Technical report

Public workshop: “Engaging users with Destination Earth’s energy research”, Brussels, 09 June 2026

1. Background

The electricity system is increasingly facing impacts from climate change and extreme weather events, requiring adequate planning to ensure its resiliency and stability. In this context, the European Commission initiative, Destination Earth (DestinE) aims to develop highly accurate Digital Twins (DT) of the Earth – a Climate DT and an Extremes DT – to monitor and predict the interaction between natural phenomena and human activities.

For the energy sector, several activities within DestinE have been started to demonstrate the capabilities of the Digital Twins, including Use Cases, Machine Learning (ML) Demonstrators and Pilot Services. Efforts have been made to expose these activities, their outputs and relevance to energy-sector stakeholders and decision-making processes.[1] However, more active engagement could serve to better align these activities with the changing needs of energy users and changing regulatory and policy requirements in Europe.

To fill this need, Renewables Grid Initiative (RGI) and the German Aerospace Center organised a public workshop to strengthen cooperation and co-design activities of DestinE’s energy research with relevant stakeholders on a technical level. The workshop’s goal was to inform DestinE’s energy research applications and future avenues, identifying how to support industry and other stakeholder’s pro-active contribution to designing and operating the future European energy system.

The workshop was held in a “World Café” format, in which participants discussed energy themes related to DestinE in 6 groups (“tables”): *machine learning, extreme events, dynamic line rating, energy use case for the Climate DT, climate risk assessment* and *energy system planning*. The discussions were moderated by organisations involved in energy contracts under DestinE (the German Aerospace Center; GeoSphere – the Austrian geological, geophysical, climatological, and meteorological service; AU – Aarhus University; BSC – Barcelona Supercomputing Center; RMI – the Royal Meteorological Institute of Belgium) and the European Network of Transmission System Operators for Electricity (ENTSO-E), which provided an external user perspective, while not being involved directly with DestinE’s contracts.

This workshop was organised under DestinE’s 5th User eXchange event (DestinE UX5) that took place on 09-10 June 2026 in Brussels. The workshop was complemented by a dedicated session on energy titled “Using DestinE for energy applications: in conversation with users” during the UX5 event (10 June, 14:05 – 15:05 CET).

[1] See, for example, the 2024 Webinar ‘Modelling for climate resilience and adaptation’.

Agenda	
Time	**Topic**
08:50	Registration
09:15	Introduction to the workshop (RGI & the German Aerospace Center)
09:25	Setting the scene: knowledge gaps in energy system planning (ENTSO-E)
09:35	Brief presentations of energy themes under DestinE (RMI, the German Aerospace Center, AU, BSC, GeoSphere)
09:55	Round 1: Small groups discussions
10:25	Refreshment break
10:35	Round 2: Small groups discussions
11:05	Round 3: Small groups discussions
11:35	Briefings from the groups' discussions
11:50	Concluding remarks and announcing next steps (RGI & the German Aerospace Center)

2. Summary of groups discussions

The following paragraphs provide a summary of discussion points, open questions and opportunities for future activities.

Table 1: High Resolution forecasts for Next Generation Dynamic Line Rating computation

Moderation: Piet Termonia and Joris Van den Bergh, the Royal Meteorological Institute (RMI), Belgium

1. Background

Studies conducted within this project show that transmission line capacity along an Alpine corridor (the "Westtirol–Zell am Ziller" line, 220 kV) can vary significantly, ranging from –36% to +147%. This highlights a substantial potential for optimising transmission system operations with Dynamic Line Rating (DLR), compared to conventional static rating approaches. Accordingly, this project develops DLR solutions tailored for both Transmission System Operators (TSOs) and Distribution System Operators (DSOs).

Two complementary approaches are explored. First, a 6-class compound-event severity scale has been developed, providing operators with clear and actionable information on operating conditions. Second, the project advances methodologies that range from continent-wide screening down to the identification of a single critical span up to 48 hours in advance. These applications estimate ampacity using the DestinE Extremes DT (~750 m resolution), combined with CIGRE and IEEE thermal models.

The project is characterized by intensive stakeholder engagement and co-design activities with European grid operators across four countries, including:

- Austria: APG (220 kV, Alpine Tyrol) and Energienetze Steiermark (110 kV, complex terrain)
- Belgium: Elia (150/380 kV)
- France: RTE (400/225 kV, shared use case)
- Germany: TransnetBW (380 kV, quantile forecasts)

In addition, ENTSO-E's network is actively informed. Lessons learned from these collaborations were discussed during the workshop.

