power plants have relatively low CAPEX, and fuel costs are high, the main decision generating companies have to make in short-term electricity markets is whether it is economical to run these power plants. For solar and wind power plants, which have relatively high CAPEX, companies are interested in getting as many bids accepted and as much of the electricity generated sold as possible.

Objectives

The main research objective of this project is:

> *To develop an open-source electricity market model for the North Sea region which will help electricity generating companies that participate in short-term electricity markets (i.e., day-ahead and intra-day markets) to develop operational and bidding strategies that maximise their revenue under uncertainty of VRE generation. The model will consist of a forecaster based on machine learning, which will use high resolution time series weather forecasts for the upcoming period, and recent historical measurements of electricity generation, demand and market prices, to forecast the latter three quantities for the upcoming period. These forecasts will serve as inputs to a decision-making tool, which decides whether to sell, store and/or convert the electricity based on the most economical approach for the company's production*

portfolio.

Based on the main research objective, the following research questions have been derived:

- What methods and resources are needed to process and store the large volume of high resolution data required for this model?
- What type of machine learning algorithms are suited for the time series forecasting of electricity prices, demand and generation?
- What methods can be used to analyse the inputs and outputs of the model and translate them into operational strategies relevant to the market participant?
- How can this model be standardised and published so that it is available for use openly by any participant in the electricity market, as well as other interested parties, such as policymakers?
- How can this high resolution electricity market operational model be integrated with the overall North Sea energy systems model to provide insights on long-term planning and investments in the energy sector?

Regions

Territories in the North Sea region

As per the definition provided by the European MSP Platform [21] and the CPMR North Sea Commission [22], the North Sea region consists of eight countries: Belgium, Denmark, France, Germany, Netherlands, Norway, Sweden and United Kingdom.

The nomenclature of territorial units for statistics (NUTS) classifies territorial units in Europe in different levels [23]:

- NUTS 0: country-level
- NUTS 1: major socio-economic regions
- NUTS 2: basic regions for the application of regional policies
- NUTS 3: small regions for specific diagnoses

As explained in the problem definition section, short-term operational planning and systems with a high penetration of VRE must be described using data of high temporal and spatial resolutions. Therefore, NUTS 3 territories will be used as a standard in this project for aggregating short-term forecasting data.

This Jupyter notebook lists the NUTS territories in the North Sea region at all four NUTS levels. France is the only North Sea country with overseas territories included in the NUTS data (RUP FR - RÉGIONS ULTRAPÉRIPHÉRIQUES FRANÇAISES), so these were removed accordingly.

Performing the forecasting task at NUTS 3 level would be straightforward if it does not include the electricity market. Since the electricity market is considered in this project, it is important to look at how the bidding zones overlap with NUTS 3 territories.

Bidding zones in the North Sea region

A bidding zone is the largest geographical area within which market participants are able to exchange energy without capacity allocation [24]. According to [24], there are three types of bidding zones:

1. national borders (e.g., France or the Netherlands) - majority of bidding zones in Europe
2. larger than national borders (e.g., Germany and Luxembourg or the Single Electricity Market for the island of Ireland)
3. smaller zones within individual countries (e.g., Italy, Norway or Sweden)

The bidding zones in the North Sea electricity markets and surrounding regions are illustrated in fig. 5.

The power exchanges (market operators) that operate in the North Sea region are APX (Netherlands, United Kingdom), Belpex (Belgium), EEX (Germany, Denmark, France, Norway, Sweden), EPEX (Germany, France), N2EX (United Kingdom) and Nord Pool (Denmark, Norway, Sweden) [26], [20], [27], [28]. The day-ahead market takes place generally as an hourly auction 24 hours prior to dispatch [20]. The intra-day market has continuous trading and will operate until two hours and up to five minutes before dispatch [20].

