User Perspectives Report

DE_370b_DLR – Use Case Energy Systems

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Change Log

Version	Date	Description
V0.0	21/02/2024	Draft of User Perspectives Report
V1.0	01/03/2024	Complete User Perspectives Report, as delivered to ECMWF
V2.0	02/04/2024	Revised version
V2.0public	18/04/2024	Public version for dissemination
V2.1public	26/04/2024	Public version for dissemination with consent of the workshop's speakers

Contents

Table of Figures

Table of Tables

Glossary

ACER	European Agency for the Cooperation of Energy Regulators
AU	Aarhus University, Research partner of the Destination Earth Use Case Energy Systems
Climate DT	Destination Earth's Climate Change Adaptation Digital Twin
C3S	Copernicus Climate Change Service
DestinE	Destination Earth
DESP	Destination Earth Core Service Platform
DLR	Deutsches Zentrum für Luft- und Raumfahrt / German Aerospace Center, Lead partner of the Destination Earth Use Case Energy Systems
ECMWF	European Centre for Medium-Range Weather Forecasts, partner of the Destination Earth initiative and lead partner on the implementation of the Destination Earth Digital Twins
ESA	European Space Agency, partner of the Destination Earth initiative
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites, partner of the Destination Earth initiative
ENTSO-E	European Network of Transmission System Operators for Electricity
ERAA	European Resource Adequacy Assessment
EVA	Economic Viability Assessment (part of ERAA)
Extremes DT	Destination Earth's Weather-induced and Geophysical Extremes Digital Twin
IPCC	International Panel on Climate Change
LOLE	Loss Of Load Expectation, power system reliability standard, indicating the upper boundary of the expected number of hours in a year, during which energy is not served as supply is insufficient to meet the demand.
PEMMDB	Pan-European Market Database of ENTSO-E
PECD	Pan-European Climatic Database of ENTSO-E
RGI	Renewables Grid Initiative, User Engagement partner of the Destination Earth Use Case Energy Systems
TSO	Transmission System Operator, operator of the high-voltage electrical grid
TYNDP	Ten-Year Network Development Plan of ENTSO-E and ENTSOG (gas)
User community	User of climate information through energy system models – in the context of the DestinE Use Case Energy Systems, the categories of "users" include, but are not limited to: transmission and distribution system operators, researchers and in (climate-)energy system modelling, and policy makers using such models.

1. Executive summary

The German Aerospace Center (DLR), the Aarhus University (AU) and the Renewables Grid Initiative (RGI), under contract of ECMWF, are collaborating on the Use Case *Energy Systems* of Destination Earth (DestinE), which aims at: (i) evaluating the benefits of using DestinE climate data in electricity system modelling applications for grid planning and resource adequacy assessment, (ii) lowering barriers for adequate use of climate information in workflows of energy system models.

As a major contribution to the Use Case, the partners developed a Demonstrator, representative of common tools in electricity transmission infrastructure planning, that will showcase the use of DestinE data in grid planning and adequacy assessment workflows. The Use Case added value lies in supporting the choice and integration of meteorological scenarios in operational energy system workflows, at quantifying the scenarios uncertainty, and adequately communicating about this uncertainty.

The user community has been involved throughout the development and in the evaluation of these approaches. Integrating the user perspectives in the Performance and Impact Assessment of the DestinE Use Case Energy System was enabled through two RGI-lead co-creation activities, taking place in early 2024: (i) a user survey and (ii) a stakeholder workshop.

The relevance of user challenges addressed, as well as the tools developed, in the Use Case were in average rated high by the respondents. The stakeholders provided relevant feedback on how to further shape user-friendly tools and approaches. The stakeholders also expressed the benefit of DestinE to their work, which offers both a platform of collaboration as well as technical support to understand, and account for, the impact of climate change. In addition, the survey and workshop also enabled to enrich the community of interested stakeholders. Finally, the Use Case consortium will consider the users' feedback in the future improvements of the tools and further engage with interested actors.

2. Introduction and background

The Destination Earth (DestinE) Initiative, led by the European Commission and implemented by ECMWF, ESA and EUMETSAT, aims at developing a highly accurate replica of the Earth System, to help predicting and building resilience to extreme weather events and climate change. Key components of this EU-funded programme are the development of multiple models – or digital twins (DTs), that represent different areas of the Earth system (like *Weather-induced and Geophysical Extremes* DT and *Climate Change Adaptation* DT), and the DestinE Core Service Platform (DESP), which will provide decision-making tools in a cloud-based environment.

The German Aerospace Center (DLR), the Aarhus University (AU) and the Renewables Grid Initiative (RGI), under contract of ECMWF, are collaborating on the Use Case *Energy Systems* of DestinE, which aims at: (i) evaluating the benefits of using DestinE DTs' capabilities in electricity system modelling applications for grid planning and resource adequacy assessment, (ii) lowering barriers for adequate use of climate information in workflows of energy system models.

Through the DestinE Use Case *Energy Systems*, DLR and AU are developing a prototype of decision-making support tool for the energy sector, which builds upon the partners' capabilities in energy system model development and energy meteorology. Therefore, new integration and data processing methods and tools for meteorological datasets into energy system models are being implemented and tested. These modelling developments are based on the latest European Resource Adequacy Assessment (ERAA) and Ten-Year Network Development Plan (TYNDP) methodologies. These developments are pursued hand-in-hand with co-design activities, with experts and key users of energy system models in order to provide user-oriented end-products. In particular, the Use Case consortium developed a strong collaboration with European Transmission System Operators (TSOs), climate/meteorological and energy system researchers.

At a *User Needs Workshop*, organised by RGI in February 2023, the Use Case partners have identified specific needs for energy system modellers for integrating large amount of climate data into their workstreams. DLR and AU focused on addressing these needs through the Use Case demonstrator, by developing tools and methods accordingly. Namely, the Use Case demonstrator includes tools and approaches for:

1. **showcasing the sensitivity analysis of energy system models to climate data**, supported by:
    - the sensitivity of ERAA to several meteorological datasets
    - an approach to support the communication and quantification of uncertainties originating from the selection of meteorological datasets for energy system modelling applications.
2. **reducing complexity of climate-energy models via clustering of climate years, while considering climate scenario,** supported by:
    - A multi-dimensional assessment of weather scenarios
    - The visualisation of the information in points (1) and (2) on the interactive user dashboard

The user community has been further involved in the evaluation of these approaches, and therefore actively contributes to the Use Case **Performance and Impact Assessment**. This document describes the streamlined integration of the user perspectives in the Performance and Impact

Assessment of the DestinE Use Case Energy System. Two main co-creation activities will ensure this goal: (i) a user survey (DE370b.5.3.1: *'User Survey',* see section 3) and (ii) an expert workshop "User Perspectives Workshop" (Task370b12: '*User meetings',* see section 4). The survey and expert workshop serve complementary objectives to assess the performance of the use case demonstrator.

