European Network of
Transmission System Operators
for Electricity

ERAA 2024
POST CONSULTATION EXPLANATORY NOTE

Final version | 16 September 2024

ENTSO-E Mission Statement

Who we are

ENTSO-E, the European Network of Transmission System Operators for Electricity, is the association for the cooperation of the European transmission system operators (TSOs). The 40 member TSOs, representing 36 countries, are responsible for the secure and coordinated operation of Europe's electricity system, the largest interconnected electrical grid in the world. In addition to its core, historical role in technical cooperation, ENTSO-E is also the common voice of TSOs.

ENTSO-E brings together the unique expertise of TSOs for the benefit of European citizens by keeping the lights on, enabling the energy transition, and promoting the completion and optimal functioning of the internal electricity market, including via the fulfilment of the mandates given to ENTSO-E based on EU legislation.

Our mission

ENTSO-E and its members, as the European TSO community, fulfil a common mission: Ensuring the security of the inter-connected power system in all time frames at pan-European level and the optimal functioning and development of the European interconnected electricity markets, while enabling the integration of electricity generated from renewable energy sources and of emerging technologies.

Our vision

ENTSO-E plays a central role in enabling Europe to become the first climate-neutral continent by 2050 by creating a system that is secure, sustainable and affordable, and that integrates the expected amount of renewable energy, thereby offering an essential contribution to the European Green Deal. This endeavour requires sector integration and close cooperation among all actors.

Europe is moving towards a sustainable, digitalised, integrated and electrified energy system with a combination of centralised and distributed resources. ENTSO-E acts to ensure that this energy system keeps consumers at its centre and is operated and developed with climate objectives and social welfare in mind.

ENTSO-E is committed to use its unique expertise and system-wide view – supported by a responsibility to maintain the system's security – to deliver a comprehensive roadmap of how a climate-neutral Europe looks.

Our values

ENTSO-E acts in solidarity as a community of TSOs united by a shared responsibility.

As the professional association of independent and neutral regulated entities acting under a clear legal mandate, ENTSO-E serves the interests of society by optimising social welfare in its dimensions of safety, economy, environment, and performance.

ENTSO-E is committed to working with the highest technical rigour as well as developing sustainable and innovative responses to prepare for the future and overcoming the challenges of keeping the power system secure in a climate-neutral Europe. In all its activities, ENTSO-E acts with transparency and in a trustworthy dialogue with legislative and regulatory decision makers and stakeholders.

Our contributions

ENTSO-E supports the cooperation among its members at European and regional levels. Over the past decades, TSOs have undertaken initiatives to increase their cooperation in network planning, operation and market integration, thereby successfully contributing to meeting EU climate and energy targets.

To carry out its legally mandated tasks, ENTSO-E's key responsibilities include the following:

› Development and implementation of standards, network codes, platforms and tools to ensure secure system and market operation as well as integration of renewable energy;

› Assessment of the adequacy of the system in different timeframes;

› Coordination of the planning and development of infrastructures at the European level (Ten-Year Network Development Plans, TYNDPs);

› Coordination of research, development and innovation activities of TSOs;

› Development of platforms to enable the transparent sharing of data with market participants.

ENTSO-E supports its members in the implementation and monitoring of the agreed common rules.

ENTSO-E is the common voice of European TSOs and provides expert contributions and a constructive view to energy debates to support policymakers in making informed decisions.

Table of Contents

Disclaimer

Although this data set and explanatory note is considered a post-consultation release, it is important to note that it remains a preliminary dataset, which is subject to change in view of the final ERAA 2024 delivery (end 2024). Stakeholders are invited to share further feedback to info@entsoe.eu.

Introduction

This data package includes revised input data package following public consultation in March-April 2024. Data was initially collected from TSOs, amended based on stakeholders' feedback collected in the Call for Evidence and even further scrutinised by ERAA modellers. Moreover, data package was further expanded by centrally computed or consolidated data (e.g. Maintenance profiles, Economic and Technical investment data) and by some explicitly requested additional data. Yet, the data remains still preliminary even if considered rather mature.

