24/7 - A new paradigm for power procurement?

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What is 24/7 carbon-free procurement?

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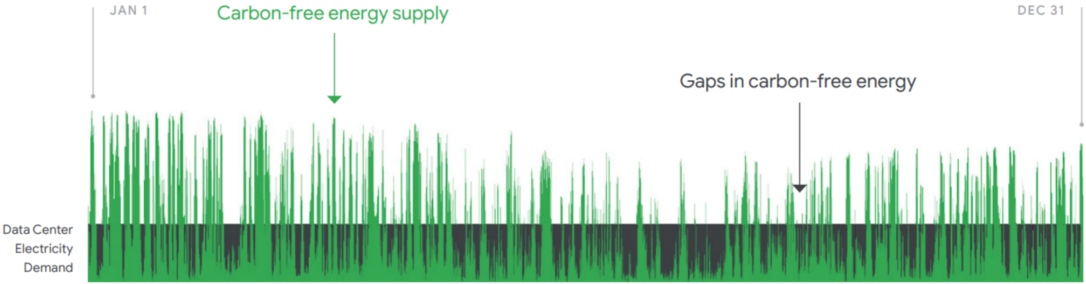
- Many companies are signing **Power Purchase Agreements** (PPAs).
- PPAs for renewable energy are typically used to match generation and consumption on **average over a year**.
- Such voluntary commitments **accelerate the deployment** of renewable capacity and **pave the way** for others to follow.

More than 370 companies have joined **RE100**

source: RE100

Great, so what's the problem?



source: Google 2021, 24/7 CFE: Methodologies and Metrics

24/7 carbon-free energy

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There is growing interest from leaders in voluntary clean electricity procurement to cover their consumption with clean energy supply on a **truly 24/7 basis**.

Achieving 24/7 Carbon-Free Energy (CFE) means that every kilowatt-hour of electricity consumption is met with carbon-free electricity sources, **every hour of every day**.

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Ideas behind **24/7 CFE** procurement:

- Insist that demand is matched on an **hourly basis**
- Insist that contracted power is **additional**
- Insist power comes from the **same bidding zone**
- Insist that power is **carbon-free** rather than renewable (i.e. technology neutrality)

The 24/7 Carbon-free Energy Compact initiative was launched in 2021.
It now includes more than 80 companies and organizations.

Study design

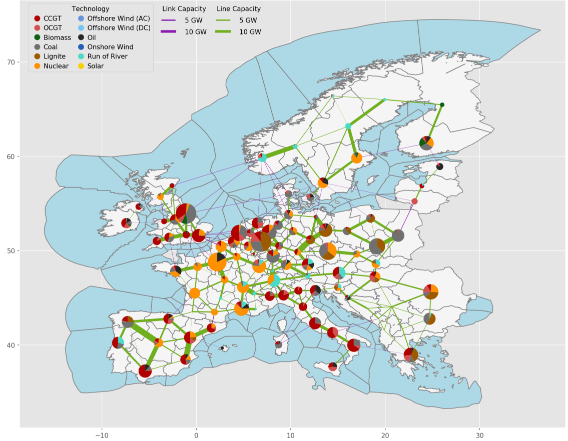
Study design

In cooperation with Google Inc, we want to investigate both the **means and costs of 24/7 procurement** for companies in a selection of European countries and the **system impacts** for the rest of the European electricity system.

For this purpose, we co-optimize:

- A model of the European energy system **PyPSA-Eur(-Sec)**
- A fraction of corporate and industry (C&I) electricity consumers that commits to a voluntary clean energy procurement
- We explore: different countries and years (states of the system), different shares of demand pursuing 24/7, different technology options, different 24/7 targets, impacts of C&I load profiles, and more!

Clustered electricity network of 100 nodes without variable renewable energy sources



Results and takeaways

What you can learn from our study

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Takeaway 1: Reaching carbon-free energy (CFE) for 80-90% of the time has **comparable cost and system impact** to annually matching 100% renewable energy. A CFE target of 80-90% can be met through a combination of wind, solar and batteries.