3. Online survey

The User Perspectives online survey collected feedback on the Use Case developments from a broad range of energy system modelling experts, which included among others: TSOs, energy modelling consultancies and research centers, energy agencies. The User Perspectives online survey was disseminated over a period of 6 weeks, in early 2024. The next sections detail the objectives and methods behind the online survey, as well as summarise and discuss the respondents' answers.

3.1 Objectives and methods

The User Perspectives online survey was designed for experts and interested stakeholders to give feedback on the status of Use Case tools, with the aim to further co-develop the DestinE Use Case for Energy Systems with relevant actors. The survey was shared with the Use Case consortium's extended network of energy system modellers, including RGI Members and stakeholders previously involved in other Use Case activities.

The survey aimed at assessing user needs, in terms of conditions for usability, timeliness, accessibility, available documentation, improved interactivity and the readiness-for-purpose of the approaches developed in the Use Case. As a secondary objective, the survey also offered the opportunity of joining the DestinE community to a broad network of energy system modellers.

The questionnaire combined both rating[1], multiple choices, and open questions, and alternating compulsory questions and non-compulsory ones (e.g., to comment a rating value or explain a process). Documentation on DestinE and the Use Case was included along the survey, including a technical factsheet and short videos, describing the Use Case tools. However, the consultation of the document was not mandatory neither necessary to complete to the survey. Therefore, the Use Case partners are aware that the answers may reflect views of respondents, without highlighting specific shortcomings to the developed tools.

The User Perspectives online survey was disseminated over a period of 6 weeks, in January and February 2024, and collected the answers from 23 individuals from 21 different organisations. Although participants were asked to provide their affiliation, it is assumed that their answers may not represent the entire strategy of their organisation, and may be influenced by their personal view and experience.

[1] Rating questions ranged from 1 (not relevant) to 5 (very relevant). In the following sections, a qualitative indicator was assumed for each rating value as follows: 1 – not relevant, 2 – low, 3 – moderate, 4 – high, 5 – very relevant.

3.2 Results summary and discussion

3.2.1 Background on survey respondents: a community of climate-energy experts

Most survey respondents indicated being introduced to the DestinE Initiative for the first time, which shows the survey reached a larger audience and enriched the group of interested stakeholders (Figure 1). 75% of the respondents represent an organisation based in the EU, 13% for an organisation with global operation, and few EU-neighbouring countries (such as Ukraine and Switzerland). The group of participants range within strategic and technical (e.g., modelling for system operation, asset management) roles in energy-related businesses and public bodies (e.g. National Energy Agency and Regulator), and include both climate and/or energy modelling experts from research institutions, technology providers, and thinktanks. Representatives of TSOs, which is a key group of users for the Use Case, constitute 35% of the group.

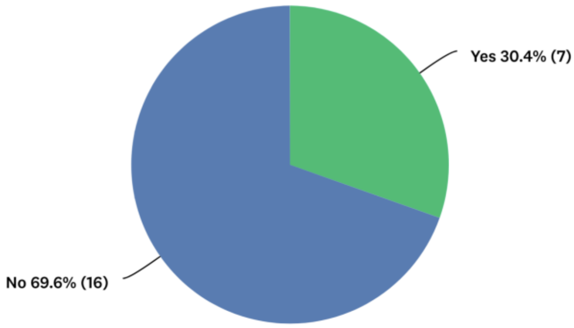

Figure 1: Acquaintance of respondents with DestinE Initiative

Some general questions aimed to assess the respondents' use of climate information. Answers show that the group mostly use historic climate conditions, present conditions and short-term weather forecast (Figure 2). 35% indicated using decadal climate projections, 22% considering projections up to the next century. Most respondents use climate information for future availability of energy resources for long-term infrastructure planning, which also reflects the objective of the Use Case (Figure 3).

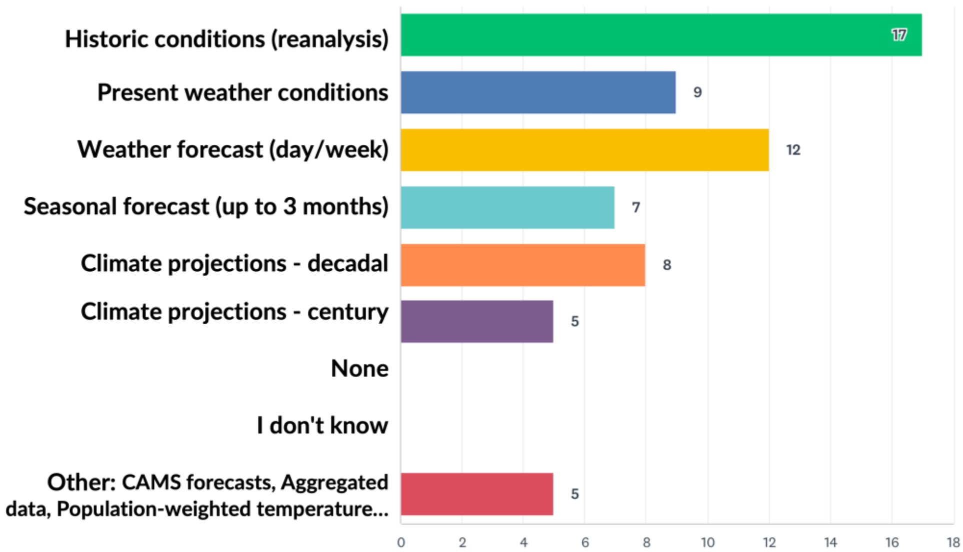

Figure 2: Respondents use of climate information - Type of climate information (multiple choice, absolute number of answers)

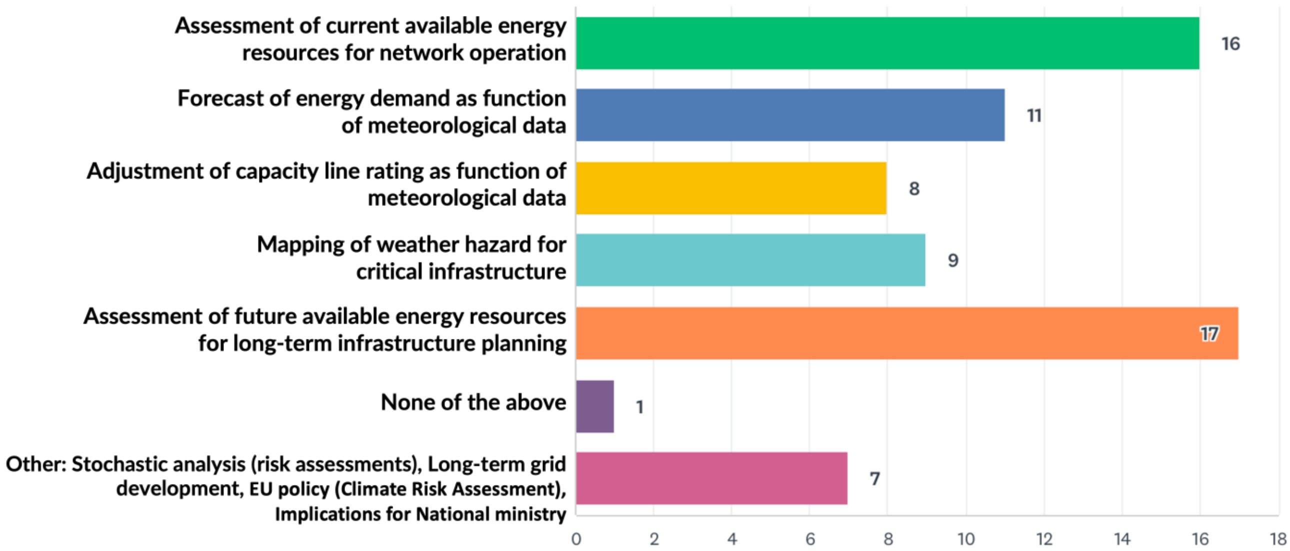

Figure 3: Respondents use of climate information - Purpose for use (multiple choice, absolute number of answers)

