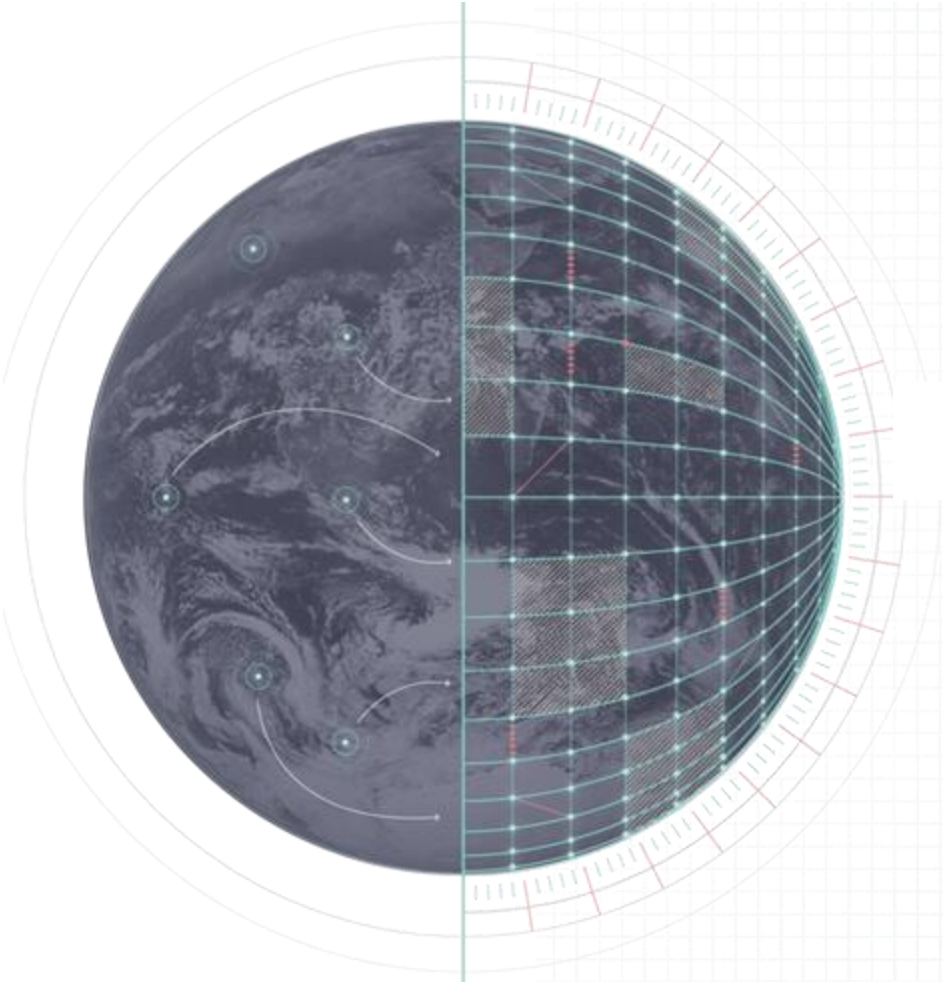
DESTINATION EARTH



Energy research themes under DestinE

Renewables Grid Initiative

DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

DESTINATION EARTH

Piet Termonia & Joris Van den Bergh , (Belgium's Royal Meteorological Institute (IRM)

Irene Schicker, Senior Scientist, GeoSphere

Alexander Kies, Associate Professor, Aarhus University

Francesc Roura-Adserias, Research Engineer, Barcelona Supercomputing center (BSC)

Bruno Schyska, Research Assistant, German Aerospace Center (DLR)

DESTINATION EARTH

DE_374a: High Resolution forecasts for Next Generation Dynamic Line Rating computation

Funded by the European Union
Destination Earth implemented by ECMWF esa EUMETSAT

Static Line Rating

Conservative assumptions:

- Wind speed: 0.6 m/s
- High ambient temperature
- Clear sky radiation

→ **Underutilization of capacity**

→ **Limits renewable integration**

Dynamic Line Rating

Weather-dependent capacity:

- Real-time conditions → Real-time capacity
- Studies show: +40% to +170% increase
- Critical for **renewable integration**

→ **Unlock extra transmission capacity**

More electricity can be transported by taking advantage of favourable weather (cool and windy conditions)!

Multi-Scale NWP solution

Continental

ECMWF IFS ENS

~9 km, 51 members

Early warning and uncertainty (2-5 days)

Global DT (Optional)

DestinE Global

~4.4 km

European screening

Regional (Optional)

AROME/ALARO

1 - 2.5 km

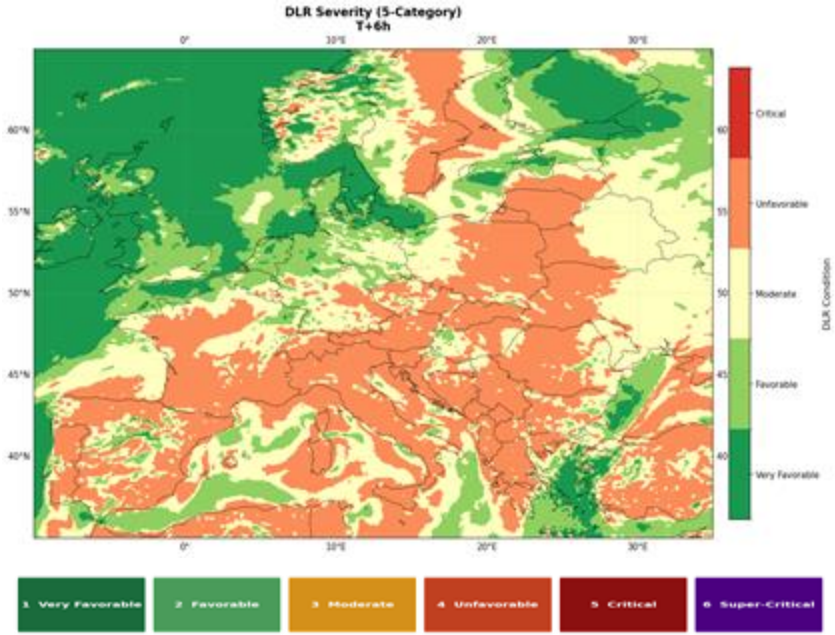
Mesoscale features

Hectometric

DestinE Extremes

~500 m

Bottleneck resolution



DLR severity maps

- Compound-event severity scale, **ensemble-based probability**
- Operators receive **actionable conditions**, not raw meteorological fields