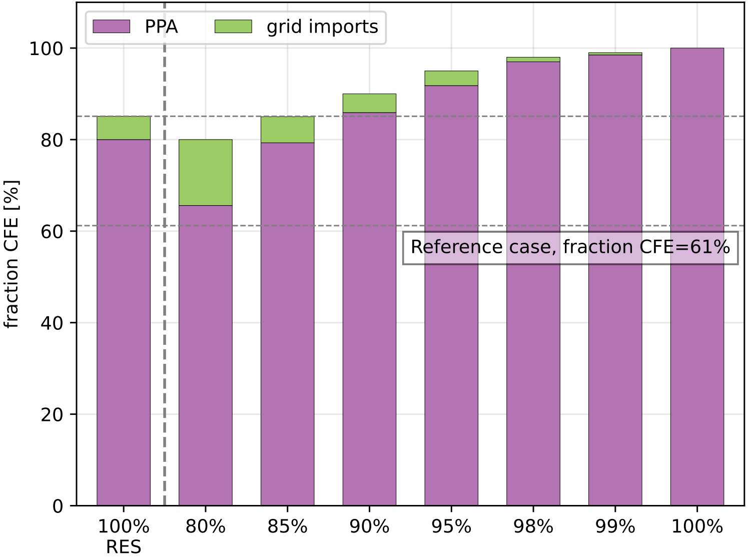
Takeaway 2: Reaching 100% CFE is possible but costly with existing renewable and storage technologies, with **costs increasing rapidly above 95%**.

Takeaway 3: 100% 24/7 CFE procurement could have a **much smaller cost premium** if long duration energy storage or clean dispatchable technologies like advanced geothermal are available.

Takeaway 4: 24/7 CFE procurement leads to **lower emissions for both the buyer and the system**, as well as reducing the needs for flexibility in the rest of the system.

Takeaway 5: 24/7 CFE procurement targets would create an early market for advanced technologies, stimulating innovation and learning from which the **whole electricity system would profit**.

Fraction of hourly demand met with carbon-free electricity

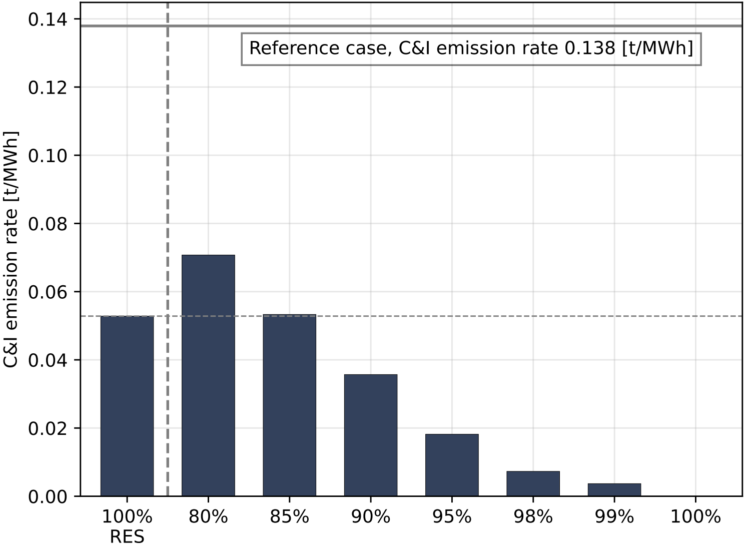


If C&I consumers do not procure resources and rely purely on grid purchases, **only 61%** of demand is met with CFE.

100% annual renewable matching results in **85% fraction**.

When CFE target approaches 100%, C&I participants **rely more on procured resources**.