2. Potential Users

Two additional stakeholders participated in the discussions: the Greek TSO IPTO and the Slovenian company operaTO. Some TSOs collaborate with forecast data providers, which could become additional users of this pilot service (while DLR implementation in operational settings is progressing, it has not yet been fully deployed).

3. Data for Verification

A key challenge in advancing this service is access to data needed for verifying the model's output, which currently is available only to a small number of TSOs. Pilot testing is currently conducted on specific power lines. Available data sources include sensors installed on power lines (typically at heights of 30–60 meters) and ground-based weather stations. Some TSOs report using direct ampacity measurements, while others estimate ampacity based on IEEE and CIGRE methodologies. To overcome the gap in data availability, the DLR project's consortium is prepared to sign non-disclosure agreements (NDAs) where necessary to facilitate data sharing.

4. Required Service

Implementing Dynamic Line Rating in operational environments is complex and requires clear, digestible information, similar to the challenges faced by meteorologists in weather forecasting. The proposed 6-class compound-event severity scale offers a potential solution by translating complex data into actionable insights for system operators.

Table 2: Energy Use Case for Climate Adaptation Digital Twin

Moderation: Francesc Roura, the Barcelona Supercomputing Center (BSC)

This project introduces open-source, high-resolution tools utilizing kilometre-scale climate projections to deliver selected indicators such as energy demand and generation at a global scale relevant for project developers (especially, but not limited to, wind and solar energy). The goal is to deliver tailored insights and indicators that project developers can genuinely trust for long-term planning. Key points discussed were as follows:

1. Validation and trust:
Participants stressed that energy indicators will only be trusted if they are benchmarked against widely used references such as the European-Reanalysis (ERA5), the pan-European Climate Database (PECD), and the Coupled Model Intercomparison Project (CMIP). Because the Climate DT provides global, high-resolution (~5 km) data, direct comparisons are challenging. A proposed approach is to validate against intermediate-resolution regional products (e.g., EURO-CORDEX, ARRA, DREAM/ICON) to demonstrate the added value of higher resolution. The key requirement is to show that increase of resolution delivers meaningful improvements in the production of energy-relevant indicators, rather than simply finer spatial details, ideally through targeted case studies.

2. Demand indicators:
There was a strong requirement for indicators on the demand side by participants, which are currently underrepresented in the use case. A combined demand indicator (Heating and Cooling Degree Days) was suggested to be valuable in this context. Participants also highlighted the value of compound supply-and-demand indicators in identifying periods of severe mismatch between energy production and demand. Such indicators, together with pricing information and scenarios involving changes in the penetration of energy storage, could support more compelling "what-if" storylines.

3. New indicators and the value of resolution:
Climate DT energy indicators should match the capabilities of PECD, while differentiating itself through indicators that benefit from higher resolution, such as wind ramp events (short-term changes in wind speed) and/or atmospheric boundary layer (ABL) stability metrics. Discussions highlighted also limitations of commonly used indicators like capacity factor, which do not account for farm-level effects such as wakes and the related losses. This raises a broader question about the limits of what can and cannot be credibly delivered without any further downscaling of the climate simulations.

4. Cross-cutting priorities:
A recurring recommendation shared by the participants was to thoroughly review existing energy indicator services, particularly PECD and the Copernicus energy products, to better understand user needs and identify where 5 km resolution could provide additional value. Participants also expressed interest in access to time-series data and emphasised the need to define spatial aggregation and delivery methods.

Table 3: On Demand Extremes Digital Twins

Moderation: Irene Schicker, GeoSphere

1. Discussion themes

The session revolved around the following discussion themes:

- Theme A: Defining extreme events for the energy system.
- Theme B: Identifying areas where high (spatial and temporal) resolution is cost-efficient.
- Theme C: The "what-if" scenarios that matter the most to users.
- Theme D: Shifting from current extremes to future-climate impacts.

2. Conclusions

Seven cross-cutting messages emerged from the 4 mentioned discussion-themes:

- **"Extreme" is defined by impact and not meteorologically.** Across all group discussions, participants stressed that characterising events will be linked to capacity, infrastructure, market signals and asset behaviour, but not as meteorological metrics in isolation. This validates the impact-sector framing of the project. Remaining open questions were: 1) what definitions are appropriate at climate timescales, as opposed to operational? 2) Should sabotage be treated as a compound-event class in scenario planning?
- **Compound events are a commonly identified gap.** Temporal compounding (consecutive Dunkelflaute[2], heat and low-wind, storm and flood) and spatial compounding (multi-region wind shut-offs, continental convective outbreaks) are common identified weaknesses of the existing forecast- and planning tools.
- **Hectometric resolution (100m resolution) is cost-efficient in two specific contexts:** complex orography (Alpine, coastal, mountain) and asset-level operational decisions (transmission re-routing, substation placement, maintenance dispatch). It is not obviously cost-efficient for large-area, slow-evolving phenomena like continental Dunkelflaute. Being transparent about this blind spot contributes to trust building and increase credibility regarding the extreme events assessment and its cost-effectiveness among users.
- **Sub-hourly temporal resolution is a distinct requirement, not subsumed by spatial resolution.** Especially, fog, convection, Aerosol Optical Depth (AOD)/cloud cover and snow need temporal (not just spatial) resolution. Solar nowcasting (real time casting) and ensemble post-processing is essential and cannot be optional.
- **What-if scenarios fall naturally into two timescales, both requested by users:** (i) Operational what-ifs — alternative turbine types, wind-farm layouts, storage placement, and ramping behaviour applied to observed events — which are the current strength of the "on demand extremes" project, and (ii) Climate-conditioned what-ifs — future regime adaptation and asset sizing for changing extremes — represent the bridge to

2 Dunkelflaute is a simultaneous lack of wind and solar radiation episodes. In contrast, Hellbrise is a simultaneous excess of wind and solar power generation.

the Climate DT. The seam between the two timescales is where the European Commission's policy interest seems to concentrate.

- **Markets and regulation are part of the definition of "extreme."** Imbalance signals, negative prices and bidding-zone design serve both as early warnings of extreme events and as the operative definitions used by regulators and market operators. This opens an opportunity to collaborate with organisations such as ENTSO-E and the European Commission, less in terms of modelling and more in terms of data-provisioning by GeoSphere.
- **Probabilistic framing is non-negotiable.** Robustness, quantifying uncertainty, and safety margins were raised in every theme. Ensemble approaches to ensure this should be considered a requirement, not a "nice-to-have".

3. Synergies and cross-cutting opportunities

With the DestinE energy contracts:

- Climate DT energy indicators (led by BSC): concerning the regime-shift / changing-weather-pattern discussion (Theme D, "Defining extreme events for the energy system"). Proposed joint activity: co-design of indicators that bridge operational extremes and climate-regime changes, building on BSC's Climate DT energy indicators.
- ML demonstrator and climate risk assessments (led by the German Aerospace Center): concerning probabilistic compound-scenario work (Theme D). Ensemble of compound storylines for risk assessment could become a joint product.

With other DestinE impact sectors

- Air quality: Aerosol Optical Depth (AOD), fog and convective extremes appear in both energy (PV impact, ramps) and air quality contexts. Coordinated detection / nowcasting could benefit both.
- Hydrology: flash floods and low water already surfaced from energy participants. Shared hectometric detection.
- Health / urban: heat-stress overlap with PV derating (reduced performance) and demand-side load.

With external stakeholders

- The European Commission:[3] confirmed appetite for climate-conditioned what-ifs that can complement ERAA / TYNDP. Concrete next interaction: a paired example for operational what-if and a climate-conditioned variant for the same event.
- ENTSO-E: market and regulatory dimension of "extremes" (Themes A and C: "Defining extreme events for the energy system" and "the 'what-if' scenarios that matter the most to users", respectively). Possible collaboration on event-definition standards.
- National TSOs (APG, Elia, TenneT): hectometric resolution justifies its cost for asset-level operational decisions; clear pilot use cases identified. With RTE, market-extreme

[3] Added following the panel discussion during the session "Using DestinE for energy applications", on the UX5 event, 10 June, 14:05-15:05.

definitions (Theme A) and bidding-zone what-ifs (Theme C) correspond to TSOs/DSOs operational decision-making.

<u>Methodological synergies</u>

- Probabilistic framing for "what-ifs" is a common methodology across all DestinE energy work, and hence a joint-paper on the topic by the contractors can be explored.
- Compound-event detection and characterisation are similarly a shared methodological challenge across impact sectors (energy, air quality, hydrology, urban). Coordinating on definitions and detecting suitable algorithms would multiply the value for each sector.