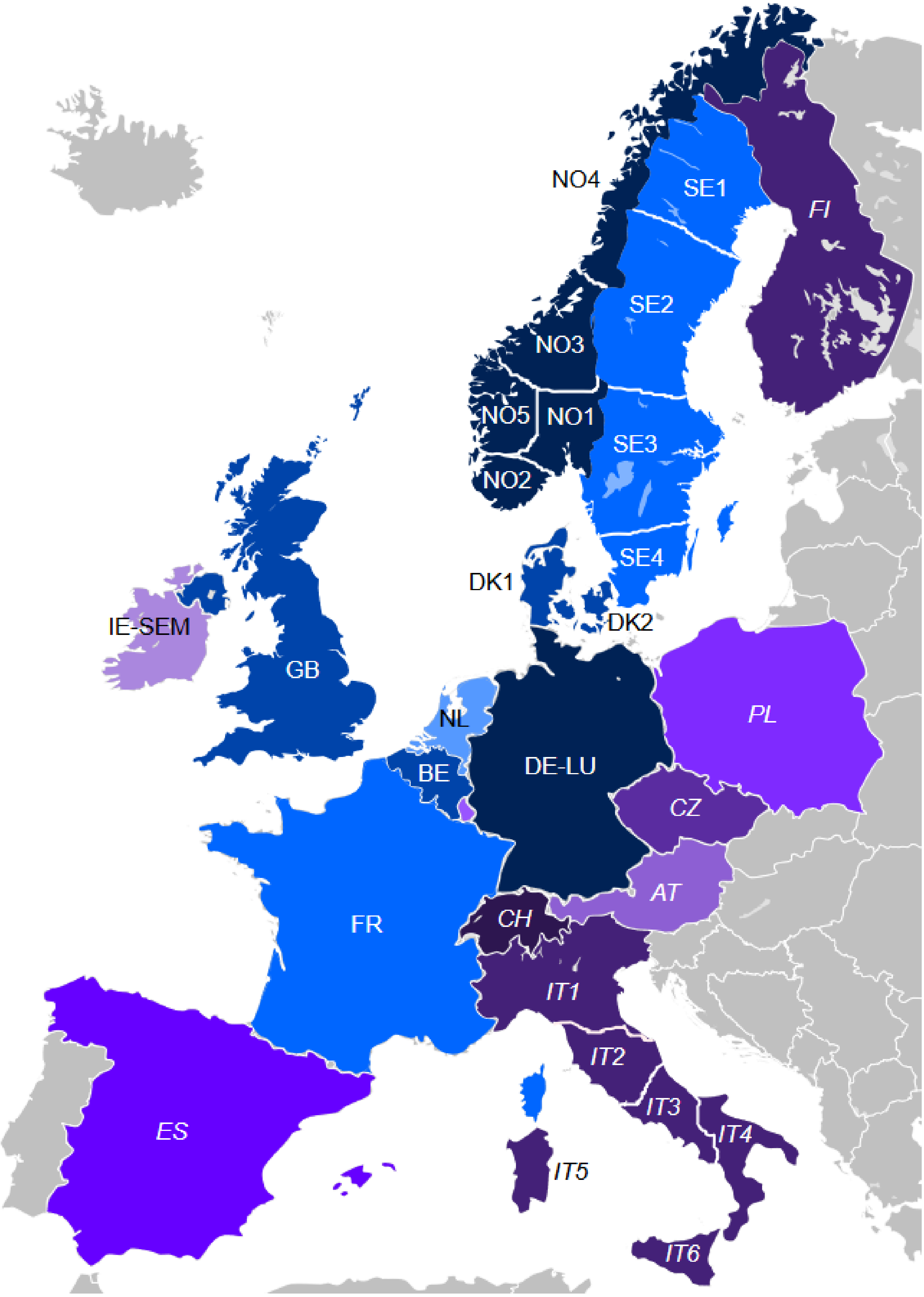

Figure 5: Bidding zones in the North Sea electricity markets and surrounding regions. Countries in the North Sea region are in blue, while neighbouring contries with interconnections are in purple. Made using a blank SVG map of Europe from Wikimedia Commons (CC-BY-SA-4.0) [25].

Both Nord Pool and EPEX are part of the Price Coupling of Regions (PCR) project which aims to develop a single price coupling solution for the calculation of day-ahead electricity prices in Europe, taking into account day-ahead network capacities [29].

Tbl. 2 below lists all bidding zones in the North Sea region by country and market operator.

Table 2: Bidding zones and market operators in the North Sea region.