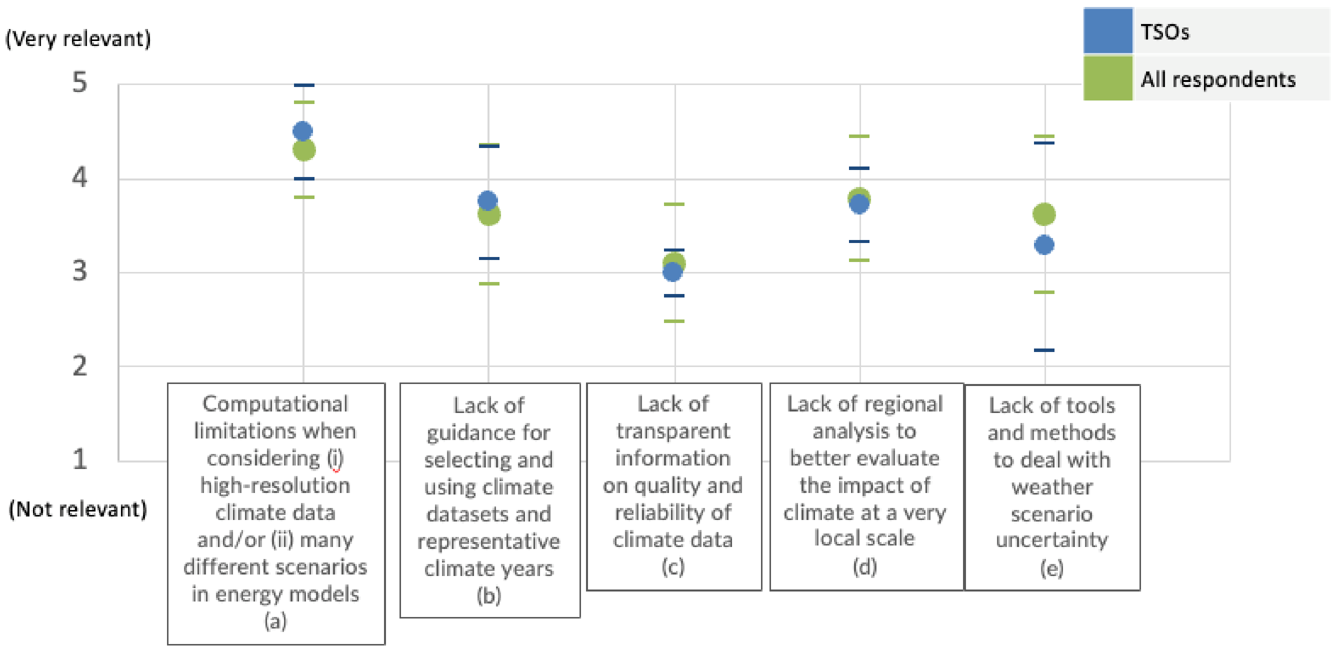

Figure 4: Rated relevance (1 to 5) of given challenges to integrate climate information in energy models

3.2.2 Assessment of the user needs

A. Challenges and knowledge gaps to better use of climate modelling knowledge in energy applications

The survey participants were required to rate the relevance of 5 given challenges to integrate climate information in energy models. These challenges and knowledge gaps were defined as key limitations to better use of climate modelling knowledge in energy system planning applications, by a group of stakeholders at the User Needs Workshop in February 2023, organised in the context of the Use Case.

Figure 4 shows the average and variance value of the rating by both the entire group of respondents, and by the sub-group of TSOs. **All challenges were rated between 3 and 4.5 (moderate to high relevance) by both groups. The challenge relating to computational limitations (a) appears as a major concern, while the lack of transparency in climate data (c) seems of least concern.**

The Use Case tools focus on several aspects of 3 challenges: (a) computational limitations, (b) guidance for climate year selection and (e) methods to represent climate information uncertainty in energy applications. The first two challenges are rated high for both groups (4.5 and 3.8 respectively), which reconfirms the needs and relevance to address these topics for the users benefit. The challenge (e), relating to representing climate information uncertainty, might appear of lower relevance to some users, in comparison to the other challenges. However, the next section will show that the groups rated of high relevance the related tool that was developed in the context of this Use Case.

In terms of other specific challenges limiting the use of climate information, respondents mentioned:

- **security limitations** (specifically IT infrastructure of TSOs are highly secured and may limit the interactions with climate information systems),
- **lack of standards for climate data, models and interfaces**,
- **lack of transparent information on projection geodata and lack of local analysis** (risk in using projection geodata for a different locations), and
- **lack of tools to align energy-demand data to projected weather years** (to ensure matching between demand data and weather year match).

B. Criteria and procedures for selecting adequate climate datasets

Regarding the selection of climate datasets, respondents indicated basing their selection on the following criteria:

- **recommended by regulators or peers**,
- **accessible and complete documentation specific to a given energy application**,
- **compatibility with in-house models**,
- **usability of dataset interface** (e.g. compatible with security constraints, data consistency), and
- **availability of suitable and concise dataset depending on end-application** (e.g, relevant space and time resolutions, same years for weather information and grid/demand data).

Regarding the procedures of dataset selection, some respondents have tested, compared, and used different ones, in particular different datasets provided by ECMWF, open-access datasets, and other datasets provided by national meteorology institutes. Some respondents have designed their own dataset in-house. Some TSOs mentioned that the **use and existence of a single reference dataset, such as the Pan-European Climate Dataset (PECD), is preferable**, and that datasets were selected jointly with other TSOs through ENTSO-E working groups. For selecting a specific weather year, respondents have mentioned basing their choice on the extremes analysis of several climate years, or on an uncertainty analysis. **Finally, several survey respondents expressed the complexity of climate dataset selection procedures.**

3.2.3 Assessment of the Use Case tools

The survey participants were required to rate the relevance and applicability of the Use Case tools currently being developed (Figure 5). The respondents were also asked to detail the conditions of usability, timeliness, accessibility, available documentation, improved interactivity and readiness-for-purpose, for integrating these tools in their organisation and energy workflow. The capabilities of these tools are described in the Use Case technical factsheet and short videos, to which the survey respondents had access to.

