Smart4RES

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INSTITUT CARNOT M.I.N.E.S

Final conference

Paris, 14 April 2023

ARMINES · MINES PARIS · PSL · METEO FRANCE · INESCTEC · energy & meteo systems · whiffle precision weather forecasting · DNV · DTU · Imperial College London · DLR · Dowel innovation · NEW by EDP & CTG · ICCS · HEDNO

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864337

Session 1

General overview

09:15 - 10:00	**SESSION 1: GENERAL OVERVIEW** Moderator: Stéphanie Petit, Dowel Innovation
	- **Welcoming words**, A. Laboudigue (Deputy Director of Research of Mines Paris and Director of operation Carnot M.I.N.E.S) - **Keynote speech 'EU's research and innovation priorities on renewable energy'**, M. Soede (DG Research and Innovation, European Commission) - **Evolution of the state of the art and The Smart4RES project in a nutshell** G. Kariniotakis (MINES Paris)

Smart4RES

MORNING SESSIONS

Download the programme

Agnès Laboudigue

CARNOT M.I.N.E.S

Matthijs Soede

DG Research – Energy Directorate
European Commission

EU’s research and innovation priorities on renewable energy

Smart4RES - Final conference

Paris 14 April 2023

Dr ir. Matthijs Soede
DG Research & Innovation
Clean Planet Directorate
Unit Clean Energy Transition
Policy Officer

EU Energy and climate strategies and plans (1)

Greenhouse gas emissions reduction and renewable sources share: increasingly ambitious targets

- January 2014: A policy framework for climate and energy in the period from 2020 to 2030
  - At least 20% share for renewable energy in 2020 and 27% in 2030

- **REVISED RENEWABLE ENERGY DIRECTIVE** – 11 December 2018
  - binding target of **renewable sources** in the EU's energy mix to at least 32% by 2030

- **European Green Deal – December 2019**
  - no net emissions of greenhouse gases by 2050
  - Circular economy

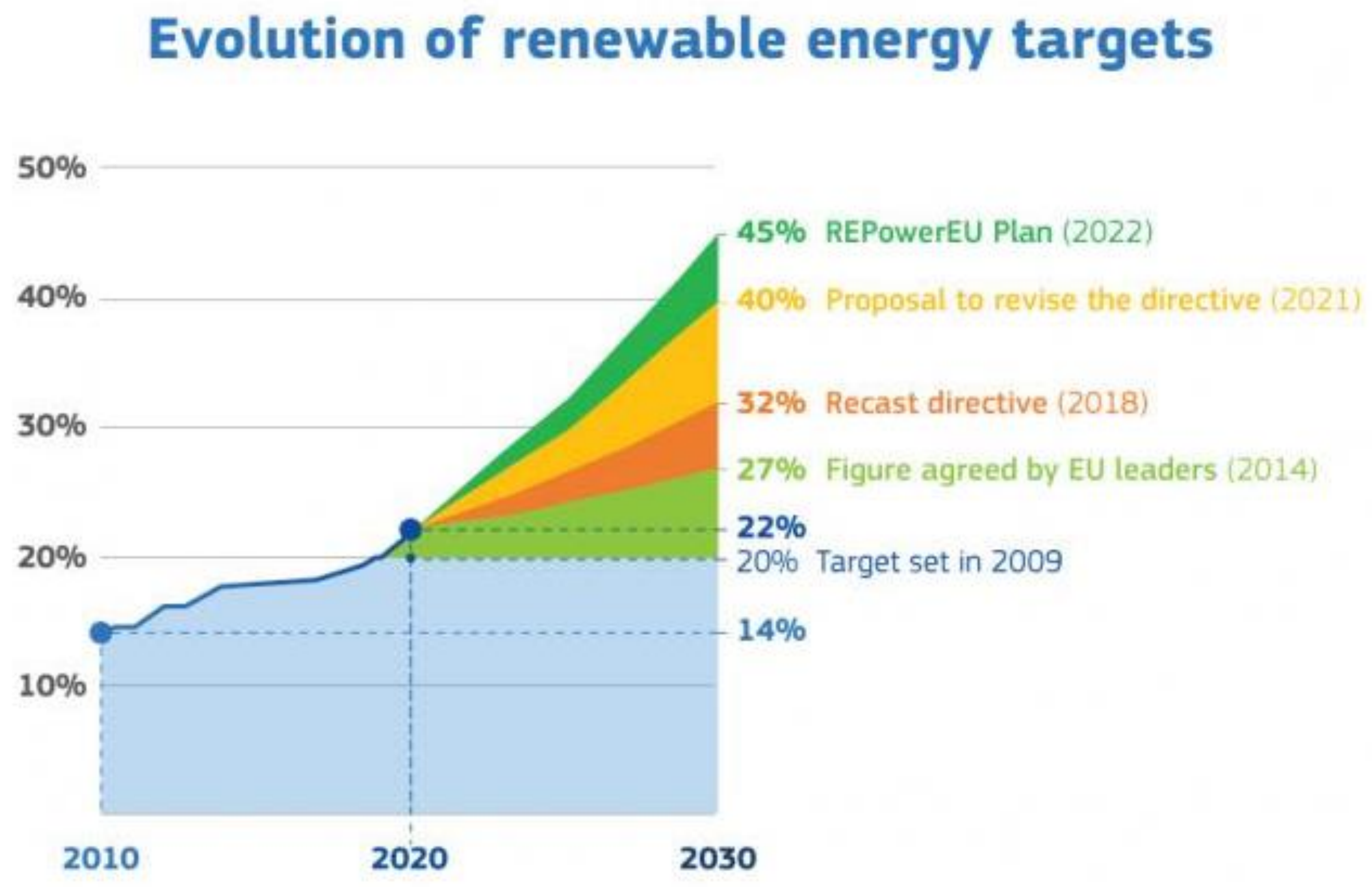
- **2030 Climate Target Plan – 17 September 2020**
  - greenhouse gas emissions to at least 55% below 1990 levels by 2030