Country	Markets	Zones[4]
Belgium (BE)	Belpex	BE
Germany (DE)	EEX, EPEX	DE-LU
Denmark (DK)	EEX, Nord Pool	DK1, DK2
France (FR)	EEX, EPEX	FR
Netherlands (NL)	APX	NL
Norway (NO)	EEX, Nord Pool	NO1, NO2, NO3, NO4, NO5
Sweden (SE)	EEX, Nord Pool	SE1, SE2, SE3, SE4
United Kingdom (UK)	APX, N2EX	GB, IE-SEM

Prior to 01/10/2018, Germany was part of the DE-AT-LU bidding zone, together with Austria and Luxembourg, which had split into the DE-LU and AT bidding zones, as reported by European Network of Transmission Systems Operators for Electricity (ENTSO-E) below [30].

> *[. . .] DE-AT-LU bidding zone split on the 23rd of August. BZN | DE-AT-LU will be separated into 2 new bidding zones BZN | DE-LU and BZN | AT.*
>
> *New bidding zones will be active from the 1st of October, however, first data submissions, like month ahead forecasts, are expected from the 1st of September.*
>
> *Validity end date for BZN | DE-AT-LU is the end of September 2018. [. . .]*

Mapping bidding zones to NUTS 3 territories is straightforward for Belgium, Germany, France and Netherlands (bidding zone type 1 or 2) – all NUTS 3 territories in these countries have the same bidding zone.

Denmark and United Kingdom are both conveniently separated into two zones that are easily distinguishable. For Denmark, these are Western Denmark (NUTS IDs containing DK03-DK05) and Southern Denmark (NUTS IDs containing DK01-DK02). For United Kingdom, these are Great Britain (NUTS IDs containing UKC-UKM) and Northern Ireland (NUTS IDs containing UKN).

There is no clear indication of the bidding zone boundaries for Norway and Sweden, so some assumptions were made. Both countries have multiple smaller bidding zones (type 3) with flexible borders [31], [32]. This was done to optimise allocation of resources and reduce the overall price of electricity [31], [32]. Norway has five zones and Sweden has four zones. By cross-referencing Nord Pool market data [27], NUTS 3 data and county maps of Norway [33] and Sweden [34], the territories are split into the bidding zones as shown in tbl. 3. Nord Pool associates each bidding zone with a major reference city in that zone. However, there were six cities for Norway instead of the expected five. Historical Nord Pool market data for Norway suggests that two cities, Trondheim and Molde, have had the same system price since 2003. The ELSPOT area change log [32] also confirms that Trondheim and Molde are city references for the NO3 bidding zone . Therefore, these two cities are grouped into the same bidding zone, which also satisfies what the maps suggest.

Table 3: Bidding zones and their territories for Norway and Sweden, approximated based on Nord Pool market data [27], [32], NUTS 3 data and county maps of Norway [33] and Sweden [34].

Bidding zone	Reference cities	Counties	NUTS 3 IDs
NO1	Oslo	Oslo, Akershus, Hedmark, Oppland, Østfold, Buskerud, Vestfold, Telemark	NO011-034
NO2	Kristiansand	Aust-Agder, Vest-Agder, Rogaland	NO041-043
NO3	Trondheim, Molde	Sogn og Fjordane, Møre og Romsdal, Trøndelag	NO052-060
NO4	Tromsø	Nordland, Troms, Finnmark	NO071-073
NO5	Bergen	Hordaland	NO051

[4] *Luxembourg (LU); Great Britain (GB); Irish single electricity market (IE-SEM), which includes Republic of Ireland and UK's Northern Ireland.*

Bidding zone	Reference cities	Counties	NUTS 3 IDs
SE1	Luleå	Norrbotten	SE332
SE2	Sundsvall	Gävleborg, Västernorrland, Jämtland, Västerbotten	SE313-331
SE3	Stockholm	Stockholm, Uppsala, Södermanland, Östergötland, Örebro, Västmanland, Jönköping, Gotland, Västra Götaland, Värmland, Dalarna	SE110-211, SE214, SE232-312
SE4	Malmö	Kronoberg, Kalmar, Blekinge, Halland, Skåne	SE212-213, SE221-231

This Jupyter notebook lists all NUTS 3 territories and their bidding zones in the North Sea region, and explains how the different bidding zones were assigned to the territories.