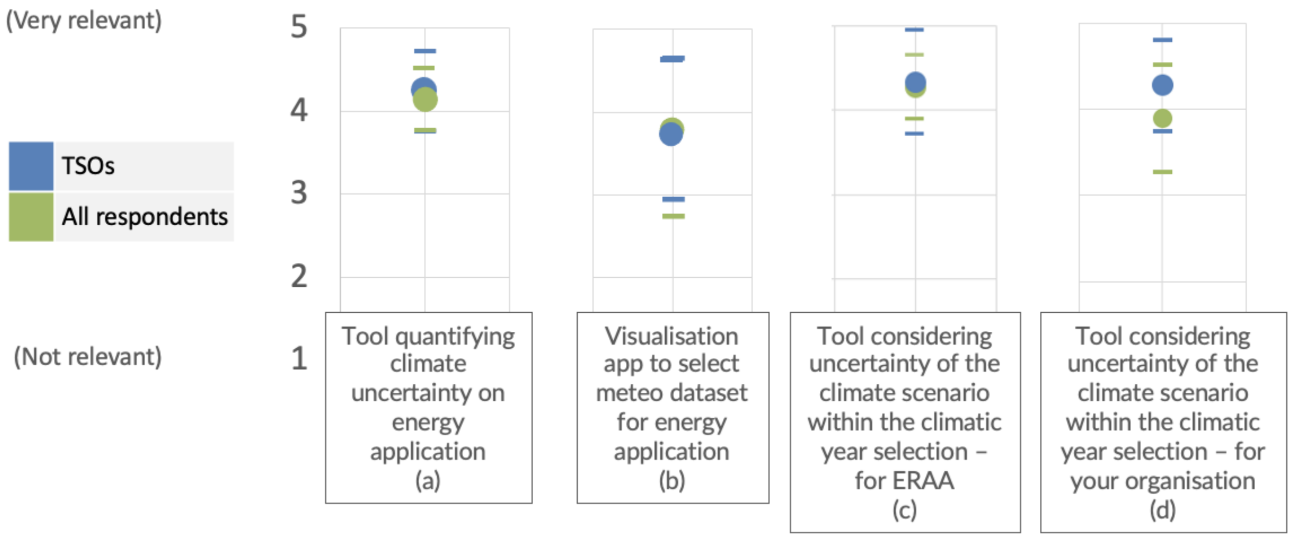

Figure 5: Rated relevance (1 to 5) of Use Case tools

A. On the tool and methodology that quantifies the uncertainties originating from different weather-dependent energy datasets for long-term system planning or other given energy application (a)

The survey respondents rated high the relevance of the tool quantifying climate uncertainty on their energy application: **average of 4.1 and 4.3/5**, for all respondents and TSOs respectively (Figure 5.a).

The respondents gave the practical examples on how such tool would be relevant for their organisation and energy application, such as to:

- re-evaluate currently used datasets and applied methodologies in energy system planning,
- evaluate the uncertainty in the evolution of the renewable energy generation,
- increase robustness dimensioning of grid assets,
- contribute to better policy development and support to governments,
- indicate the effect of a changing climate on observed energy-meteorological variability (e.g., impacts on dynamic line rating, transformer capacity, or infrastructure design) with additional operational aspects.

The respondents expressed a specific requirement regarding this tool capability:

- The **output data** should include the following: *probability bands of energy generation, renewables (wind, solar and hydro) capacity factors, electric vehicles and heat pumps operating profiles, overall demand profiles*; as well as being availability for different time and spatial resolutions.

B. On the visualization app to provide relevant information and guidance in selecting a meteorological data base for a given energy application (b)

The survey respondents rated as moderate-high the relevance of the visualization app to provide relevant information and guidance in selecting a meteorological data base: **average of 3.8 and 3.7/5,** for all respondents and TSOs respectively (Figure 5.b).

The respondents expressed specific requirements regarding this tool capability:

- The tool should **integrate information on the climate uncertainty**. The tool should provide a **summary of the variance between the years**, as the integration of natural variability in operational decisions is vital in some processes, while in others processes only information on extremes (at certain return periods) is needed.
- The tool should allow to **compare different meteorological models** and inform on their accuracy to predict renewable energy generated and consumption, in order to support the selection.
- An **accessible documentation and methodology description** should be provided, as some users might not use the app and prefer/need to run the analysis themselves.

C. On the tool and methodology that considers uncertainty of the climate scenario within the climatic year selection, for ERAA (c), and existing workflow on system adequacy or planning models in one's organisation (d).

The survey respondents rated high the relevance of such tool in the ERAA process: **average of 4.3/5,** for all respondents as well as for TSOs. The survey respondents also rated high the relevance of such tool in the context of their organisation's energy application: **average of 3.9 and 4.3/5**, for all respondents and TSOs respectively (Figure 5.c and 5.d).

For all tools, the respondents also suggested the following conditions for usability of these tools, and expressed specific requirements regarding the tool capabilities:

- The **documentation** should be easily accessible, peer-reviewed, and include clear and transparent references.
- The tool should be **accessible to all European TSOs**, and include an **uncertainty analysis for PECD v4.**
- The tools should fulfil **open-source standards**, similarly to other popular open-source tools for energy application (e.g. pandas, scipy, pandapower, atlite, pypsa).
- The tool should be **compatible with other existing tools** (e.g., PLEXOS for Energy Market Modelling).

3.3 Conclusions

The survey respondents reflect a **representative user group** that is relevant for the use case co-development, as described in the Use Case's User Engagement Roadmap. A broad dissemination of the survey enabled to enrich the community of interested stakeholders, as most of the respondents were new to the DestinE Initiative (section 3.2.1). **The relevance of user challenges addressed and tools developed in the Use Case were in average rated high by the respondents.** Although the limited number of respondents does not allow to draw statistically relevant conclusions, the narrow and expert-oriented scope of the survey and detailed answers delivered by respondents showcase the relevance of the Use Case tools for the targeted users and their organisations. **The Use Case consortium will consider the users' feedback in the tools' future improvements and stakeholder engagement activities**.

The final section of this report will provide further comment to the user feedback, and next steps.

4. Stakeholder workshop

The User Perspectives workshop aimed collected feedback on the Use Case developments from a targeted group of energy system modelling experts. On 6 February 2024, the User Perspectives workshop was attended by a group of 30 experts from 18 organisations in the field of climate and energy system modelling. The next sections detail the workshop objectives and summarise the workshop inputs and discussions.

4.1 Objectives

The User Perspectives Workshop had the following objectives:

- **Collecting feedback from users** how the Use Case tools address the specific needs in the user community to integrate large amount of climate information in energy system models and **derive further user-oriented improvements.**
- **Stimulating exchanges within the user community of climate-energy models** and promote the potential integration of new knowledge into existing and future workflows.
- **Contributing to other DestinE workstreams co-design process**, such as for ClimateDT and ExtremeDT, to ensure highly user-oriented modelling developments.