Average emissions rate of C&I consumption



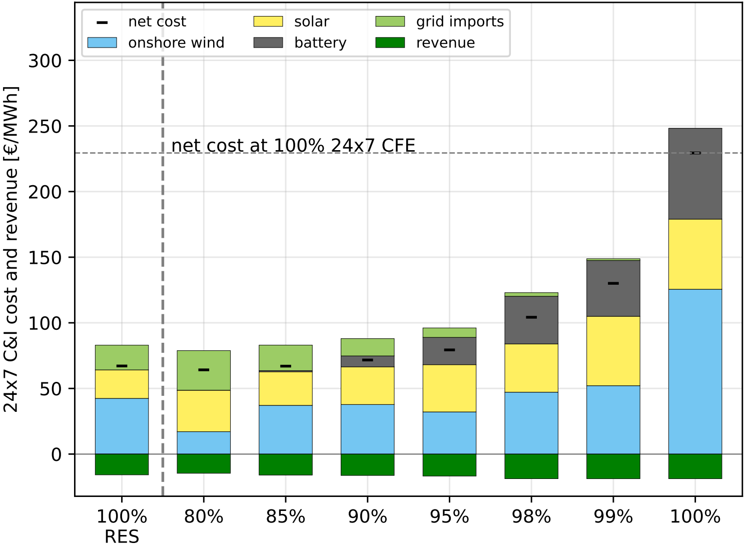
Already in 2025, Ireland has a moderately clean electricity system: (138 kg/MWh).

100% RES - the best case of the annual renewable matching – yields **53 kg/MWh**.

With 24/7 CFE mathing, C&I participants achieve lower emission rate than with the 100% RES policy with CFE targets beyond 85%.

As CFE target is tightened further, emissions rate **drop to zero**.

C&I procurement cost breakdown



100% RES procures wind and solar.

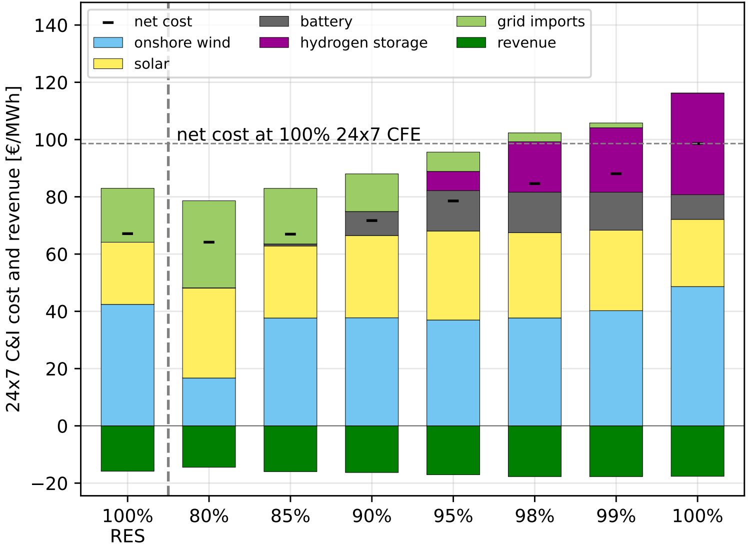
Higher CFE targets include **battery storage**.

Rapid increase of procurement costs for high CFE targets:

– 98% CFE has cost premium of only 55% over 100% RES;

– while **the last 2%** of hourly CFE matching **more than doubles the cost**.

C&I procurement cost breakdown (+LDES in tech palette)