- **'Fit for 55' package - 14 July 2021**
  - The Commission proposes to increase the binding target of **renewable sources** in the EU's energy mix to 40%

- **REPowerEU Plan – 18 May 2022**
  - The Commission is proposing to increase the EU's 2030 **target for renewables from the current 40% to 45% (42.5+2.5)**.

European Commission

EU Energy and climate strategies and plans (2)



Projected wind energy capacities – scenarios (1)

2030 Climate Target Plan – 17 September 2020

Projected capacities in onshore wind and offshore wind according to 2030 Climate Target Plan - CTP-MIX scenario:

- Onshore: 366 GW in 2030, 963 GW in 2050
- Offshore: 73 GW in 2030, 290 GW in 2050

Projected electricity generation in onshore wind and offshore wind according to CTP-MIX scenario:

- Onshore: 847 TWh in 2030 (share of total electricity generation: 27.3%), 2 259 TWh in 2050 (share:32.9%);
- Offshore: 229 TWh in 2030 (share: 7.4%), 1 154 TWh in 2050 (share: 16.8%).

Current share of total electricity generation (2020): Onshore wind 13.7%; Offshore wind (1.7%)

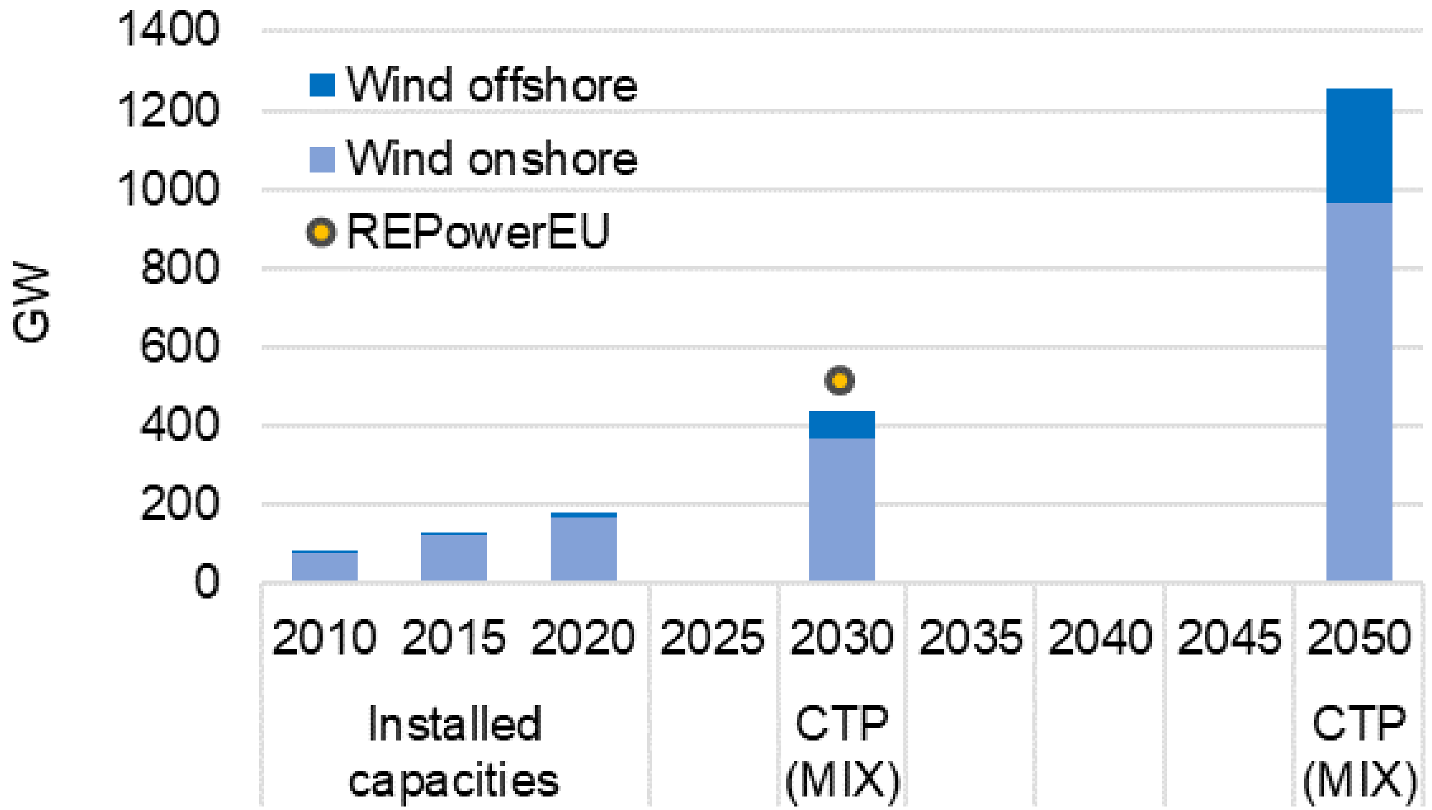
➢ **EU Offshore Strategy – 19 November 2020**
  - **60 GW by 2030, 300 GW by 2050 (offshore only)**

➢ **'Fit for 55' package - 14 July 2021**
  - **469 GW by 2030**

➢ **REPowerEU Plan – 18 May 2022**