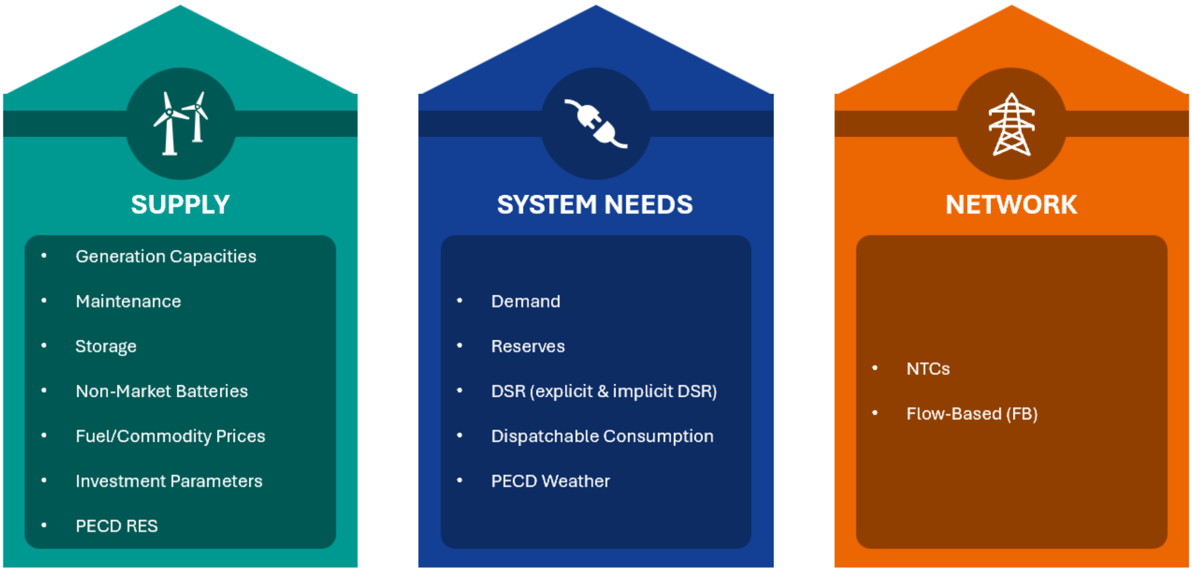

Figure 1 | Three main pillars of ERAA data input

The following list includes all data input files, which have been further grouped in three categories (Supply – System Needs – Network) as visualised in Figure 1.

- **Dashboard_raw data** *(folder)*: This folder contains key data helping to interpret data used in ERAA 2024. Some of the files contain the detailed data (E.g. generation capacities.csv), while other files contain descriptive data (e.g. aggregated_demand.csv contains statistical information about demand time series, which are also published in respective folder).
    - **Aggregated_Demand.csv**: Descriptive data of how the electricity demand will evolve until 2035 – estimated as demand (TWh) per geographical area. This data is derived from the Gross Demand data in Demand folder (c.f. below item under complementary data).
    - **Commodity Prices.xlsx**: How will fuel and commodity prices evolve until 2035 – estimated as prices per blend.
    - **Flow-Based_Core_KPI.csv**: Descriptive data of the FB domains (c.f. below item under complementary data). It presents how will potential electricity exchanges

capability [1]evolve until 2035 in the Core Capacity calculation region – estimated as import and export capability (MW) per study zone permitted by FB domains.

- **GenerationCapacities.csv**: How will domestic supply capacities evolve until 2035 – estimated as capacities (MW) per technology. The supply capacities include also explicit DSR capacities which could be dispatched in the models. This considers only known information about system development over coming years and is used as starting point in Economic Viability Assessment which results will be published in ERAA 2024 report.

  - **MaintenanceDaily_PerTechnology.csv:** How are maintenance and other planned unavailability distributed over each specific target year until 2035 – estimated as a combination of TSO data and the result of a ERAA central maintenance optimization.

- **Non-Market Batteries.csv**: How will capacities of non-market batteries evolve until 2035 – estimated as capacities (GWh).

- **Reserves Requirements.csv**: How will balancing reserves requirements evolve until 2035 to ensure system stability – estimated as balancing reserves (MW) per type (FCR/FRR), per technology (RES/thermal), and per geographical area.

- **Storage.csv**: How will battery and hydro storages evolve until 2035 – estimated as capacities (GWh) per type (market/non-market).

- **Hydro capacities.csv:** How will hydro capacities evolve until 2035 – estimated as hydro turbine and pumping capacities (MW) per technology (Reservoir, Run-of-river, Open loop, Closed loop, and Pondage) and study zone.