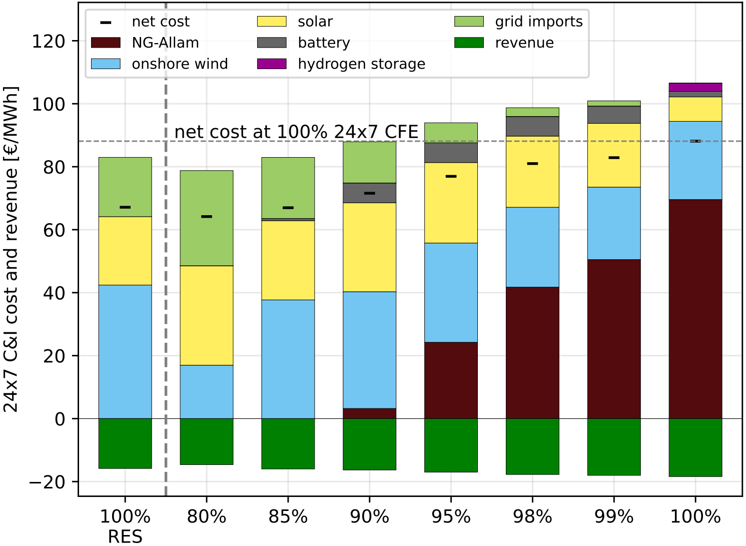


Long duration energy storage (here 2.5 €/kWh hydrogen storage in caverns) significantly **limits the procurement cost increase**.

With LDES, 100% CFE is ca. **50%** above 100% RES policy.

(Of course, this result strongly depends on cost assumptions and system parameters.)

C&I procurement cost breakdown (+LDES and advanced clean tech)

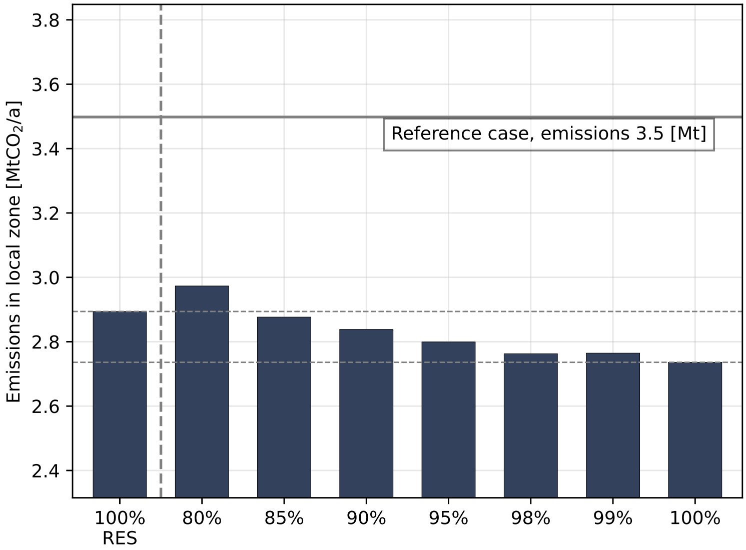


NG Allam Cycle generator is added to the portfolio.

The clean dispatchable technology **further reduces the CFE cost premium** above 100% RES (in some scenarios - nearly remove the cost premium).

NG: advanced dispatchable technology also reduces storage requirements.

Carbon emissions in the regional grid



Without any procurement, the Irish power sector carbon emissions are at 3.5 $MtCO_2$ (for comparison, **seai.ie** reports 8.4 $MtCO_2$ in 2020, with a strong decreasing trend).

100% RES can deliver greater system-level CO_2 emissions reductions than lower CFE scores. 100% RES reduces emissions by ca. 0.6 $MtCO_2$ per year (at 10% participation = 220 MW C&I load).

System emissions reduce with higher CFE scores, as system-friendly CFE eats into fossil backup in system.

24/7 - A new paradigm for power procurement?

A study resease is on the next week (11 October 2022)

All input data and code for this study is already open and freely available at

https://github.com/PyPSA/247-cfe

For questions and inquiries, feel free to contact

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backup

PyPSA: an energy systems modelling toolbox

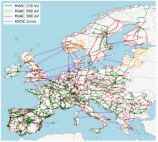
- PyPSA (Python for Power System Analysis) is an open source toolbox for for state-of-the-art energy system modelling.
- Fills gap between power flow software (e.g. PowerFactory, MATPOWER) and energy system planning software (e.g. TIMES, OSeMOSYS).
- PyPSA development and maintenance is coordinated by the TU Berlin, **Department of Energy Systems**.
- PyPSA is used worldwide by dozens of research institutes and companies. See **list of users**.