Multi-scale: continental to corridor

From European-wide screening to identifying the single critical span 48 hours ahead

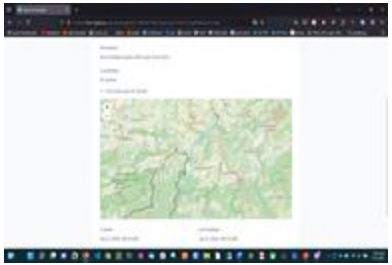
DestinE Extremes Digital Twin (~750 m) + CIGRE / IEEE thermal model

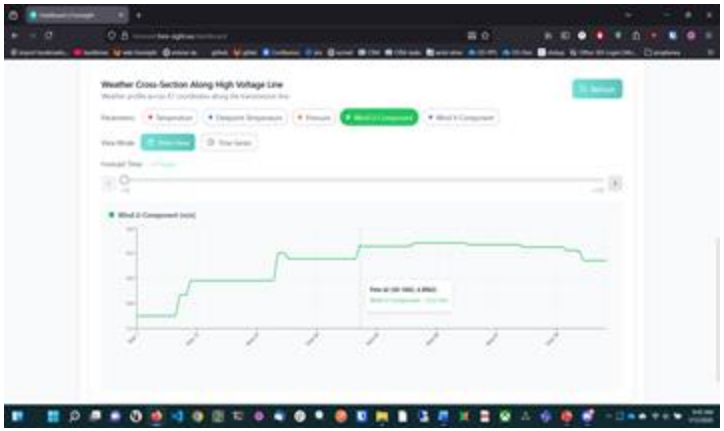
→ spatially resolved ampacity per line segment - bottleneck identification at pylon level

Capacity varies from −36% to +147% vs. static rating along one alpine corridor (Westtirol–Zell am Ziller, 220 kV)

Destination Earth DLR Pilot Application

Users upload transmission lines through pylon coordinates. Forecasts delivered along the full corridor.





Live on DESP: hirenext.dev.desp.space

Co-designed with European TSOs across 5 countries

AT APG 220 kV · Alpine Tyrol	**AT** Energie Stmk 110 kV · Complex terrain	**BE** Elia 150/380 kV · Belgian use case
FR RTE 400/225 kV · Shared use case France	**DE** TransnetBW 380 kV · Quantile forecasts	**EU** ENTSO-E Stakeholder network

Try it

https://hirenext.fore-sight.eu

Your feedback matters:
survey.zohopublic.com/zs/HBBhPl

DESTINATION EARTH

DESTINATION EARTH ML DEMONSTRATOR

Alexander Kies, Bruno Schyska, Matthias Zech, Ira Shefer, Lueder von Bremen, Andrzej Ceglarz

Funded by the European Union

Destination Earth implemented by ECMWF esa EUMETSAT

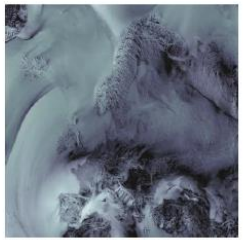
WHY MACHINE LEARNING FOR ENERGY SYSTEMS?

Challenge

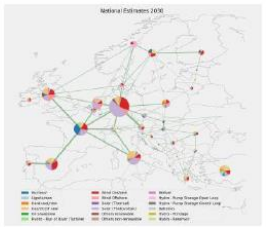
- Growing number of climate scenarios
- Growing spatial resolution
- Millions of power-flow and adequacy calculations

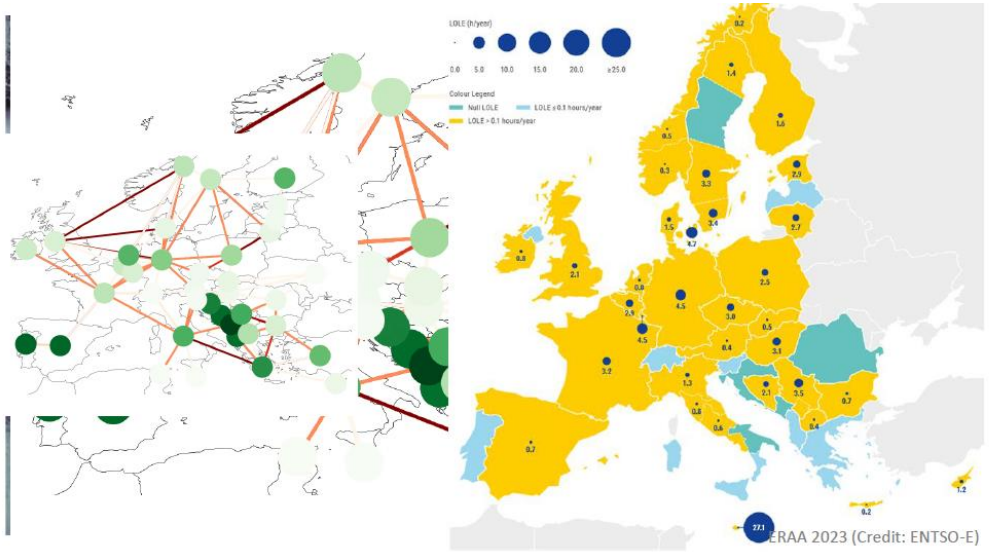
Question

- Can ML provide sufficiently accurate approximations to enable near-real-time assessments?