Table 4: Machine learning (ML) Demonstrator energy systems

Moderation: Alexander Kies, the Aarhus University (AU)

This project implements an innovative ML Demonstrator based on a sophisticated Physics-Informed Neural Network designed to handle the complex and dynamic nature of power systems, in particular electricity grids with high share of renewable energy. The demonstrator builds on existing energy modelling tools and services (e.g., Copernicus and grid operators) but introduces advanced machine learning techniques and data from the Climate DT to provide faster, scalable and more adaptative solutions for users. Key points discussed were as follows

1. Validating the ML Demonstrator:

- ML models should identify situations where their accuracy may deteriorate.
- Critical and extreme cases should be detected automatically and potentially re-solved using conventional methods.
- Reliability metrics and confidence indicators are needed to support operational acceptance.
- Rigorous validation, verification, and quality assurance are more important for validation than explainability.
- Users would need evidence that predictions produced by ML can be trusted.
- A hybrid workflow was suggested for validation: ML screening → identifying critical cases → verification using classical simulation.

2. Trust building:

The ML model does not have to be trusted blindly by the users. Rather, its outputs can be checked afterwards against physical and optimisation criteria, such as power balance, generation and transmission line limits, storage constraints, operating costs, Energy Not Served (ENS), Loss of Load Probability (LOLP), feasibility of the reconstructed dispatch (i.e., whether the predicted dispatch satisfies all optimisation constraints), and, where appropriate, Karush–Kuhn–Tucker (KKT) -like optimality checks (e.g., assessing the optimality gap or residual violations of the KKT conditions to quantify how closely the ML solution approximates the true optimum).

3. Extreme events:

Extreme events are a major issue to address, as they are particularly important for grid operators and other stakeholders. Hence, dedicated identification of critical situations would be valuable. For that, the following should be considered:

- Training specialized models focused on extreme events.
- Building benchmark datasets that represent critical cases.
- Characterising situations where model performance degrades.
- Finally, developing an *extreme event library* and targeted validation framework.

4. Uncertainty and ensembles:

Users rarely rely on a single simulation outcome. Ensemble approaches are preferred over single deterministic predictions. Hence, ML could enable exploration of many more weather years and climate scenarios than currently feasible.

5. Transparency and understanding model behaviour:

- Regional variations in model quality should be visualized (e.g., maps).
- Users would like to understand where the model performs well and where it struggles.
- Feature reduction and sensitivity analyses could reveal which inputs are most important.
- Questions remain regarding limited transparency / public availability of TSOs' datasets.

6. Operational use cases:

The most relevant applications identified by stakeholders are:

- Resource adequacy assessments.
- Grid adequacy and network development planning.
- Sensitivity studies around baseline scenarios.
- Exploration of large numbers of weather years.

7. Key message:

Stakeholders see strong potential in ML for accelerating large-scale adequacy and planning studies, but adoption will depend on trust-building measures such as uncertainty estimates, reliability metrics, extreme-event validation, and hybrid ML–physics workflows.

8. Planned extensions and continuations based on stakeholders' feedback, indicating their implementability potential:

- Reliability indicators (implementable).
- Critical case identification (implementable).
- Hybrid ML–physics workflow (implementable).
- Regional performance visualisation (mapping) and sensitivity analysis (implementable).
- Large climate-ensemble exploration (implementation is questionable).

Table 5: Opportunities in energy system planning

Moderation: Benedict Englisch and Aron Zuiker, the European Network of Transmission System Operators for Electricity **(**ENTSO-E)

1. Initial open Guiding Questions

ENTSO-E prepared three open guiding questions to facilitate the discussion among the participants:

- Which set of climate variables significantly impacts power energy system operations?
- Which regional weather conditions significantly impacts power system operations?
- How could weather scenarios be classified by, e.g., regional extreme events?

The subsequent group discussions focused especially on the classification of weather scenarios.

2. Key insights from group discussion 1:

- Combination between historical and projection outlooks
    - Looking at historical data/ observations can provide "thresholds" of events, that can be critical for projections of future events.
    - Climate is not static: events might get less frequent, but their intensity and probability will increase (e.g., extreme colds in the winter or heatwaves in the summer).
- Preparedness of the energy system should consider how predictions are considered – as “averages” of climate change or toward increase of extreme events.
- The pan-European views on climate hazards can be significantly different than national views.
    - A national extreme event does not necessarily affect the full pan-European region (e.g., DunkelFlaute in one region).
    - Pan-European DunkelFlaute, e.g., is less likely to happen compared to regional events.

3. Key insights from group discussion 2:

- Weather impact and change of weather conditions / other impacts.
- How do local seasonal effects aggregate to the European level? Can these impacts amplify each other or reduce each other’s effects? What about seasonal differences (heating/cooling demand South vs. North of Europe)?
- How to account for uncertainty in the data?
    - It is hard to assess connections between meteorological situations and energy system(s); it is hardly predictable for models.
- Flexibility Issue.
- Optimal solution for very-near future for the energy system (the “tomorrow’s forecast”).