PyPSA

A python software toolbox for simulating and optimising modern power systems.

Documentation »

PyPSA-Eur



An open optimisation model of the European transmission system.

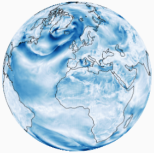
Documentation »

PyPSA-Eur-Sec

A sector-coupled open optimisation model of the European energy system.

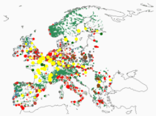
Documentation »

Atlite



A Lightweight Python Package for Calculating Renewable Power Potentials and Time Series

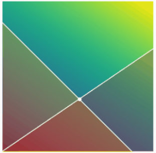
Powerplantmatching



A toolset for cleaning, standardizing and combining multiple power plant databases.

Documentation »

Linopy



Linear optimization interface for N-D labeled variables.

PyPSA-Eur(-Sec): open models of the European energy system

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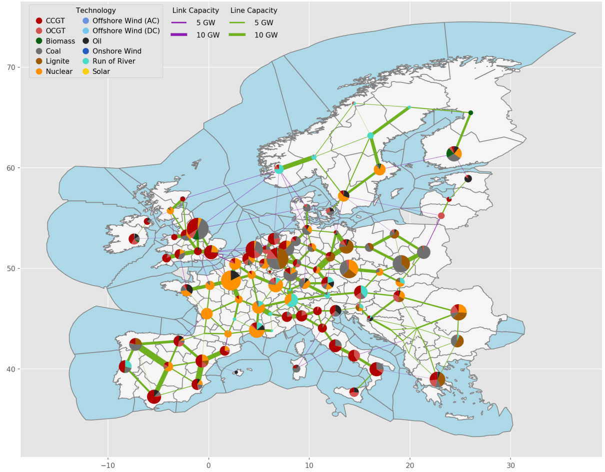
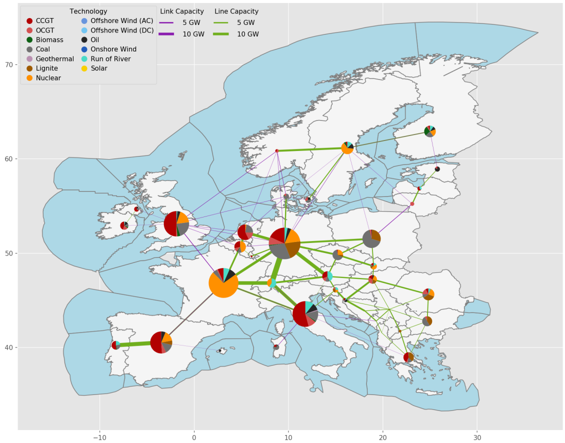
- PyPSA-Eur is an open model of the European power system at the transmission network level that covers the full ENTSO-E area.
- Only freely available and open data.
- Automated and configurable software pipeline from raw data to optimised electricity system.
- Adjustable temporal and spatial resolution.
- See **documentation** and **feature summary** for more details.
- PyPSA-Eur-**Sec** version of the model adds building heating, transport and industry sectors, as well as gas networks.

Clustered electricity network of 100 nodes without variable renewable energy sources



PyPSA-Eur(-Sec) suite of models are available on **GitHub**

Scenario setup 1/3



PyPSA-Eur network clustered to 37 zones

- In each scenario, we model the full European power system clustered to **37 zones**.
- Each zone represents an individual country. Some countries that straddle different synchronous areas are split to individual bidding zones, such as DK1 (West) and DK2 (East).
- Consumers following 24/7 approach can be located in either of the **four zones**: Ireland, Denmark (zone DK1), Germany and the Netherlands.
- We assume that all consumers committed to 24/7 matching, form an alliance and sign contracts with CFE generators so that their aggregated consumption can be matched on an hour-by-hour basis with clean generation to achieve a given CFE matching score.