4.2 Agenda

The User Perspectives Workshop was organised as one full-day hybrid event. The in-person meeting was hosted by ENTSO-E offices, in Brussels. The full workshop agenda is listed in Table 2.

Table 1: User Perspectives workshop agenda

Time	Session
9:30 – 10:00	Registration and coffee
10:00 – 10:10	**Welcome** – Renewables Grid Initiative & ENTSO-E & DLR & ECMWF
10:10 – 10:25	**Opening speech** – Jakub Dabrowski, DG CNECT & Derck Koolen, DG ENER
10:25 – 10:35	**Status of Destination Earth** – Jörn Hoffmann, ECMWF
10:35 – 11:00	**Status of the DestinE Use Case Energy Systems and tools demonstration** – Bruno Schyska and Fransceco Witte, DLR & Léa Hayez, RGI
11:00 – 11:20	**User Perspectives** – Simon Hellmuth, TenneT & Laurent Dubus, RTE / ENTSO-E
11:20 – 11:50	**Discussion and interactive assessment of Use Case tools – part 1**
11:50 – 12:05	Coffee break
12:05 – 12:45	**Discussion and interactive assessment of Use Case tools – part 2**
12:45 – 13:45	Lunch break
13:45 – 14:05	**Status of the DestinE Climate Digital Twin: focus on model outputs specific to the energy sector** – Aleksander Lacima, Barcelona Supercomputing Center
14:05 – 14:20	**Status of the DestinE Extreme Digital Twin: focus on model outputs specific to the energy sector** – Kristian Pagh Nielsen, Danish Meteorological Institute
14:20 – 14:45	**Discussion – DestinE Digital Twin outputs and energy modellers needs**
14:45 – 15:00	**Co-visualizing climate and enger system data, and potential application of AI** – Alexander Kies, Aarhus University
15:00 – 15:20	**Discussion – Further opportunities of bridging DestinE and Energy systems**
15:20 – 15:30	**Conclusions and end of the workshop**

4.3 Participating organisations

A group of 30 experts joined the workshop, physically or online, which included: energy system modellers (for adequacy assessment, infrastructure planning or asset management) representing Transmission System Operators or research entities, energy regulators, policy officers, and Earth system researchers and modellers. The participating organisations are listed below in Table 3.

Table 2: List of participating organisations and region

	Organisation	Region
1	Aarhus University	Denmark
2	European Union for the Cooperation of Energy Regulators (ACER)	Europe
3	Barcelona Supercomputing Center (BSC) - DestinE ClimateDT	Spain
4	Danish Meteorological Institute (DMI) - DestinE ExtremeDT	Denmark
5	E3Modelling / CLINT project	Greece
6	European Commission – DG CNECT	Europe
7	European Commission – DG ENER	Europe
8	European Center for Medium-Range Weather Forecast (ECMWF)	Europe
9	European Network of Transmission System Operators for Electricity (ENTSO-E)	Europe
10	Geosphere	Austria
11	German Aerospace Center (DLR)	Germany
12	Redeia	Spain
13	Redes Energéticas Nacionais (REN)	Portugal
14	Renewables Grid Initiative (RGI)	Europe
15	Réseau Transport Electricité (RTE)	France
16	Stattnet	Norway
17	TenneT	Germany / NL
18	TransnetBW	Germany

4.4 Summary of presentations and discussions

4.4.1 Introduction to Destination Earth

- **Jakub DABROWSKI** (Policy Officer, DG CNECT) **opened the workshop with a high-level introduction to Destination Earth.**

  Building on the first phase, the phase 2 of DestinE will kick-off mid-2024, and will particularly focus on engaging with users to reflect their needs and challenges in the DestinE tools. Stakeholders that will be invited to further engage in DestinE include both policy makers, public and business sector users, as well as general public.

- **Derck KOOLEN** (Policy Economist, DG ENER) **presented recent modelling work in energy and climate policy at the European Commission, that consider the variability of climate and its impacts on energy systems.**

  As an example, the Commission analysed weather patterns and their effects on the European power systems, to better understand how to operate renewable-based systems in the future [1]. The Energy and Industry Geography Lab support energy infrastructure planning decision for identification acceleration areas for renewables [2]. These fed several pieces of legislation, such as the 2040 Climate Target, Emergency measures and Electricity Market Design Reform, and Storage Requirements.

  These policy-oriented studies and tools can benefit from using DestinE data to further bridge the climate science and energy system modelling. As a practical example, DestinE data and knowledge can support energy system modellers understand, and account for, the impact of physical phenomena, that may be unknown from the energy system community, and that potentially have a significant impact on the energy system (such as aerosol variations and cloud effects).

- **Jörn HOFFMANN** (Application Partnership Lead for Destination Earth, ECMWF) **emphasized that Destination Earth Initiative aims at integrating impact-sector models with the Earth System models, and improve their interactivity with technological developments.**

  The main digital components of DestinE are the Digital Twins, the Digital Twin Engine, the Service Platform (DESP) and the Data Lake (Figure 6). The co-design is enabled through the DestinE Use Cases in various domains, including the energy sector.

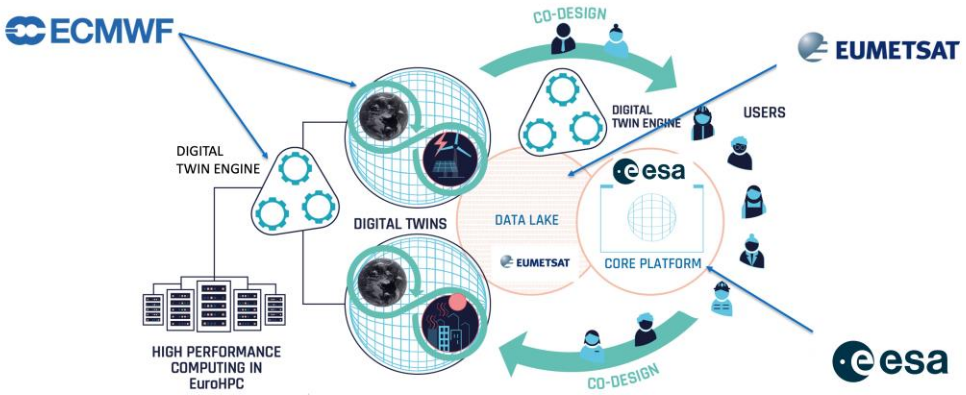

Figure 6: Destination Earth architecture (Credits: ECMWF)

DestinE Climate Adaptation Digital Twin supports efforts of defining and planning climate change adaptation, for instance thanks to climate projections at km-scale. DestinE phase 1 will be delivered in mid-2024, and the ClimateDT will include, among other capabilities: the advanced high-resolution global Earth System and impact-sector simulation, the monitoring and assessment of DT simulations quality, and capability to add selected impact models in the DT workflows. DestinE wants to offer an operational climate projection service, as users can benefit from frequent model updates, from accessing information while models are running, and co-define the model simulations.