Credit: Nikolay Koldunov + Thomas Rackow





ERAA 2023 (Credit: ENTSO-E)

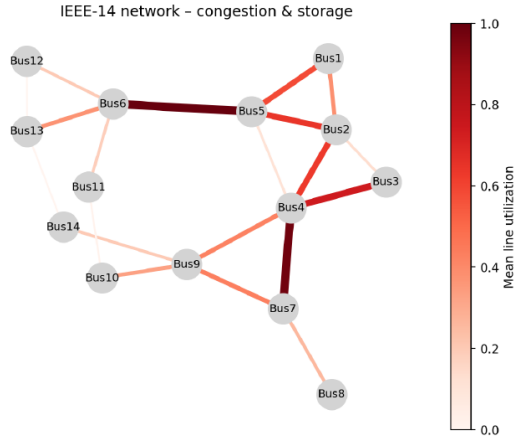
From information → through simulation → to impact

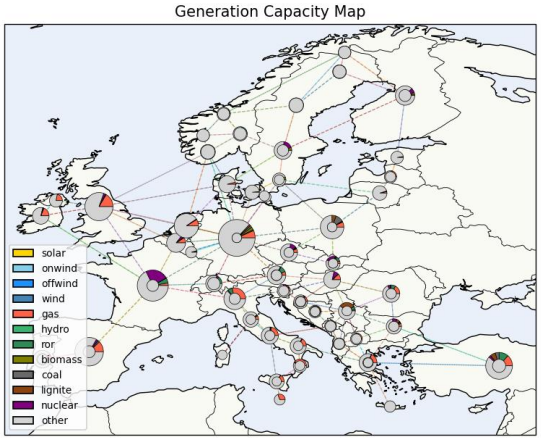
Bottleneck

SCALING THE DEMONSTRATOR

- Started with small benchmark systems
- Progressively increased complexity
- Now training on ERAA-scale European systems

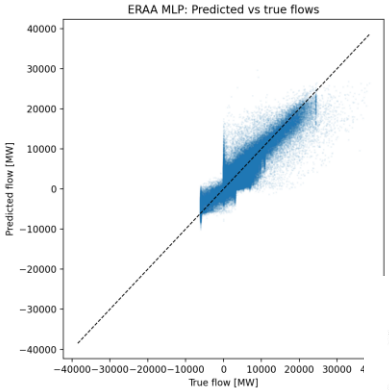
Current ERAA dataset
50 buses
421 transmission links
447 weather/generation features
969 weekly samples

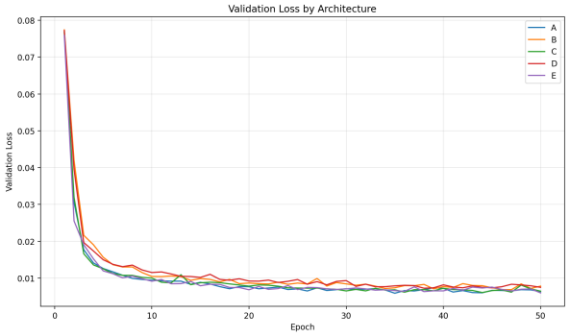


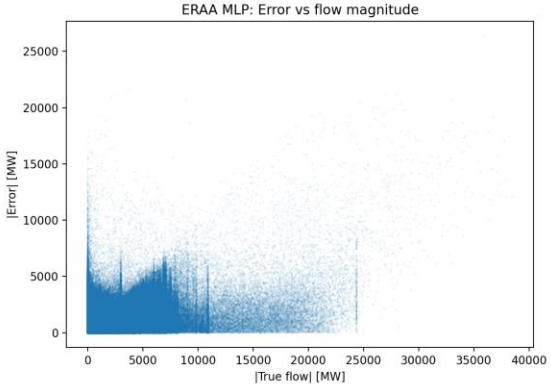


IMPLEMENTATION & VALIDATION STATUS

- ML captures most flow patterns
- High overall correlation with simulation results
- Largest errors occur during extreme conditions
- Extreme situations are exactly the cases we care most about. How should these be validated?





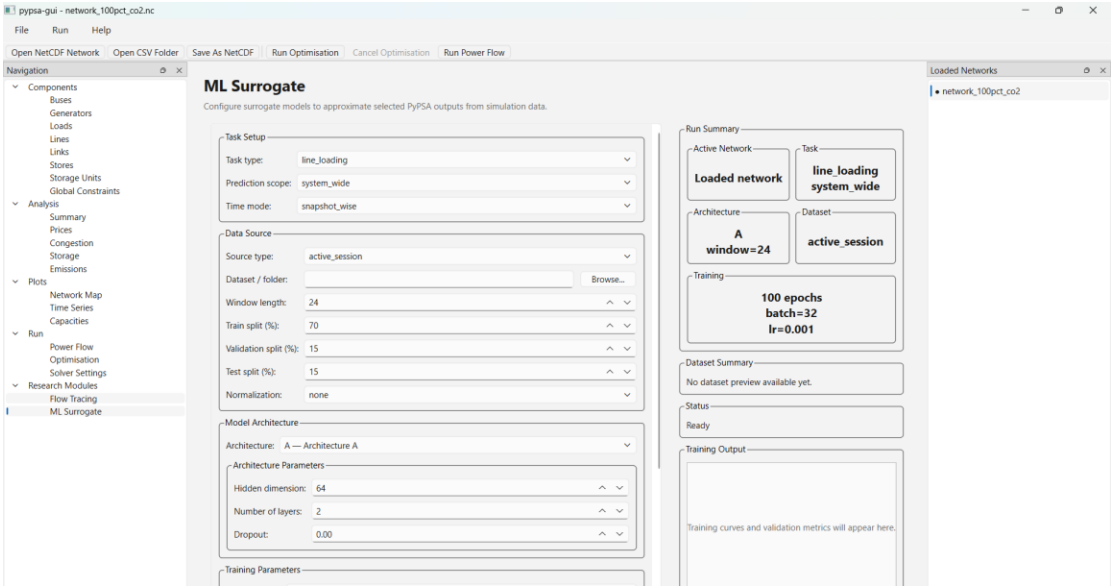


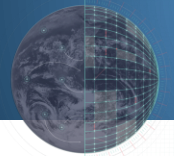
TOWARDS INTERACTIVE ENERGY SYSTEM ANALYSIS

Replace network.optimize() with ml_surrogate.predict()