Scenario setup 2/3

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- We model various procurement policies and targets. The scenarios include:
  (i) **24/7 CFE matching** with seven different CFE scores in a range from 80% to 100%,
  (ii) **100% annual renewable matching** – the best case scenario for the annual matching policy,
  (iii) **A reference case** when 24/7 consumers cover their load purely with grid purchases without any policy regarding the origin of electricity.

- We conduct an analysis for different rates of participation. The two scenarios assume that **10%** and **25%** of commercial and industrial load in a given zone participate in 24/7 CFE matching.

- We focus on two periods: **2025** and **2030**. The two periods differ by
  (i) Technology cost assumptions,
  (ii) National renewable expansion pathways,
  (iii) Power plant fleet (changes take place due to decommissioning based on generators' age or national policies),
  (iv) System-wide assumptions, such as price for EU ETS allowances.

Scenario setup 3/3

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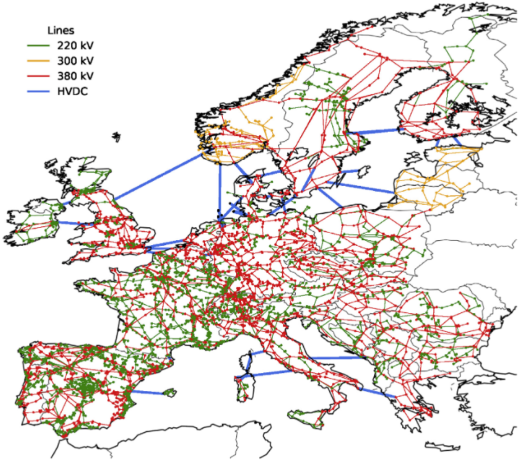
- We assume that 24/7 consumers have an access to a wide palette of carbon-free technologies that are either available on the European market now or expected to be available for a commercial scale up in the near future.
- We deliberately encode prospective technologies into the analysis. The **technology inclusivity** is an **important principle** of the 24/7 CFE methodology. Thus, we consider carbon-free power generation technologies that we believe can play important roles in facilitating CFE matching on hourly basis, while enabling deeper decarbonization of electricity systems at the same time.
- We formulate three scenarios grouping generators by a degree of technological maturity as of now:
  Palette 1: onshore wind, utility-scale solar, battery storage
  Palette 2: all above + long-duration energy storage (hydrogen storage system)
  Palette 3: all above + Allam Cycle natural gas generator with carbon capture and sequestration + advanced clean dispatchable generator (e.g., advanced geothermal system or advanced nuclear technology)

Summary of data sources: electricity grid

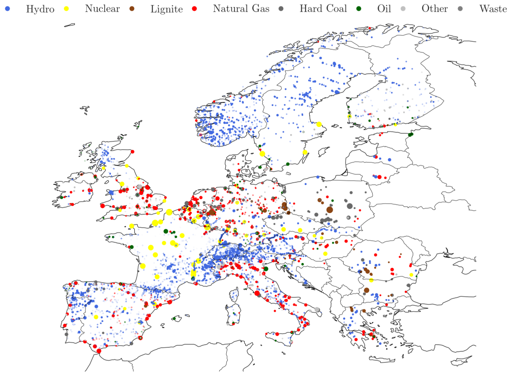


Basic validation of grid model in **Hörsch et al. (2018)**

- Grid data contains AC lines at and above 220 kV voltage level, all high voltage DC lines, and substations for the full **ENTSO-E area**.
- Grid data is collected by **GridKit extraction** of ENTSO-E interactive map
- Spatial resolution is **adjustable**, what allows spatial and topological analysis at different levels (e.g. by transforming the transmission grid to a 380 kV only equivalent network).