DestinE Weather-Induced Extreme Digital Twin offers both a global and an on-demand regional components to predict weather extremes, also with improved spatial and temporal resolution. The On-Demand component can enhance disaster resilience by informing on local impacts, and can also reduce economic vulnerability by offering better forecast. At the end of phase 1, the ExtremeDT will include, among other capabilities: enhanced simulation scales (2,8 to 4.4 km globally, and 500-700 m regionally) at weather time scales, and an unified simulation framework (weather, hydrology, air quality models) to provide Earth-system to feed impact-sector models. Phase 2 will focus on operationalising the ExtremeDT.

DestinE Digital Twin Engine is the software architecture around the other DestinE component, that manages data and steers the workflows. The Service Platform will allow users to discover the DestinE Ecosystem. The Digital Twins outputs are designed to also host external or federated datasets, such as impact-model data, which will all be articulated in the DestinE Data Lake. The Data Lake is a distributed architecture that connect with other European data spaces. By the mid-2024, the latter DestinE components will also reach some standards of maturity and will be further improved during phase 2.

4.4.2 DestinE Use Case on Energy Systems and User Perspectives

- **Bruno SCHYSKA** (DLR, Scientist and Project Lead of DestinE Use Case Energy Systems) **introduced the objectives and status of the DestinE Use Case on Energy Systems.**

  The Use Case on Energy Systems aims at bridging the DestinE modelling developments with the existing climate-energy services, such as the Copernicus Climate Change and Atmosphere Monitoring Services, **and national/European climate-energy mandates**, such as the Ten-Year Network Development Plan (TYNDP) and European Resource Adequacy Assessment (ERAA). Integrated climate-energy modelling allows to efficiently combine expertise from both fields, and to address specific needs from the impact-model users.

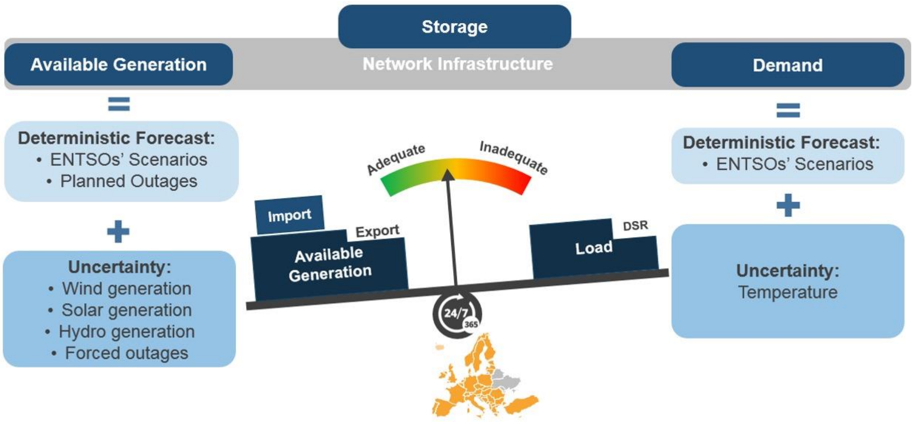

Figure 7: European Resource Adequacy Assessment as Use Case Demonstrator (Credits: ENTSO-E)

As a major contribution to the Use Case, the partners developed **a Demonstrator, representative of common tools in electricity transmission infrastructure planning, that will showcase the use of DestinE data in grid planning and adequacy assessment workflows.** This Demonstrator is a simplified version of the ERAA (Figure 7) in an open-source energy system modelling framework, and allows to observe the effect of meteorological data both on the energy generation and demand.

The sensitivity of the demonstrator to meteorological scenario was quantified by: i) in the first step, replacing the input wind power capacity factor time series[2] by various alternative, openly available, datasets [3], and ii) by comparing the adequacy simulation results in terms of Energy Not Served. As a result, the Demonstrator showed an expected sensitivity to the meteorological information. **The Use Case added value lays in supporting the choice and integration of meteorological scenarios in operational energy system workflows, at quantifying the scenarios uncertainty, and adequately communicating about this uncertainty**.

- **Léa HAYEZ** (RGI, Manager in Energy Systems and Lead of User Engagement in DestinE Use Case Energy Systems) **presented initial results of the User Perspectives online survey.** Final analysis of the survey results can be found in Section 2 of this report.

- **Simon HELLMUTH** (TenneT, Energy System Planning and Market Analysis) **presented TenneT perspective in interested user of DestinE data and knowledge, and in engaging in the Use Case co-design with an industry perspective.**

  TenneT sees potential in **benefiting from DestinE in all three areas of services: transmission services, system services, and market facilitation**. During the Use Case development, TenneT supported the partners on market modelling challenges and with benchmarking simulation results. TenneT sees potential in using DestinE data for energy system planning applications specifically, and made the following suggestions for efficient and fit-for-purpose further developments:

  - Becoming established within the TSO community requires effort in **standardizing the data and further engaging with the community**.
  - **Transparency and easy access to DestinE tools and data** should remain a priority, as well as putting effort in the **documentation and communication on the data validation**.
  - **Data quality** and ensuring that datasets are ready-for-purpose for energy applications is also important.

- **Laurent DUBUS** (RTE, Leading Climate, Long-Term Power System Adequacy and Planning Group – ENTSO-E, Convenor of Expert Group in Climate and PECD) **presented the**

[2] The Pan-European Climate Database is used as input to the ERAA, in its version 3 (2021) at the time of the Use Case analysis.

updating work of the PECD4, and suggested complementarities between the DestinE Initiative and existing climate services for energy planning applications.

The new Pan-European Climate Database, PECD4, developed by the Copernicus Climate Change Service (C3S) in cooperation with ENTSO-E, is the new climate reference dataset for ENTSO-E and some of its Members for long-term planning studies. The previous PECD3.1 was based on ERA5[3], historical data, which are no more suitable for medium and long-term studies. Long-term prospective studies, such as ENTSO-E's European Resource Adequacy Assessments (ERAA) and Ten-Year Network Development Plans (TYNDP), should now take climate change into consideration by using climate projections, and also account for different greenhouse-gas emission scenarios.

The new version of the PECD is currently being developed to overcome the need of reflecting climate change in climate scenarios for energy applications [4,5]. PECD4 is more flexible to different energy models, and will offer open-access data and methodologies. PECD4 will contain a much larger dataset, reflecting a higher number of climate scenarios, and including both historical data and climate projections. PECD4 contains both climate information (e.g., temperature, wind speed, solar radiation, precipitation) and corresponding energy data (e.g., renewable energy capacity factors and generation), at various geographical scales (from 25 km to larger aggregation). Additionally, PECD4 offers training and guidance for users.