- Complementary data:

  - **Common data** *(folder)*: default characteristics regarding the different thermal generation technologies; among others fuel efficiency, CO2 emission factor, variable O&M cost, forced unavailability rates; and planned unavailability rates, which are used in maintenance optimization given in "MaintenanceDaily_PerTechnology.csv".

  - **Demand** *(folder)*: various files containing data for each target year per country: gross demand, demand segments (electric vehicles and heat pumps parts), and PV-battery system additions.

[1] *Exchange capability permitted by FB domains means only theoretical capability allowed by FB domains, which technically might be infeasible considering available generation in Core or Nordic study zones.*

- **Dispatchable consumption (*folder*):** it contains capacities of additional dispatchable consumption of electrolysers and power-to-heat (P2H). C.f. section below on "Additional consumption dispatch".

- **Economic and technical investment parameters** *(CONE folder)*: relevant parameters used to assess viability of new investments or extraordinary measures on existing generation units (mothballing – de-mothballing; and life extension).

- **FB Domains** *(folder)*: domains calculated for the CORE capacity calculation region.

- **iDSR ratios** *(folder)*: percentage ratios estimated of each flexible demand side element which is expected to be market-price responsive. Data is presented for each target year per study zone. C.f. Implicit Demand Side Response (iDSR) section below for more detailed explanation.

- **NTCs** *(folder)*: How will interconnection capacities evolve until 2035 – timeseries of NTCs on each border and reported individually per interconnection technology (HVAC or HVDC).

- **PECD – RES** *(folder)*: package describing RES generation and hydro inflow estimate in each of the assessed hour in ERAA study and for all assessed Weather Scenarios, which are coherent with the ones given in PECD – weather folder.

- **PECD – weather** *(folder)*: package describing weather conditions under each Weather Scenario in each of the assessed hour of ERAA study. This package was used for Demand Forecasting activities.

Geographical configuration and market coupling

The geographical configuration adopted in the ERAA 2024 is illustrated in Figure 2. The list of Study Zones are elaborated in Table 1. The study zones have been encoded as follows: the alpha-2 ISO 3166 codes of each country, followed by a two symbol code to indicate if there are multiple study zones per country. The second part of the study zone code could also be related to geographical directions or other variables. Study zones which are offshore are highlighted in grey in Table 1. Those study zones have an explicit offshore areas mainly with offshore wind generation which in the models are connected via interconnectors[2] to onshore study zones or even in between themselves. Nevertheless, some other onshore study zones may have offshore wind generation which are in the models connected directly to the onshore study zone and does not have an explicit offshore zone. In such cases offshore generation capacity is reported under the same onshore study zone. In any case wind load factor time series of both cases can be found in PECD – RES offshore package under respective study zones.

[2] *For a list of interconnections please refer to the published preliminary NTC file.*

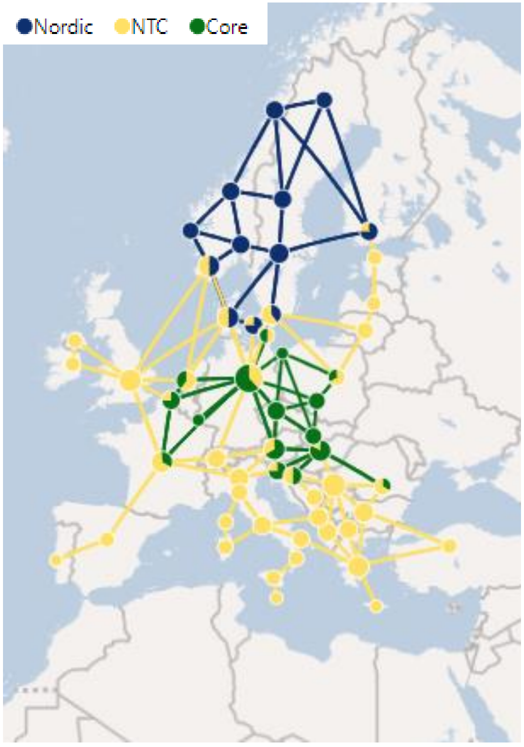

Figure 2 | Exemplary map (general) of Cross-Border interconnections and Market Coupling regions