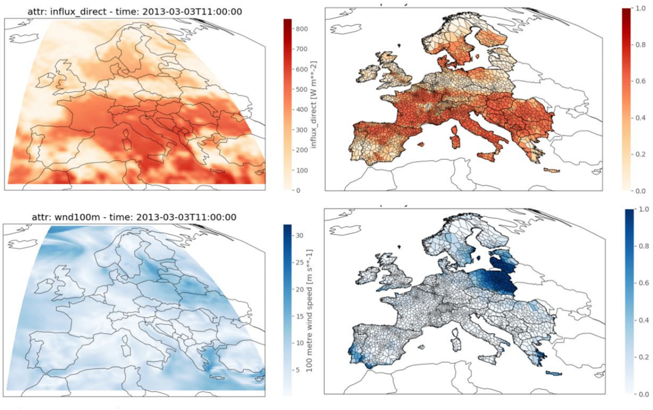
Summary of data sources: power plants and technology costs

- Existing generation fleet data is collected by cleaning, standardizing and merging multiple power plant databases.
- The process is transparent and open-sourced via the **powerplantmatching** package. The package provides all the important information about power plants in a ready-to-use format for the European power system.
- Assumptions on energy system technologies (such as capital and operational costs, efficiencies, lifetimes, etc.) are gathered from variety of open sources. The process is also open-sourced via the **technology-data** project.
- Both tools are maintained by TU Berlin team.



A showcase example of **powerplantmatching**

Summary of data sources: renewable potentials and time series



Converting weather data to energy system data with **atlite**

- Renewable power potentials and generation profiles are processed by the open-source **atlite** package, which converts terabytes of weather data (like wind speeds, solar influx) into the data for energy systems modelling.
- Geographic potentials for renewable energy are based on the **GLAES** framework. We gather and process datasets for land cover (CORINE2018), natural protection areas (NATURA2000), bathymetry (GEBCO2018) and **other** to conduct own geospatial land availability analysis.
- The **atlite** project is also maintained by TU Berlin team.

Other assumptions

- Model is set to perform a **perfect-foresight optimization** of investment and power dispatch decisions to meet electricity demand of the 24/7 consumers, as well as the demand of other consumers in the European electricity system for 2025 or 2030.
- Electrical demand time-series is based on the **OPSD project**. We assume the same demand profile per bidding zone for 2025 and 2030, as in the representative year 2013.
- Similarly, we assume 2013 as the representative climate year for renewable in-feed.
- Renewable expansion in the regional grid where 24/7 consumers are located is based on the **national energy and climate plans**.[1]
- National policies and decommissioning plans for coal and nuclear power plants are based on the **Europe Beyond Coal**, and **world-nuclear.org** projects.
- We assume price for EU ETS allowances to be 80 €/tCO_2 and 130 €/tCO_2 for 2025 and 2030, accordingly. The price for natural gas is assumed to be 35 €/MWh.[2]

[1] For Germany, we assume the **Easter package** to come into force as planned, i.e. RES cover 80% of gross electricity consumption by 2030.

Technologies available for 24/7 consumers - 2025

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Palette	Technology	CAPEX (overnight cost)	FOM (%/year)	VOM (€/MWh)	Eff. (per unit)	lifetime (years)	Original reference (**technology data**)
1,2,3	solar	612 €/kW	1.7	0.01	-	37.5	**DEA**
1,2,3	onshore wind	1077 €/kW	1.2	1.42	-	28.5	**DEA**
1,2,3	battery storage	187 €/kWh	-	-	-	22.5	**DEA**
1,2,3	battery inverter	215 €/kW	0.3	-	0.96	10.0	**DEA**
2,3	hydrogen storage[3]	2.5 €/kWh	0	0	-	100.0	**DEA**
2,3	electrolysis	550 €/kW	2.0	-	0.67	27.5	**DEA**
2,3	fuel cell	1200 €/kW	5.0	-	0.50	10.0	**DEA**
3	NG Allam cycle[4]	2760 €/kW	14.8	3.2	0.54	30.0	**Navigant**, **NZA**
3	Advanced dispatchable[5]	10000 €/kW	0	0	1.00	30.0	own estimates

[3] Underground hydrogen storage in salt cavern

[4] Costs also include estimate of 40 €/ton for CO_2 transport & sequestration.