Potential applications:

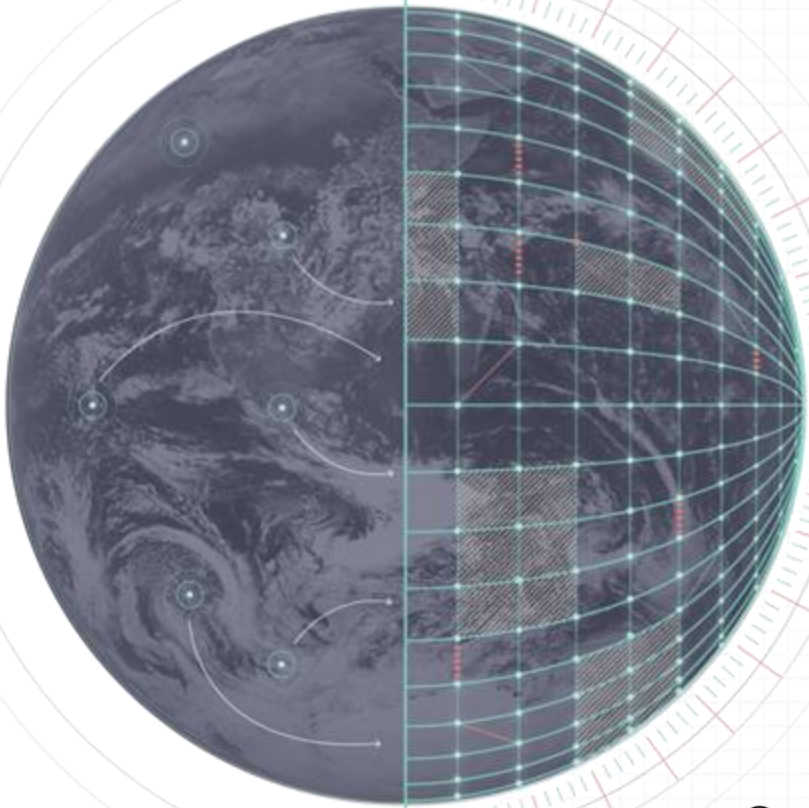
- Rapid scenario exploration
- Large climate ensembles
- Uncertainty quantification
- Interactive digital twins
- Stakeholder-facing visualisation





DISCUSSION

Plausibility
Does this approach seem realistic?
What would increase trust?
Validation
What validation would you require?
Which metrics matter most?
Applications
Where would this be most useful?
What analyses are currently limited by computational cost?
Future
What could become possible if simulation time were no longer a bottleneck?
Trust
At what point would you be willing to use an ML surrogate instead of a conventional simulation?



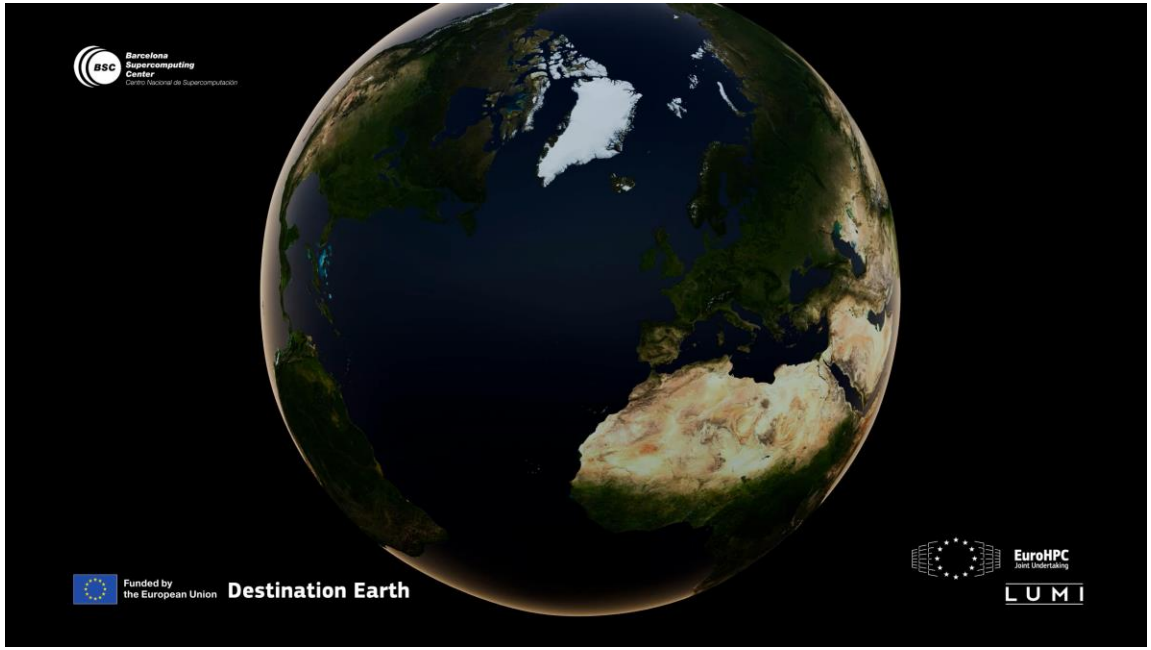
Advancing wind energy services through operational km-scale climate projections

5th user exchange meeting, Brussels, June 2026

Francesc Roura-Adserias, on behalf of the Climate Services Team from the BSC

energy-destine@bsc.es

State-of-the-art vs Climate DT

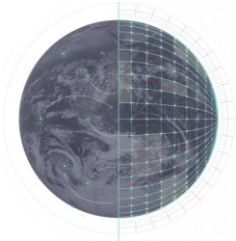


Feature	Traditional GCMs	ClimateDT
Spatial resolution	25 to 100km	5 to 10km
Temporal resolution	>= 6h	=< 1h
Purpose	Research driven	User driven
Updates	Every 5-7 years	Every few months