So far, the PECD4.1 include climate information from 3 projection models (from CMIP6[4]) following the SSP2-4.5[5] scenario until 2065, which is assumed to be the scenario representing the current global emission trends. By the end of 2024, the PECD4.2 will also include 3 additional scenarios SPP1-2.6, SSP3-7.0 and SSP5-8.5, which will allow to assess the effect of different emission scenarios on long-term studies. It will also be extended to 2100. Other projection models will be added in the future, allowing to assess the uncertainty due to climate models. Regular updates and higher resolution simulations will be considered in the future, depending on the availability of regional climate simulations like CMIP6 based EURO-CORDEX. The Copernicus Climate Data Store will also allow for online applications.

DestinE Use Case on Energy Systems is a great opportunity to complement and push forward the Copernicus work with stakeholders such as ENTSO-E and TSOs. Areas of complementarities include: quantifying and communication about climate models uncertainties, qualifying climate year selection methodologies (depending on type of study), better exploring extremes and impacts on the power systems, downscaling Global Circulation Model simulations, running on-demand simulations (e.g. for stress tests). **To efficiently achieve their common objectives, Copernicus and DestinE should then reinforce collaboration.**

[3] ERA5 is the fifth generation ECMWF reanalysis for the global climate and weather for the past 8 decades.
[4] Couple Model Intercomparison Project 6: last-generation climate models featured in the IPCC AR 6. More information at: https://www.wcrp-climate.org/wgcm-cmip/cmip-video
[5] Shared Socioeconomic Pathways: defined in the IPCC AR 6, climate change scenarios of projected socioeconomic global changes up to 2100, and used to derive different greenhouse gas emission scenarios, including the impact of climate policies.

Discussion point 1: Complementarity between Copernicus / PECD activities and the DestinE Use Case Energy Systems

The Use Case is a research demonstrator, aiming to understand the interactions and support the integration process of meteorology and energy systems. The collaboration between ENTSO-E and C3S on using climate information has made significant progress, and is still an ongoing work. The DestinE Use Case can complement this existing collaboration, and both activities can learn from one another, for the benefit of the users. ***The DestinE Use Case will indeed build on the PECD work, and support the climate year selection procedure within the PECD ensemble.***

At the same time, the Use Case also tries to understand the user needs to further engage with DestinE knowledge, as for instance: would users be open to use, and upload proprietary information on a public cloud system to run some of their models? What level of trust would be required, and under which technical conditions should this be possible?

- **Francesco WITTE** (DLR, Scientist and Tool Developer of DestinE Use Case Energy Systems) **presented the tools developed in the context of the DestinE Use Case Energy Systems, for the quantification of power system model sensitivity to climate information, and complexity reduction techniques for integration of climate information into energy system models.**

  The Use Case is a simplified replica of the ERAA, which include 1) Economic Viability Assessment (EVA, i.e., assessment of capacity expansion or decommissioning for the power plants) and 2) System Adequacy assessment (i.e., quantification of unmet demand). DLR neglected modelling some aspects of the ERAA, for reducing complexity or due to availability of data, such as: the EVA, demand-side response, unit commitment and probabilistic modelling of unplanned thermal power plant outages. The input data is based on the latest Pan-European Market Database (PEMMDB) and the PECD, and the output data results in hourly power plant dispatch (for given zone).

  The Use Case studied the power system model's sensitivity to climate scenarios, and as an example, highlighted the pronounced sensitivity to wind power scenario. This sensitivity (e.g., in terms of insufficient generation or storage capacities in the system) is quantified using the Loss of Load Expectation (LOLE, i.e., the number of hours of unmet demand), and technological assumptions embedded in the climate scenario (e.g., hub-heigh and location of wind turbines).

  By studying the characteristics of given weather years, the Use Case aims at finding patterns, and eventually clustering methods, that could help reducing the amount and the complexity of energy system model simulations for various climate scenarios. As a first attempt, DLR looked at the number of extreme events in given climate years, that are defined as long-duration loss of load during low renewable energy production.

Discussion point 2: Use Case "ERAA" demonstrator as a representative workflow

The Use Case's "ERAA" demonstrator is a less sophisticated model than actual models used at ENTSO-E or by TSOs. The simplifying assumptions embedded in the use case demonstrator influence the final numbers of loss of load, and one should not focus on the absolute value but on the results sensitivity. ***The goal of the Use Case study is not to precisely replicate the ERAA, but to offer valuable information regarding the sensitivity and uncertainty relating to climate information.***

Discussion point 3: Need for new complexity reduction techniques

There is a need to further develop concepts for complexity reduction for integrating climate signals in energy system modelling*, that improve the in-depth analysis of climate/weather uncertainty and results representation, compared with classical Monte Carlo approaches.*

DLR's initial research with historical climate data shows that it would be possible to define clusters of climate scenarios for a given year (i.e., that show similar characteristics in terms of their effects on the energy system), as well as assigning representative weights to each cluster. Another approach could be to analyze weather regimes that are of high relevance and impact for the energy system. ***DLR plans on further experimenting these approaches in the context of the DestinE Use Case on Energy Systems, with the newest PECD data, as well as the DestinE data, as soon as available.***

To define complexity reduction methodology and criteria (e.g., complexity reduction for ERAA 2023 based on cost metrics), one should reflect on 1) what the study objectives (or KPIs) are, and 2) according to the requirements of the modelling application, what is relevant for the selected scenario ensemble to represent.

Discussion point 4: Selection of technological trends and spatial allocations for renewable deployment

Although capturing climate variance in scenarios for energy planning has improved, there might still be a blind spot on the evolution of technological and spatial allocation trends (e.g., deployment of wind farms). *In most climate scenarios, the technical and spatial evolution of wind fleet are often calibrated on a specific weather year and spatial allocation of existing windfarms for a given region, and are extrapolated in the future and space.* ***Such extrapolation practice may induce bias, and thus may require further investigation and relate to policy choices****.*

ENTSO-E is constrained by ***legal mandates*** *(e.g., ERAA methodology) and* ***official national assumptions*** *relating to technology developments and spatial allocation of renewables. However,* ***ENTSO-E explores the possibility of expanding the number of scenarios, both climate (e.g., using the PECD4) and technology trends, to support their studies and plans.***

4.4.3 DestinE Climate and Extreme Digital Twins, and user needs

- **Aleksander LACIMA** (BSC, Research Engineer in Earth Sciences and Developer of DestinE Climate Adaptation Digital Twin) **presented the status of the DestinE Digital Twin for Climate Adaptation (Climate DT) and showed how this model can produce valuable data for the energy sector through initial results from the Climate DT Energy Use Case.**

  The Digital Twin for Climate Adaptation DT is a new type of climate information system based on high resolution climate simulations, impact modeling and high-performance computing. ClimateDT offer a global view, that allows to assess our vulnerability in changing climate at global scale, and to provide information for climate adaptation. **Climate adaptation encompasses the set of actions required to limit the consequences of a warming climate and requires, among many other elements, climate information about climate hazards.** New solutions are needed to **inform climate change adaptation efforts** and to **assess risks of failed mitigation actions** (see Figure 8). Transition from a top-down to a bottom-up approach regarding user interaction and engagement.