List of Study Zones						
AL00	DEKF	DKW1	ITCA	LUG1	NON1	SE03
AT00	DKBH	EE00	ITCN	LUV1	NOS1	SE04
BA00	DKE1	ES00	ITCS	LV00	NOS2	SI00
BE00	DKHE	FI00	ITN1	MD00	NOS3	SK00
BEOF	DKK2	FR00	ITS1	ME00	PL00	TR00
BG00	DKKA	GR00	ITSA	MK00	PT00	UK00
CH00	DKKF	GR03	ITSI	MT00	RO00	UKNI
CY00	DKN1	HR00	LT00	NL00	RS00	
CZ00	DKN2	HU00	LUB1	NLLL	SE01	
DE00	DKNS	IE00	LUF1	NOM1	SE02	

Legend: *Offshore study zones* / *Onshore study zones* — *Core FB Region* / *Nordic FB Region* / *Other regions (NTCs)*

Table 1 | List of study zones, where those marked in grey are offshore

Although the NTCs are published, those for the Core Capacity Calculation Region (CCR; green connections in Figure 2) are not used because flow-based domains are being applied for Core CCR in both: adequacy and economic viability assessment (EVA) simulations. Nevertheless, data was consolidated to be available as fallback solution if flow-based modelling would face difficulties and hence for information purposes we are publishing this data.

The NTCs for the Nordic CCR (blue connections in Figure 2 below) are employed in the EVA while flow-based domains are used in adequacy simulations. These domains will be published in the final publication.

Supply Capacities

Below listed generation parts were explicitly reported after input data public consultation. In the preliminary data set for consultation, they were reported aggregated to the corresponding traditional fuel technologies.

- Biofuel: biofuel units are now reported specifically.
- Hydrogen generators: data regarding hydrogen generators are also reported separately from Thermal data.
- Non-market resources: reported explicitly:
  - Supply capacities which are expected to be available for domestic adequacy issues and only activated after economic dispatch are now reported explicitly. Those resources are expected to be available on TSOs' (or responsible authority's) activation request. Those resources do not interfere with market clearing and does not distort price signals in the models.
- Substantially refined non-market battery capacities are reported with this data relies. Preliminary dataset for consultation contained notably distorted values due to a processing error. Dispatch of these batteries is already optimized exogenously within the demand forecasting tool and only the price sensitive part is considered as flexible part for further re-dispatch[3] following contingent needs in the market model. These resources are utilised within ERAA models for pan-European needs.

Reported generation capacities are further reduced to account for maintenance (according to published dataset, c.f. MaintenanceDaily_PerTechnology.csv) and further to account for deratings and eventually by forced outages (c.f. Common Data folder) simulated in the models, as referred to in Sections 10.9 and 10.11 of Annex 2 on the ERAA 2023 Methodology.

Demand Forecasting Toolbox (DFT)

Hourly demand profiles are created using temperature regression and load projection model that incorporates uncertainty analysis under various climate conditions. The model comes in a software application (DFT) developed by an external provider and is used for most of the study zones. Meanwhile some TSOs provide their own demand time-series to be used by in ERAA, using their

[3] *C.f. section on implicit DSR in this document.*

own demand forecasting tool, yet considering the common dataset of weather conditions found in PECD-weather package.