Transmission system operators and interconnections

The North Sea region consists of multiple TSOs and cross-border interconnections. These are listed, along with the bidding zones bidding zones, in tbl. 4.

Table 4: TSOs and cross-border interconnections in the North Sea region. Data: European Network of Transmission System Operators for Electricity [35], [36].

Ctry.[5]	TSOs	Cross-border interconnection[6]	Bidding zones
BE	Elia System Operator	FR, LU, NL, UK	BE
DK	Energinet	DE, NO, SE	DK1, DK2
DE	TransnetBW, TenneT TSO, Amprion, 50Hertz Transmission	AT, CH, CZ, DK, FR, LU, NL, PL, SE	DE-LU
FR	Réseau de Transport d'Electricité	BE, CH, DE, ES, IT, UK	FR
NL	TenneT TSO	BE, DE, NO, UK	NL
NO	Statnett	DK, FI, NL, SE	NO1, NO2, NO3, NO4, NO5
SE	Svenska Kraftnät	DK, FI, DE, LT, NO, PL	SE1, SE2, SE3, SE4
UK	National Grid Electricity Transmission, System Operator for Northern Ireland, Scottish Hydro Electric Transmission, ScottishPower Transmission	BE, FR, IE, NL	GB, IE-SEM

Data

All input and output data can be found in the data folder on Dropbox. Licenses and terms of the input data used can be found in their corresponding folders.

Folder navigation

- **entsoe-api** - generation and load data at TSO level for each bidding zone, downloaded from the ENTSO-E Transparency Platform
- **met** - meteorological data, grouped by country, downloaded from country-specific meteorological services
- **nuts** - territorial units, downloaded from Eurostat
- **output** - output data

Generation and load data

Generation and load data for each bidding zone are downloaded from the ENTSO-E Transparency Platform [35]. The following descriptions of the data are from ENTSO-E Transparency Platform's Knowledge Base [37]. Three types of data will be used.

[5] *Ctry. - Country; AT - Austria; BE - Belgium; CH - Switzerland; CZ - Czech Republic; DE - Germany; DK - Denmark; ES - Spain; FI - Finland; FR - France; GB - Great Britain; IE - Ireland; IT - Italy; LT - Lithuania; LU - Luxembourg; NL - Netherlands; NO - Norway; PL - Poland; SE - Sweden; SK - Slovakia; UK - United Kingdom; SEM - Single electricity market.*

[6] *These countries are not part of the North Sea region: AT, CH, CZ, ES, FI, IE, IT, LT, LU, PL.*

Actual generation per production type

- Actual aggregated net generation output (MW) per market time unit and per production type
- Published no later than one hour after the operational period
- Computed as the average of all available instantaneous net generation output values on each market time unit
- If unknown, it is estimated
- The actual generation of small-scale units might be estimated if no real-time measurement devices exist

Installed capacity per production unit

This data contains information about production units (existing and planned) with an installed generation capacity of at least 100 MW, which includes the following:

- unit name
- code
- installed net generation capacity (MW)
- voltage connection level (kV)
- bidding zone (Energy Identification Code (EIC))
- production type (e.g., fossil gas, wind offshore)

This information is published annually at the start of the year and is valid for the three following years.

Load

- Actual total load per bidding zone per market time unit
- The total load is defined as equal to the sum of power generated by plants on both TSO/DNO networks, from which is deduced:
  - the balance (export-import) of exchanges on interconnections between neighbouring bidding zones
  - the power absorbed by energy storage resources
- The information is published no later than one hour after the end of the operating period
- Calculated using the average of real-time load values per bidding zone per market time unit
- Actual total Load (including losses without stored energy) = Net Generation – Exports + Imports – Absorbed Energy
- Net generation is preferred, but gross generation could be used where it is available with the better precision
- TSOs should decide gross or net generation will be used but the net/gross characteristic should be consistent per bidding zone
- Absorbed energy is also provided as separate information with the aggregated generation output of the hydro pumped storage
- The physical flow on the tie line is measured as agreed by neighbouring TSOs or bidding zones, where applicable

Extracting data through ENTSO-E Transparency Platform's Restful API

ENTSO-E Transparency Platform's RESTful application programming interface (API) can be used to automate the data extraction process [38], [39]. Registration to the transparency platform is required to access the API. The security token can be requested by sending an email to the ENTSO-E Helpdesk.