  - With respect to wind energy the REPowerEU Plan proposes an installed capacity of **510 GW by 2030**, an increase by 16% as compared to CTP-MIX scenario

➡ (~ +41 GW/year over the period 2023-2030)

Projected wind energy capacities – scenarios (2)



Source: JRC based on 2030 Climate Target Plan Impact Assessment, 2022.

European Commission

REPowerEU Package

European Commission’s plan to make Europe independent from Russian fossil fuels well before 2030, in light of Russia's invasion of Ukraine

- REPowerEU Plan Communication, Annexes and Staff Working Documents
- Amendments to Renewable Energy Directive, Energy Performance of Buildings Directive and Energy Efficiency Directive → EP position on EED and RED II adopted on 14.9.2022
- EU Save Energy Communication
- EU Solar Strategy Communication
- EU External Energy Engagement Communication
- Recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating Power Purchase Agreements
- Amendment to RRF Regulation and Guidance
- Draft Delegated Acts on Renewable Fuels of Non-Biological Origin - RFNBO additionality and low-carbon hydrogen

Outside the package but to be adopted on the same day:

Electricity Market Design Communication

REPowerEU plan
Accelerating the clean energy transition – permitting

Recommendation on permitting and power purchase agreements

Legislative proposal on ‘go to’ areas and simpler and faster permitting (amendment of the Renewable Energy Directive - REDII)