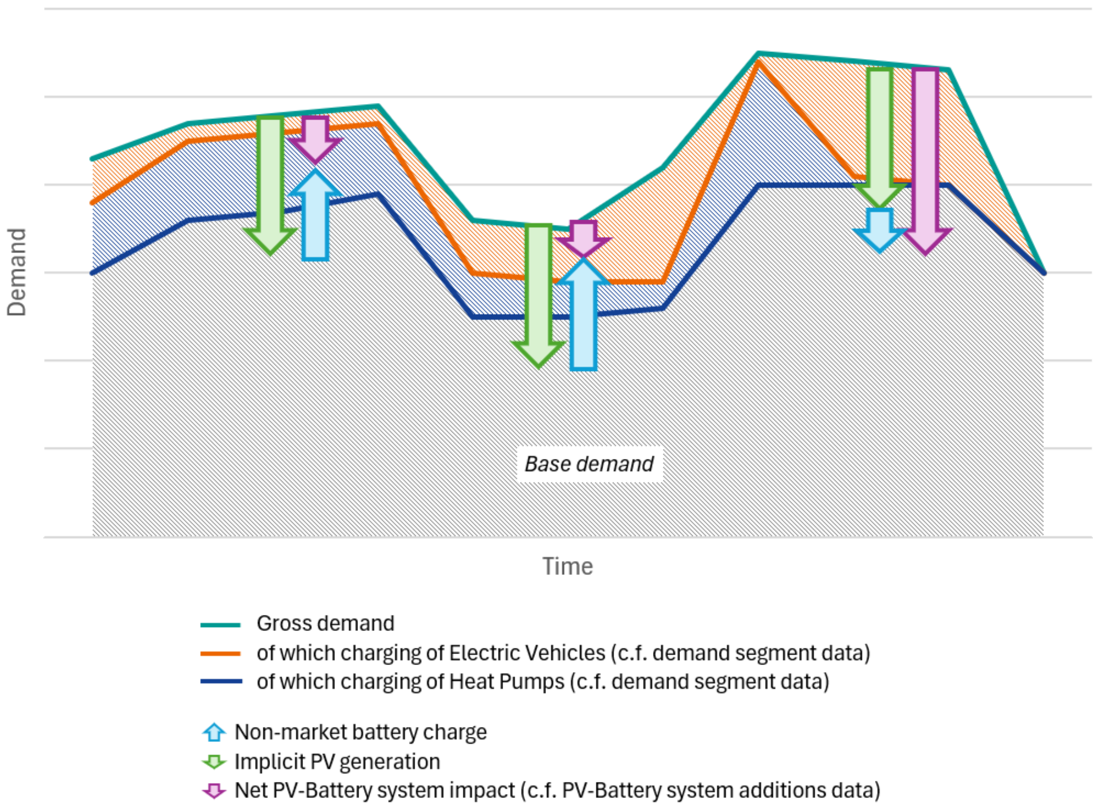

Figure 3 | Gross demand segments

Net demand could be considered as Gross demand lessen by the net PV/Battery impact if no implicit Demand Side Response (iDSR) reaction is considered; nor charging of batteries or hydro pumping; nor other large scale renewable generation. The PV/Battery impact is explained in the following section on iDSR; while large scale renewable generation is explicitly considered to supply net demand in the models. Charging of batteries and hydro pumping is optimized in the models and is not considered under gross consumption.

Implicit Demand Side Response (iDSR)

Implicit DSR (iDSR) is modelled to represent expected flexibility in European power system of Heat Pumps, Electric Vehicle (EV) charging and household battery-PV systems[4] dispatch to adapt their pre-defined dispatch in time (reschedule). This is described in Section 2.3 and Appendix 2 of Annex 2 on the ERAA 2023 Methodology.

[4] *Meanwhile, PV farms and battery systems participating to market dispatch are modelled explicitly in the ERAA models. Those capacities can be found in Generation Capacity publication file as Large scale PV and Batteries' capacity.*

In general, EVs' charging and HPs' operation are exogenously accounted for in the gross demand profiles. Furthermore, implicit PV-Battery system dispatch is also pre-defined exogenously. Then the price sensitive part of each of those technologies (i.e. part which is expected to respond to the electricity prices after the market is cleared) is identified and modelled as available flexible resources capable to be rescheduled. Meanwhile the remaining part of those technologies (price non-sensitive) is kept in the models as part of the load profiles. Those price sensitive ratios are estimated by TSOs and are available in the iDSR ratio data packages.