[5] A stand-in for clean dispatchable technologies, such as advanced geothermal (closed-loop) systems. See e.g., **Eavor** developing a promising solution for clean baseload & dispatchable power with a potential for a commercial scale up in Europe.

Technologies available for 24/7 consumers - 2030

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Palette	Technology	CAPEX (overnight cost)	FOM (%/year)	VOM (€/MWh)	Eff. (per unit)	lifetime (years)	Original reference (**technology data**)
1,2,3	solar	492 €/kW	2.0	0.01	-	40	**DEA**
1,2,3	onshore wind	1035 €/kW	1.2	1.35	-	30	**DEA**
1,2,3	battery storage	142 €/kWh	-	-	-	25.0	**DEA**
1,2,3	battery inverter	160 €/kW	0.3	-	0.96	10.0	**DEA**
2,3	hydrogen storage[6]	2.0 €/kWh	0	0	-	100	**DEA**
2,3	electrolysis	450 €/kW	2.0	-	0.68	30.0	**DEA**
2,3	fuel cell	1100 €/kW	5.0	-	0.5	10.0	**DEA**
3	NG Allam cycle[7]	2600 €/kW	14.8	3.2	0.54	30	**Navigant**, **NZA**
3	Advanced dispatchable[8]	10000 €/kW	0	0	1	30	own estimates

[6] Underground hydrogen storage in salt cavern

[7] Costs also include estimate of 40 €/ton for CO_2 transport & sequestration.

[8] A stand-in for clean dispatchable technologies, such as advanced geothermal (closed-loop) systems. See e.g., **Eavor** developing a promising solution for clean baseload & dispatchable power with a potential for a commercial scale up in Europe.

Modeling 24/7 CFE procurement

- We implement a set of additional constraints to the PyPSA-Eur to model a situation when a fraction of corporate and industry (C&I) demand commits to the 24/7 CFE procurement.
- The model optimises investment and operational decisions to meet projected electricity demand for the 24/7 CFE consumers, as well as the demand of other consumers in the European electricity system, while meeting all relevant engineering, reliability, and policy constraints.

The methods are based on the Google's CFE procurement framework, presented in paper "24/7 Carbon-Free Energy: Methodologies and Metrics"

source: Google 2021, 24/7 CFE: Methodologies and Metrics

Implementation of 100% annual matching

The model optimizes a portfolio of carbon-free generation and storage technologies procured by the participating C&I consumers. The portfolio assets have to be located in the same market zone.

The **100% annual matching** is modelled with a constraint (1), which requires C&I consumers to purchase enough renewable electricity from the local bidding zone to match all of their electricity consumption on an annual basis.

More formally, the sum of all dispatch $g_{r,t}$ for RES generators $r \in RES$ over the year $t \in T$ is equal to the annual demand d_t of C&I consumers:

$$\sum_{r \in RES, t \in T} g_{r,t} = \sum_{t \in T} d_t \qquad (1)$$

Implementation of 24/7 CFE matching

The **24/7 CFE matching** is modelled with a constraint (2), which matches demand of C&I consumers with carbon-free resources on an hourly basis.

More formally, the constraint states that sum over generators from procured CFE resources $r \in CFE$, discharge and charge from storage technologies $s \in STO$, as well as import from the grid im_t multiplied by the grid's CFE factor CFE_t must be higher or equal than a certain CFE target x multiplied with the total load:

$$\sum_{r \in CFE, t \in T} g_{r,t} + \sum_{s \in STO, t \in T} \left(\bar{g}_{s,t} - \underline{g}_{s,t} \right) - \sum_{t \in T} ex_t + \sum_{t \in T} CFE_t \cdot im_t \geq x \cdot \sum_{t \in T} d_t \tag{2}$$

The **CFE Score** x [%] measures the degree to which hourly electricity consumption is matched with carbon-free electricity generation within the regional grid.