How to make the most from user interaction?
How to provide the key indicators that are at the same time general but helping specific needs from the sector

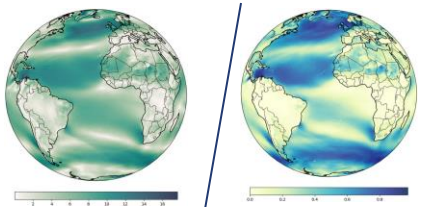
Physical world

Earth System Models



Digital Twin
(simulated 'living' replica)

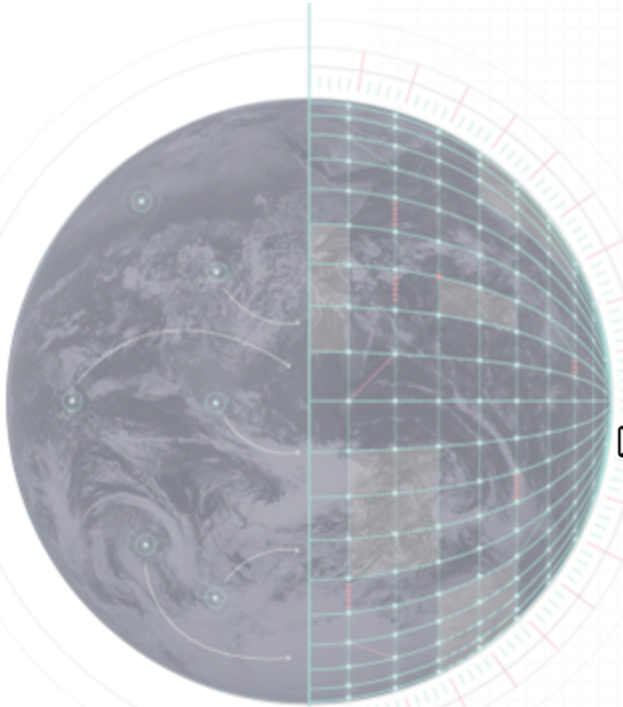
Energy indicators



Tailored insights
(e.g; Wind energy sectors)

YOU!!!

End User



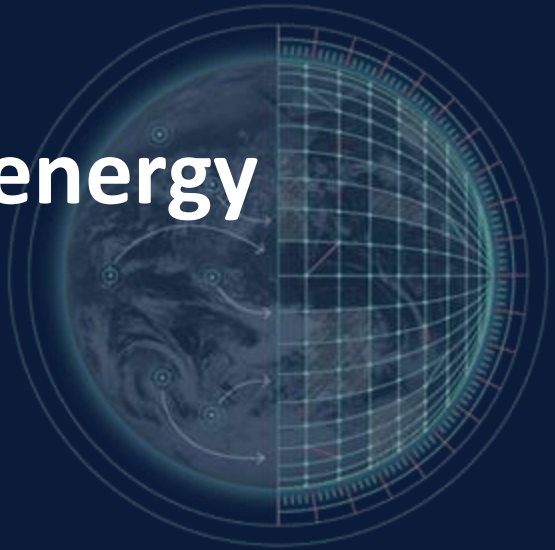
Thank you !!

energy-destine@bsc.es

DESTINATION EARTH

Extreme events for renewable energy

From hectometric forecasts to user-relevant decisions



Theme lead

Irene Schicker · GeoSphere Austria

Energy meteorology · extreme & adverse events for the renewable energy sector

DestinE context: DE_330 / DEODE · WP12 Pilot Impact-Sector Applications for Renewables

irene.schicker@geosphere.at

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The on-demand Extremes DT and the renewables impact chain

What is the on-demand Extremes DT (DE_330)?

One of DestinE's flagship Digital Twins. On user demand it runs hectometric NWP (HARMONIE-AROME / AROME / ALARO / ICON, down to 750 m → 200 m, with ensembles) for specific events and regions. **DE_330** operates the system across a pan-European consortium developing impact-sector applications in renewables, air quality, hydrology and health/urban.

750 m hectometric NWP (incl. sub-hourly option)

10+ European NWP centres

4 impact sectors

1 Detection

Renewables-tailored algorithms on IFS-ensemble and hectometric output:

- wind-power & wind-speed ramping (OPTI-THRED)
- solar-potential ramping
- thunderstorm severity (STPI)

2 On-demand hectometric NWP

Triggered by detection, the workflow launches:

- HARMONIE-AROME / AROME / ALARO at 500 - 750 m
- optional Wind-Farm Parameterisation
- ensemble runs for uncertainty propagation

3 Post-processing & what-if

From NWP to user-relevant variables:

- NWP2Wind / NWP2Solar — parametric, analog, ML
- satellite nowcasting (pySTEPS, IrradPhyDNet) integrated in post-processing
- namelist-driven what-if — turbines, layouts, PV configs

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What counts as an “extreme event” for renewable energy?

Definitions are sector-specific. The same atmospheric event can be a non-issue for one user and a major incident for another.