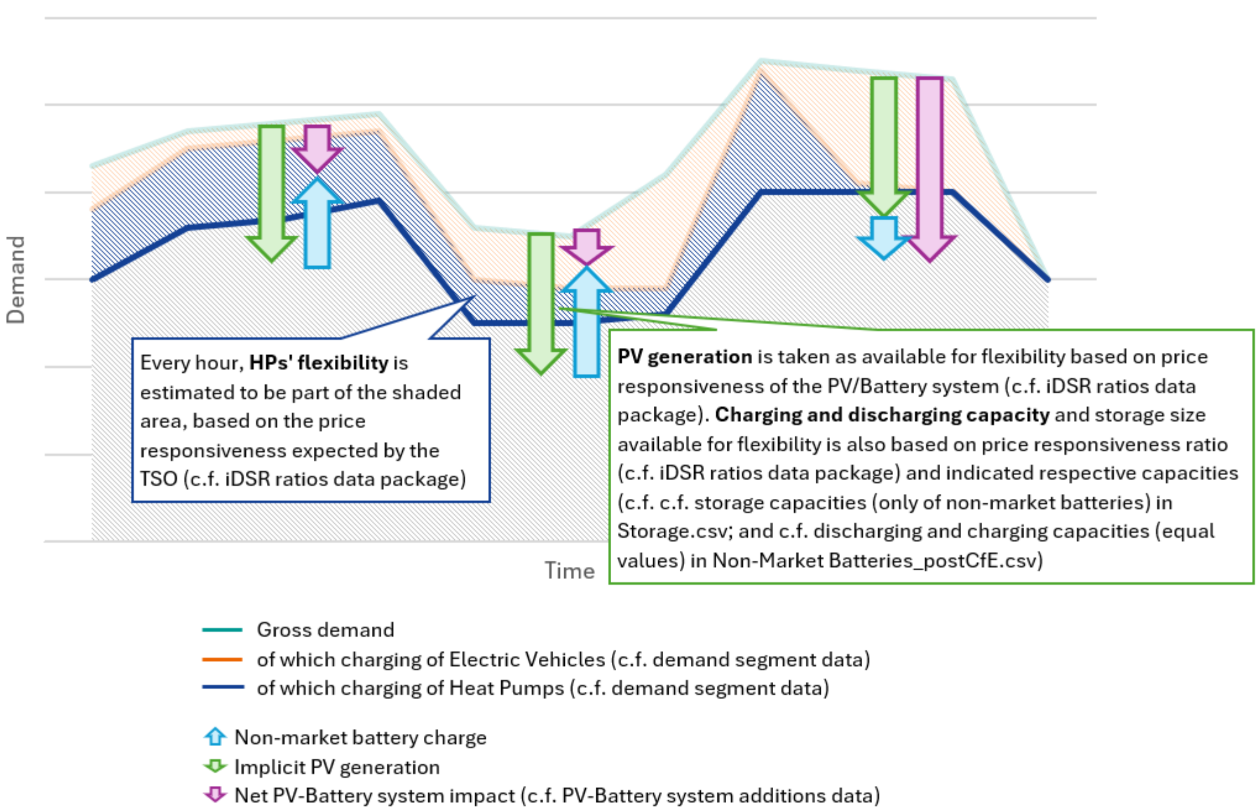

Figure 4 | Implicit DSR

Additional consumption dispatch

Some additional consumption could be dispatched in the models which refer to the expected electrolysers and Power-to-Heat assets (P2H) in the European system. The dispatch of this additional consumption depends on the electricity price in the dispatch models: if the cleared price is below the P2X price threshold, the "buy offer" is taken and the consumption gets dispatched.

The consumption capacities of electrolysers and P2H units are reported in the *Additional dispatchable consumption* file. The method for electrolyser dispatch is described in Section 7 of Annex 2 on the ERAA 2023 Methodology.

The operation of storage resources (only market based batteries and hydro storage) is optimised endogenously within model. This includes charging/pumping decisions which should be considered as additional consumptions which is storing energy for later dispatch (used as supply). The storage sizes are reported in Storage.csv file; supply capacities can be found in Generation.csv file; charging capacity for batteries is equal to the supply capacity in Generation.csv file; pumping/charging capacities for hydro plants can be found in Hydro capacities.csv.

Pan-European Climate Database (PECD)

This database describes renewable generation estimates (or hydro inflows for dispatch) for each of the Weather Scenarios (WS) used in ERAA 2024 study. It also contains weather variable used in DFT or by TSOs in their own demand forecasting tool. Please refer to the PECD documentation here.

Preliminary WS14, WS25 and WS28 are selected for EVA study as representative set. For more information about methodology and motivation to do so, please refer to the ERAA 2024 public webinar on the methodology material.

The PECD data disclosed comes in part from the PECD4.1 dataset developed by ECMWF, C3S and ENTSO-E under a CC-BY-4.0 licence. The PECD4.1 dataset will be made publicly available in the coming months via the Copernicus Climate Data Store (CDS).

Nevertheless, Hydro constraints (package within PECD RES package) were provided by the TSOs individually.

The data is based on three climate models (CMCC-CM2-SR5 (CMR5); EC-Earth3 (ECE3); MPI-ESM1-2-HR (MEHR)) and based on specific calendar year assessed in the climatic models. Specific mapping between Weather Scenario labels used in ERAA and those specific models and calendar years can be found in dedicated mapping file ("Weather Scenarios_Mapping" within PECD-weather data package).