4. Key insights from group discussion 3:

- Two angles looking at extreme events:

  - Already known events, in which the parameters can be looked for.
  - Investigating new events – a stress test on the energy system.
- Both angels could be combined by machine learning (ML) and data analysis, and both are valuable for the insights.
- General open-source theme.
- The following could be of a value for ENTSO-E and other parties to address extreme events: An “encyclopaedia” of climate-hazards, a user-driven database / registry of classified and identified weather events (e.g., in case of CMIP6 projections) to develop a knowledge base of climate events which helps users to extract data that they are interested in, when developing and accessing electricity infrastructure projects.

Table 6: Climate risk assessment

Moderation: Bruno Schyska, the German Aerospace Center

1. Background:
DestinE provides a powerful toolbox to support climate risk assessments for the energy sector: The Climate DT delivers highest-resolution, operational climate projections; the Extremes DT can provide detailed knowledge about extreme events for the energy system; DestinE’s climate storyline simulations allow to explore how climate change is reshaping extreme events; and impact sector models and machine learning applications enable investigation of real-world problems and large numbers of what-if scenarios. Through combining these capabilities, DestinE can contribute to improving the data and model-driven evidence-base for climate risk assessments by:

- Defining advanced sets of high-resolution, stakeholder-informed climate impact indicators for consecutive, compound and cascading risks for the energy system,
- Integrating DestinE’s Climate Adaptation Digital Twin simulations with energy systems models at different spatial scales,
- Performing multi-scale climate risk analysis with ML-enhanced numerical models of the energy system, user-validated risk storylines and stress-testing.

Hence, the aim of the climate risk assessment table was to discuss this approach via collecting information about existing/ongoing climate risk assessment exercises, their shortcomings and knowledge-gap, and DestinE’s potential contributions to overcome them.

2. Results:
Using climate risk assessments as an exemplary key application of the DestinE infrastructure, some key challenges for the use of the Climate DT have been discussed. The discussion followed two major lines: 1) “What are the benefits of the very high resolution of the climate DT?”, and; 2) “How can DestinE contribute to overcoming the observed gap between the scientific progress made under DestinE and the users’ capabilities to deal with climate information?”.

While both can be understood as a challenge to overcome by the DestinE's energy researchers, some concrete recommendations have been formulated:

- Emphasising the importance of local-scale demo cases, which make explicit use of the high resolution of the Climate DT output through coupling them with downstream applications, such as flood and/or wildfire models,
- Strengthening the role of social sciences in DestinE's co-design activities to build interfaces between the climate scientists and the envisaged users of DestinE's services and data sets.

3. Key takeaways from the workshop

The 6 tables represent different capabilities and addressed different users' needs in energy system planning. However, several links can be drawn between the projects. While some of these synergies were already mentioned above (especially in Table 3), the following builds on these considerations and provides additional reflections for future steps.

- As the discussions in Tables 3, 5 and 6 revealed, **defining extreme events** is highly contextual and depends much on the perception of their impact by stakeholders, and historical thresholds can only partly inform these definitions. This is relevant when assessing consecutive, compound, and cascading risks. Industry stakeholders that face such risks and impacts, as well as regulators and public authorities, are therefore key for extreme events definition exercises.
- **Compound and consecutive events** is a major challenge for forecasting and risk assessments. While machine learning (Table 4) could provide a concrete technical response by training specialised models and building benchmark datasets for extreme events, involvement of other impact-sectors (e.g., air quality, hydrology) should be considered in framing and assessing compound-event – for example, a joint-development of methodologies.
- Tables 1, 2 and 3 provide similar understanding regarding **hectometric resolution**: it would be cost-efficient for complex orography and asset-level operational decisions such as grid-rerouting and substation placement, but not for large-area and/or slow-evolving (climate change) phenomena.
- **A probabilistic approach** is desired and required over single or fixed prediction or scenario. Especially as the discussions at the Tables 3-6 showed, this could serve as a basis for a joint publication / developing a shared methodology.
- **Data availability and accessibility** was marked as a limitation several times, but it was especially emphasized during the discussions at the Tables 1 and 4. For example, TSOs cannot disclose certain data due to security concerns, which affects the process and outputs of ML operation. Raising awareness about this limitation and openly discuss it with regulators and policy makers may lead to develop adequate solutions.
- A cross-cutting theme emerged in all tables was the need to further **enhanced collaborations with stakeholders**, from energy industry to policy makers and researchers, to improve outputs of DestinE's energy themes for different target users-groups.