1 Storm & gust events

Cut-out at 22–28 m/s removes large blocks of wind capacity in minutes. Structural risk for turbines & grids.

e.g. Storm Eunice (Feb 2022) · Storm Ciarán (Nov 2023)

2 Ramp events

Steep wind- or solar-power gradients (GW per hour) challenge dispatch, balancing and reserves.

e.g. Nov 2024 European ramp event · cold-front passages

3 Convective & solar extremes

Thunderstorm-driven PV ramps, fog, hail; sub-hourly variability current operational NWP cannot resolve.

e.g. Pannonian Basin Nov 2024 · spring/summer thunderstorm fronts

4 Heat & air quality

Heat reduces PV efficiency and transmission line capacity; aerosols, Saharan dust and wildfire smoke cut solar irradiance and soil PV panels (and turbines).

e.g. June 2022 European heatwave · Saharan dust intrusions · Mediterranean wildfire smoke

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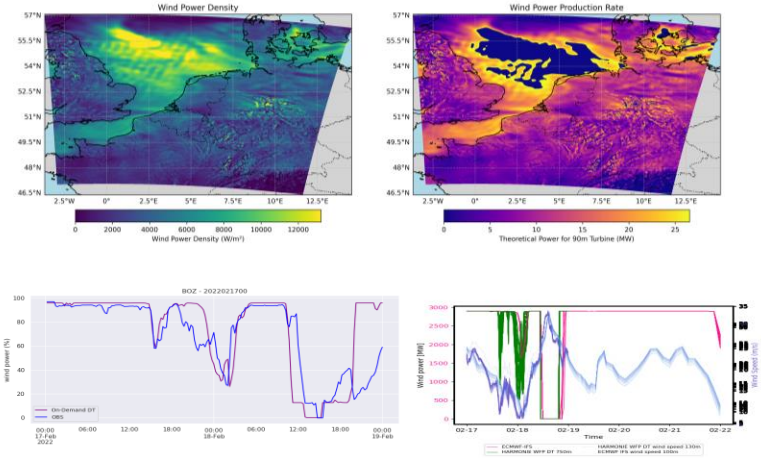
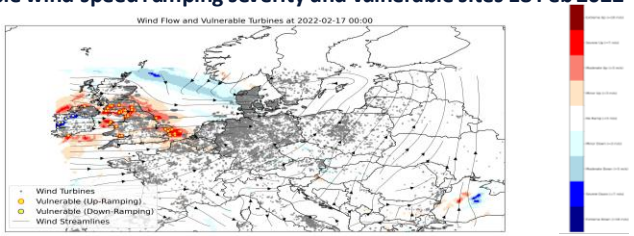
Storm Eunice & the November 2024 ramp events — captured at asset scale

Storm Eunice · Belgian Offshore Zone · 17–18 Feb 2022

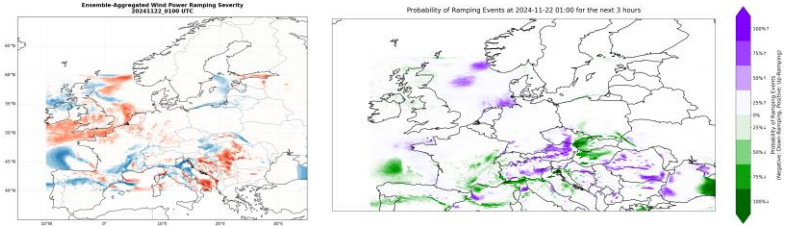


On-demand DT hectometric forecast vs. ENTSO-E observed power — three storm-driven dips well captured.

Ensemble wind-speed ramping severity and vulnerable sites 18 Feb 2022 03 UTC



Ensemble wind power ramping severity — Nov 2024



Take-home: ensemble + hectometric NWP + tailored post-processing + nwocasting = a forecast that actually reflects what happens at the asset.

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FOR DISCUSSION

Four questions w.r.t. extreme events

Q1

Which extreme or high impact weather events most affect your decisions today — and which ones do you still feel blind to?

thresholds, lead times, false alarms

Q2

What turns a forecast into a decision? Where does ensemble information help — and where does it just add noise?

deterministic vs. probabilistic in operations

Q3

Hectometric resolution comes at a cost. For which events / decisions is it actually worth it?

resolution vs. lead time vs. ensemble size

Q4

What "what-if" scenarios would make DestinE most useful for planning, operations and resilience?

turbine retrofits, layouts, climate storylines

Funded by the European Union · Destination Earth · ECMWF · ESA · EUMETSAT

CLIMATE RISK ASSESSMENTS FOR THE ENERGY SECTOR WITH DESTINATION EARTH

Bruno Schyska with contributions from Barcelona Supercomputing Center, GeoSphere Austria, Aarhus University, Renewables Grid Initiative and others