Flow-based domains

Two sets of FB domains are used for the CORE CCR in the ERAA 2024. A full set of FB domains is used in the adequacy model, which contains six FB domains per target year (three for Summer and three for Winter). The second set is simplified and is used in the EVA model. This simplified set contains 2 FB domains per target year (1 for Summer and 1 for Winter) to reduce model complexity.

CCR	Adequacy modelling	EVA modelling
Core	FB-Domain-CORE_Full_ERAA2024	FB-Domain-CORE_simplified_ERAA2024

Table 2 | Flow based domain application – published file mapping with their application in the modelling

Each FB domain within a FB domain set for a particular target year is defined by Flow Based domain ID (FB ID) identified. It consists of set of PTDFs for a number of CNECs, set of RAMs for respective CNECs. PTDFs and RAMs are stored in their own sheets and they can be linked respecting the FB ID and CNEC IDs. In particular FB domain within example of "Full Core" domain set you can refer to the six domains per target year. Furthermore, a timeseries of FB IDs are given in "FB Domain Assignment" sheet to list which domains are used in which simulation timestep for each of the assessed weather scenarios.

Please refer to the Section 4 of Annex 2 on the ERAA 2023 Methodology for more information about FB domain concept and computation methodology. Yet, please refrain from referring to section 4.3 on FB domain enlargements as for ERAA 2024 FB domains were computed for each specific target year individually. Also, refer to FB_Readme.xslx ("Lin. Constr. Representation" sheet) for a mathematical market coupling formulation.

Flow-based domains descriptive metrics

Descriptive metrics are given in FB Key Performance Indicator (KPI) files. Those include maximum import and maximum export capabilities of study zones within the Core FB CCRs. Since Core FB domains contain only handful of typical FB domains this property is computed for each of the FB domains and published along the FB domains themselves (c.f. FlowBased_Core_KPI files).

Descriptive metrics are typically computed either to estimate potential import or export capacity from within given CCR (e.g. Core; and disregarding exchange capacities with other regions outside specific CCR) or to consider potential import (or export) capacity from within given CCR (e.g. Core) and neighbouring systems (e.g. Spain for Core region). The former descriptive metrics are distinguished with "No AHC" labels suggesting that Advanced Hybrid Coupling (AHC) interconnectors are not considered in the descriptive metric calculations. The later are distinguished with "With AHC" labels suggesting that AHC interconnectors are considered.

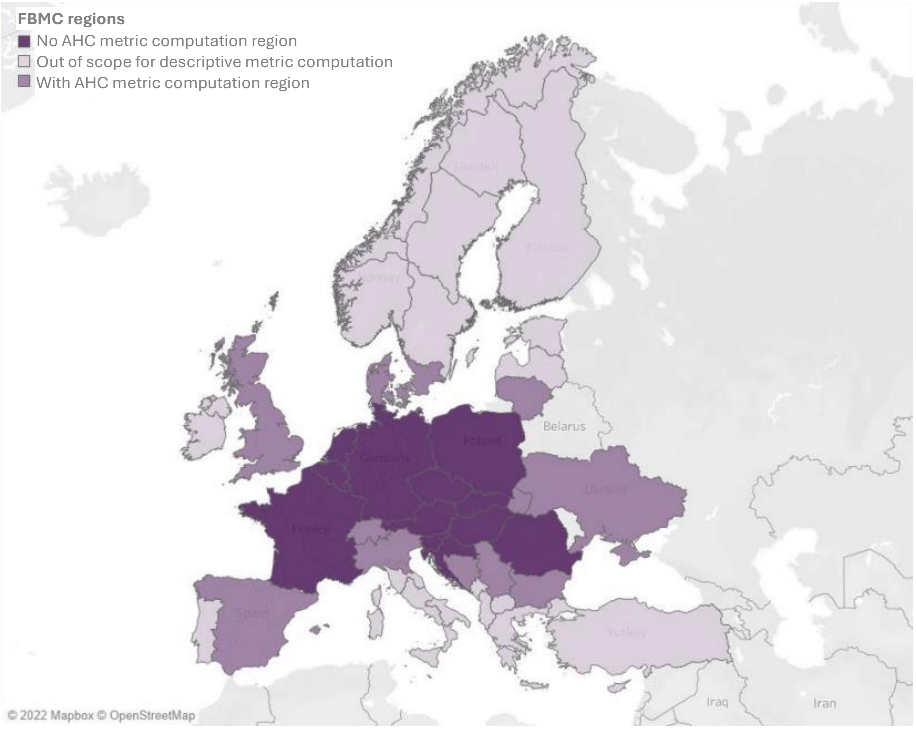

Figure 5 | Exemplary ERAA 2023 region presentation for FB domain descriptive metric computation - Consideration and disregard of AHC region[i]

Please refer to Section 2.2 of [Annex 3](#) on the ERAA 2023 Results detailed results[5] for more information about descriptive metrics.