  The Climate DT key features are: a **user-driven** approach focused on **user interactivity**, **global climate simulations** at unprecedented horizontal resolution (5km mesh, multi-decadal), novel **streaming framework** of climate model output to applications, **quality assessment and uncertainty quantification** based on historical observations, deployment on **two European pre-exascale supercomputers**. The first ClimateDT version will be deployed by mid-2024, and be further developed.

  ClimateDT uses two Earth System Models: ICON and IFS-NEMO/FESOM. The high-resolution simulations enable fine-scale processes described with improved physics and higher fidelity, regional and local information relevant for users, easier validation and comparison with observations. One major challenge with is about storing unprecedented volumes of data outcoming of such simulations. To overcome this challenge, the ClimateDT envisions a streaming framework, in which diagnostics are derived at model runtime. With such technology, although the full time series of climate data is not stored, users can stream the climate model output at high frequency and native resolution, request specific simulation based on their needs.

  The ClimateDT Energy Use Case aims to produce estimates of the changes in wind resources under climate conditions, producing local information usable for the energy sector. Several energy-related indicators are being implemented for a wind application (i.e., model runs at given hub-height and no need of interpolation), including **wind speed distributions (based on weekly average), wind speed anomalies, wind power density, capacity factors, annual energy production and the interannual variability of these metrics**.

Feature	*State-of-the-art*	*ClimateDT*
Climate variable	10m wind components (u10, v10) Requires interpolation	**100m** wind components (u100, v100)
Temporal resolution	3 to 6 hourly	**1 hourly** to sub-hourly
Spatial resolution	100 km (CMIP) 12.5 - 50 km (CORDEX)	**2.5 - 5 km**
Location	RCMs / downscaling required for regional climate information	**Regional climate information** available **globally**

Figure 8: Summary of novel features introduced by the ClimateDT in Genearal Circulation Models (Credits: BSC)

- **Kristian PAGH NIELSEN** (Meteorologist/Physicist at Danish Meteorological Institute, Technical Lead for DestinE Extreme DT) **presented the status of the DestinE On-Demand Extremes Digital Twin, and the design of the model outputs specific to the energy sector.**

The ExtremeDT envisages an on-demand high resolution system (at around 500 m, 5-15 min. frequency), capable for forecasting and monitoring a fast-moving mesoscale event around 1-2 days ahead. The ExtremeDT demonstrated improved forecasting capabilities on an energy system model, which showed that the model can be an added value for power systems operations. Inaccurate forecasting can have major impacts on the power system stability, therefore, validation of forecast models is important to improve model capabilities.

The Digital Twin currently offers the following output data, relevant for the energy sector: wind speed and direction at specific heights, wind maximum gust, and power production, direct normal and clear-sky irradiance, and solar power production (given input data on the plants location and technologies).

Discussion point 5: Climate data validation and quality

The ClimateDT includes data validation and quality analysis, for instance by running historical simulations and comparing them to observations. In the ExtremeDT, the model outputs is also verified against observation data from meteorological stations. As a practical example of user engagement in the data validation process: the Belgian Royal Meteorological Institute has collaborated with the Belgian TSO, Elia, to validate the power production from the DestinE climate-energy model against the actual data.

Discussion point 6: Pre-selection and access to DestinE climate data

Collaboration with climate data users is essential to make the most of the simulation and extract relevant indicator for the industry. *The streaming technology helps overcoming the complexity of storing the evolution of all climate variables of the multi-decadal climate model. This approach also offers the possibility of using these models to better understand how climate works, at high frequency and resolution data. However, due to the large volume of data coming out of* ***ClimateDT projection runs, the data should be well managed and only the useful parts should be stored and kept on the longer-term****.*

Users will be able to access both the raw climatic data as hourly time series for a specific location, as well as pre-defined variables relevant to their application, such as statistics of distribution of capacity factors or wind speeds. The Use Case Energy Systems already identified the need for TSOs to derive hourly timeseries from these probability distributions, but ***additional relevant variables are still to be defined****. For instance, user data needs could be as specific as "evolution of wind speed at specific hub height at specific wind farm locations".*

For example, to match the climate input to both demand and generation patterns, an energy user could either i) download the specific climate variables needed and use them as input data to their climate-sensitive demand model, such as tool to build load time series of demand based on climate input; or ii) upload a specific tool on the DESP and directly feed the downstream model with the DestinE climate data.

The Digital Twins will offer "What if" scenarios and storylines. By reproducing with global models some observed events in the past, and analysing these cases with different global warming levels, ***DestinE will show how adverse events of the past would behave in the future****.*

- **Alexander KIES** (Professor in Department of Electrical Engineering and Computer Science at Aarhus University, and Tool Developer of DestinE Use Case Energy Systems) **gave an outlook in the next developments of the DestinE Use Case Energy Systems.**

The Use Case Energy Systems aims at improving energy system models and their computational tractability to be able to handle increasingly complex meteorological data. Practically, the Use Case partners explore approaches to speed up the linear optimal power flow, that rules the energy system optimisation. An approach would be to implement a novel physics-informed neural network model for solving the linear optimal power flow problem, in power systems with high penetration of renewable energy sources [6].

Such optimisation problem aims at minimizing the total operational cost of power generation, while insuring system adequacy, under techno-economics constraints of electricity generators and transmission networks. In the European context, the computational problem is challenging due to the scale and diversity of the interconnected grids and energy mix, the renewable variability, the technical constraints of the power system, and computational intensity.

The partners proved the added value of this approach on a 30 and 300-nodes test case for the European power grid. The model accurately reflects the power generation distribution, and a strong correlation between predicted and actual power dispatches. While the benefit of this approach could not be demonstrated for the smaller test case, the difference in performance benefit and runtime was more pronounced in the larger 300-node scenario. **The Use Case partners will further improve the computational speed-up of this approach, for instance by combining it with temporal clustering.**

Finally, future research should investigate:

- the underlying mechanisms of attention matrices to improve neural network interpretability, by incorporating energy storage units due to their importance in future energy systems,
- expanding the machine learning algorithms for the complex OPF problem, acknowledging spatial and temporal variable correlations, particularly as renewable energy integration increases,
- adding storage uptake / discharge, investment problem, etc.
- developing energy system-relevant metrics to assess the quality of the models.

4.5 Conclusions

The participatory design of the User Perspectives Workshop allowed for important discussions between users and DestinE network. The stakeholders provided relevant feedback on how to further shape user-friendly tools and approaches. The stakeholders expressed the benefit of DestinE to their work, which offers both a platform of collaboration as well as technical support to understand, and account for, the impact of climate change on their specific applications. Specifically, the workshop participants encouraged the Use Case partners to further engage with the TSO community and existing climate-energy groups, such as Copernicus/ENTSO-E. The workshop also allowed to raise stakeholder interest for other DestinE workstreams, such as the ExtremeDT activities.

5. Relevant literature

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