The ENTSO-E API Python client [40] is used to easily query the required data and return them as Pandas dataframes or series. The queries for generation and installed generation capacity per unit return dataframes, while the query for load returns a series. `entsoe_api.py` is the script used to perform this.

```
import pandas as pd
from entsoe import EntsoePandasClient
from entsoe.mappings import DOMAIN_MAPPINGS, BIDDING_ZONES
# combine domain and bidding zone keys and values into the DOMAIN_MAPPINGS
    dictionary
DOMAIN_MAPPINGS.update(BIDDING_ZONES)
```

```
# import security token saved in a separate file (login.py)
from login import token
# use security token to access the api through the entsoe pandas client
client = EntsoePandasClient(api_key=token)
```

The bidding zones in the North Sea region, mapped to their corresponding EICs as shown in tbl. 5, are used when querying using the Pandas client. Note that `DE-LU` only works for timestamps starting 01/10/2018. Use `DE-AT-LU` for timestamps prior to this date.

Table 5: Bidding zones in the North Sea region and their corresponding EICs.

Bidding zone	EIC
BE	10YBE———-2
DE-LU	10Y1001A1001A82H
DK-1	10YDK-1——–W
DK-2	10YDK-2——–M
FR	10YFR-RTE——C
GB	10YGB———-A
IE-SEM	10Y1001A1001A59C
NL	10YNL———-L
NO-1	10YNO-1——–2
NO-2	10YNO-2——–T
NO-3	10YNO-3——–J
NO-4	10YNO-4——–9
NO-5	10Y1001A1001A48H
SE-1	10Y1001A1001A44P
SE-2	10Y1001A1001A45N
SE-3	10Y1001A1001A46L
SE-4	10Y1001A1001A47

Market data

Nord Pool

Historical market data from Nord Pool is stored as `.xls` files can be accessed using the following URL:

`https://www.nordpoolgroup.com/globalassets/marketdata-excel-files/FILENAME.xls`

- Membership list - Nord Pool
- Terms and conditions for use

EPEX Spot

- EPEX SPOT Exchange Members

REMIT UMM

REMIT Urgent Market Messaging (UMM) is used by market operators and companies involved in balancing and settlements, including Nord Pool and ELEXON, for market members and participants to publish information on outages in production, consumption and transmission and other relevant market information according to European transparency regulations [41], [42], [43], [44], [45]. The information is publicly available and is classified as follows:

- Event
  - Unavailability of electrical facilities (production, consumption, transmission)
  - Market information
- Infrastructure (the electrical facility(ies) that are affected)
- Areas (bidding zone and/or country and/or control area)
- Types of unavailability (planned or unplanned)
- Stations (production and consumption units)
- Fuel types (same as the production units used by ENTSO-E)
- Connections (between control areas and/or bidding zone)
- Status (active or cancelled)
- Publishers (companies that publish the information)

- Market participants
- Publication time
- Event start and stop time
- Duration of event
- Unavailable capacity (MW)
- Available capacity (MW)
- Assets (grid components, e.g., AC link, DC link, transformer, substation)
- Remarks

Meteorological data

Belgium

The Royal Meteorological Institute of Belgium

Germany

Deutscher Wetterdienst [46]

Hourly wind data

Denmark

Danish Meteorological Institute

France

Météo-France

Netherlands

Royal Netherlands Meteorological Institute

Norway

Norwegian Meteorological Institute

Sweden

Swedish Meteorological and Hydrological Institute

United Kingdom

Met Office

Territorial units

NUTS (Nomenclature of territorial units for statistics)

Terms of use

Deutscher Wetterdienst

- Terms of use for data on the CDC ftp server

ENTSO-E Transparency Platform

- GENERAL TERMS AND CONDITIONS FOR THE USE OF THE ENTSO-E TRANSPARENCY PLATFORM
- LIST OF DATA AVAILABLE FOR FREE RE-USE

Methodology

In progress

References

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