Economic and technical investment parameters

Various economic and technical investment parameters are relevant for EVA study along the fuel and commodity prices. Those values are present in Economic and technical investment parameter files (*Economic and technical investment parameters folder*).

- Economic and technical investment parameters_Country Specific: is applied for each specific study zone for which any relevant information is available. The source of data is indicated within files and it is in priority order: national study on Value of Lost Load (VoLL) or Cost of New Entry (CONE) to establish Reliability Standards; National study on the matter; Central ERAA estimate only applicable to some parameters (e.g. for DSR potential estimation). ERAA

[i] *Graph is example from ERAA 2023. In ERAA 2024 only Ukraine part should be disregarded as it is not modelled. Furthermore, some offshore zones (c.f. section 1 of this document) are also not visible in the map, but those are taken into account when computing descriptive metrics.*

[5] *C.f. Maximum theoretical import and export net position.*

study re-utilizes economic and technical parameters which were defined for a use in respective national studies.

- Economic and technical investment parameters_Default: is applied for all study zones where no country specific data is available. This data was derived from country specific values.

These parameters include:

- New investments:
    - Investment and operation related costs (respective CAPEX, FOM and VOM sheets): Capital Expenditure (CAPEX), Fixed Operational and Maintenance costs (FOM) and variable operational and maintenance costs (VOM). These costs come in addition to the fuel and CO2 credit costs needed for the dispatch if units are built.
        - DSR investments is complemented by additional economic and technical information: DSR activation price (given in “DSR Activation Price” sheet) and DSR activation limits (given in “Activation Limit” sheet). Former is important as DSR is not driven by fuel, but rather relies on the reduction of consumption, which in turn has its own cost. Latter is important as DSR can typically be used for a limited amount of time per day.
    - Potential capacity of investment (Potential sheet): is limitation for a given system to accommodate new investments builds in specific target year. Value of 2035 suggest the total investments by that target year (in any of the target year). Value of prior years should be considered as part of 2035 investments allowed by a given target year (e.g. by 2028). Example: if investment is limited to 3 GW by 2028 and to 5 GW in 2035, then total investment over studied period cannot exceed 5GW while investments until 2028 end of the year cannot exceed 3GW. However, if 3 GW investments are not commissioned by 2028 (e.g. only 2 GW are commissioned), then

remaining investment potential (1GW) could be commissioned in the following years respecting the total investment potential of 5GW by 2035.

  - Economic lifetime ("Economic Lifetime" sheet) suggests the time period under which investments are planned to be operational and should recover investment costs.

- Mothballing units:
  - Cost to mothball units ("Mothballing FOM" sheet) indicates annual costs to keep units mothballed without decommissioning. Such units are available to be de-mothballed if it becomes profitable.
  - Cost to de-mothball units ("De-Mothballing_Cost" sheet) indicates Capital Expenditure costs needed to return generating unit to operations from mothballed state.
- Lifetime extension
  - Lifetime Extension Capital Expenditure costs ("LifeTime Extension" sheet) indicates one time expenditure needed to extend lifetime of a generating unit (i.e. cost for major overhaul).
  - Lifetime extension FOM ("LifeTime Extension_FOM" sheet) suggests expenditure needed to maintain unit in operating state after it's life extension. Despite CAPEX, FOM remains relatively high in comparison with units whose economic lifetime has not expired.
- Investment margins
  - Investment expected margin thresholds are composed of Weighted Average Capital Cost (WACC; respective sheet) and Hurdle Premium (respective sheet).

For further reference about these properties you can refer to the Section 6 of Annex 1 of the ERAA 2023 Data Input and Sections 10.7 and 10.13 of Annex 2 of the ERAA 2023 Methodology for investment margin specific items.

---

[i] *The graph is example from ERAA 2023. In ERAA 2024 only Ukraine part should be disregarded as it is not modelled. Furthermore, some offshore zones (c.f. section 1 of this document) are also not visible in the map, but those are taken into account when computing descriptive metrics.*