DLR

What DestinE provides

- High-resolution, operational climate projections

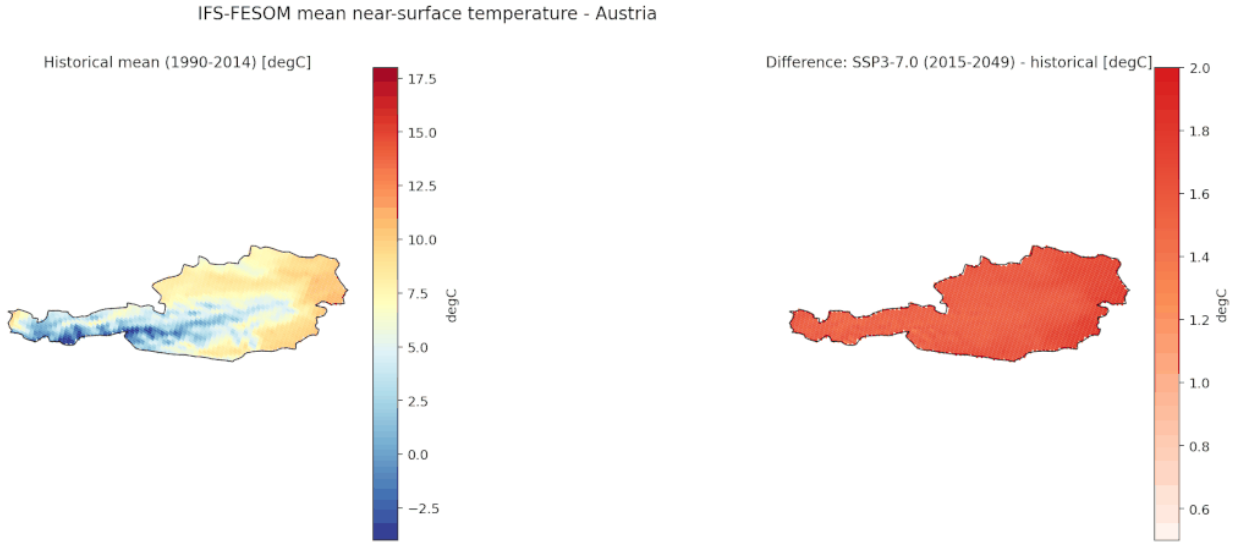
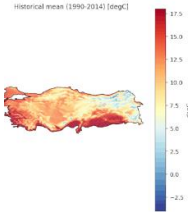
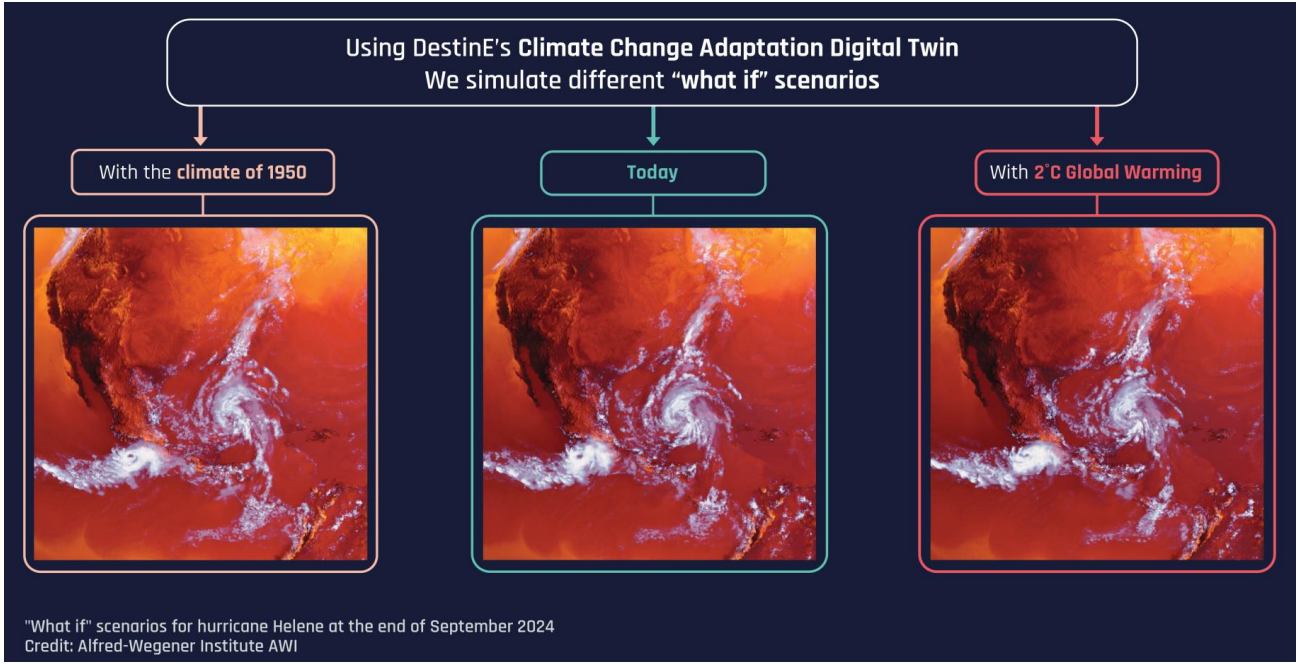


Figure created by Irina Sandu, ECMWF, #DestinEArt

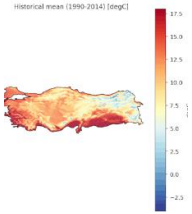
What DestinE provides

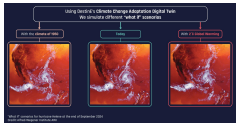


- High-resolution, operational climate projections
- Climate storyline simulations

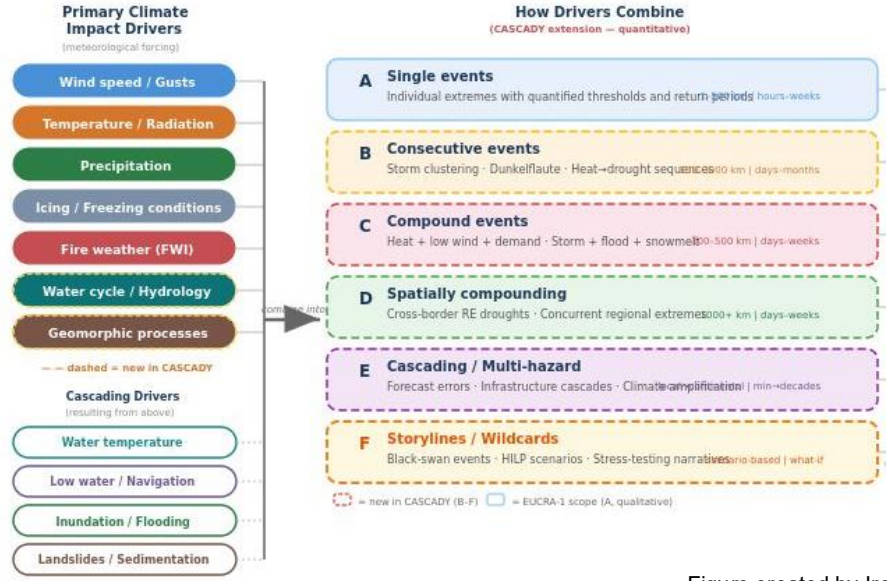


What DestinE provides





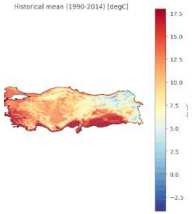
- High-resolution, operational climate projections
- Climate storyline simulations
- Detailed knowledge of extreme events

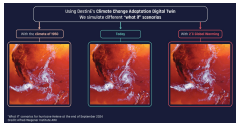


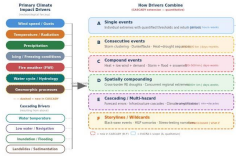
For DestinE's Extremes DT a set of extreme event indicators for the energy system is identified.

Figure created by Irene Schicker, GeoSphere Austria

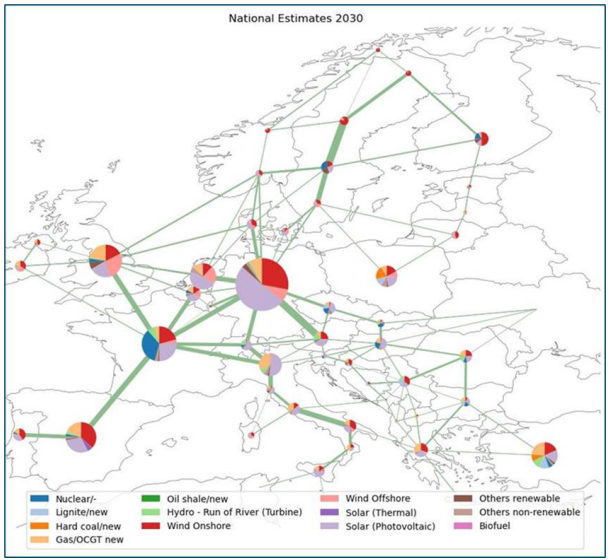
What DestinE provides







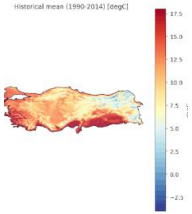
- High-resolution, operational climate projections
- Climate storyline simulations
- Detailed knowledge of extreme events
- Impact sector models embedded in DestinE's ecosystem

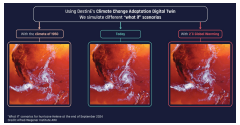


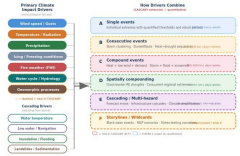
For DestinE a representative Energy Systems Demonstrator has been implemented*.

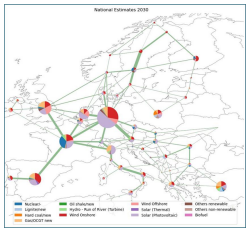
* https://github.com/destination-earth/DestinE_ECMWF_EnSys

What DestinE provides

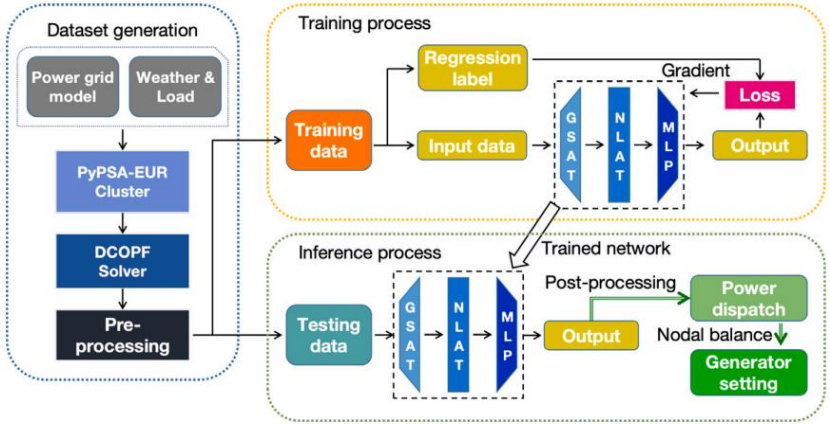






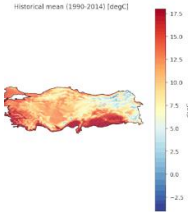


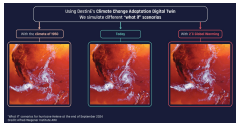
- High-resolution, operational climate projections
- Climate storyline simulations
- Detailed knowledge of extreme events
- Impact sector models embedded in DestinE's ecosystem
- Machine Learning capabilities and infrastructure

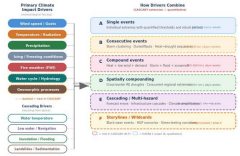


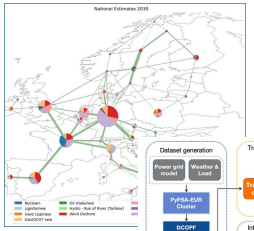
For DestinE's *ML Demonstrator Energy Systems* surrogates are implemented based on physics-informed neural networks.

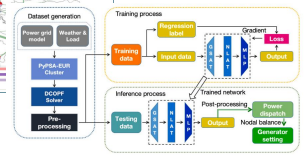
What DestinE provides





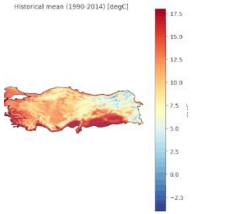


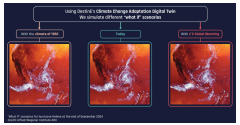


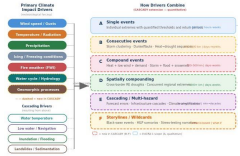


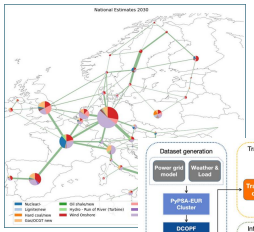
- High-resolution, operational climate projections
- Climate storyline simulations
- Detailed knowledge of extreme events
- Impact sector models embedded in DestinE's ecosystem
- Machine Learning capabilities and infrastructure
- A platform for collaboration and exchange

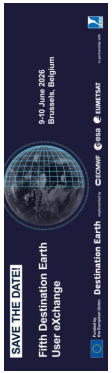
What DestinE provides

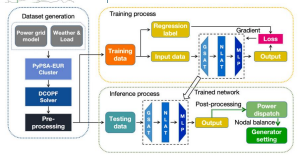












A powerful toolbox to assess climate risks for the energy sector

How to make best use of this?

Q1

Which risk assessment frameworks exist?

(intern-)national programs, climate adaptation plans, EUCRA

Q2

What is missing?

gaps, shortcomings, limitations

Q3

How can DestinE help closing these gaps?

services, demonstrators, data sets