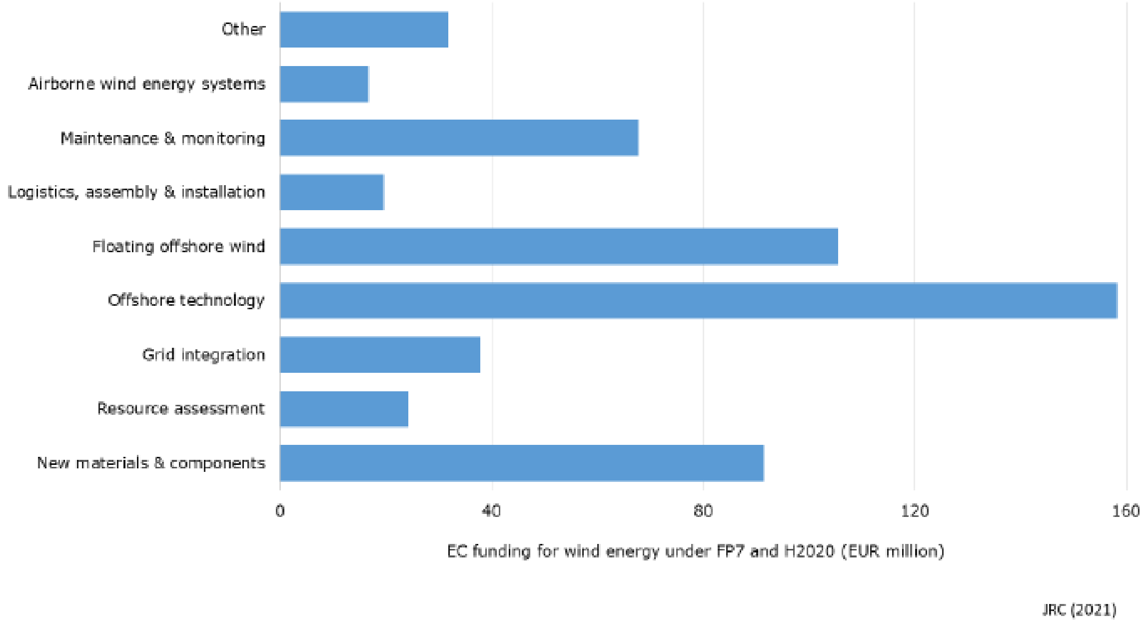
Joint event with MS RES and environmental assessment experts

Promotion of **regulatory sandboxes**

Fast transposition of current RED II to speed up permitting

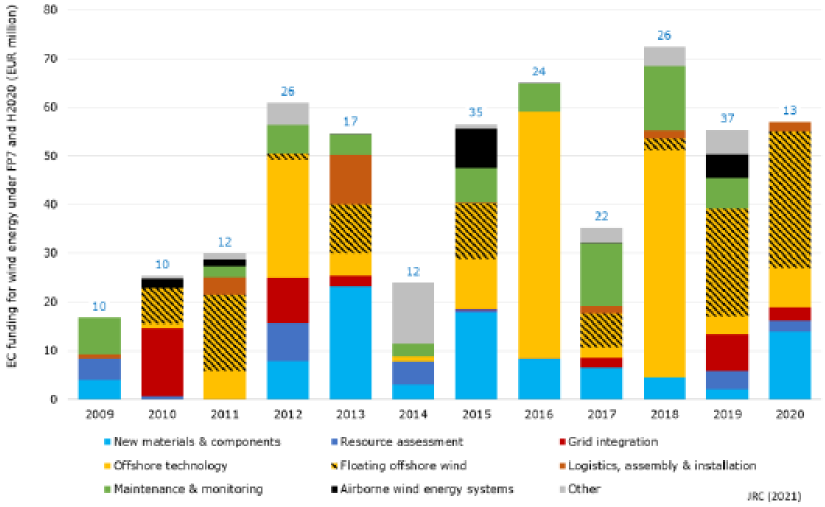
EU R&I funding – wind sector – 2009-2020

Figure 9: EC funding on wind energy R&I priorities in the period 2009 -2020 under FP7 and H2020.



Source: JRC

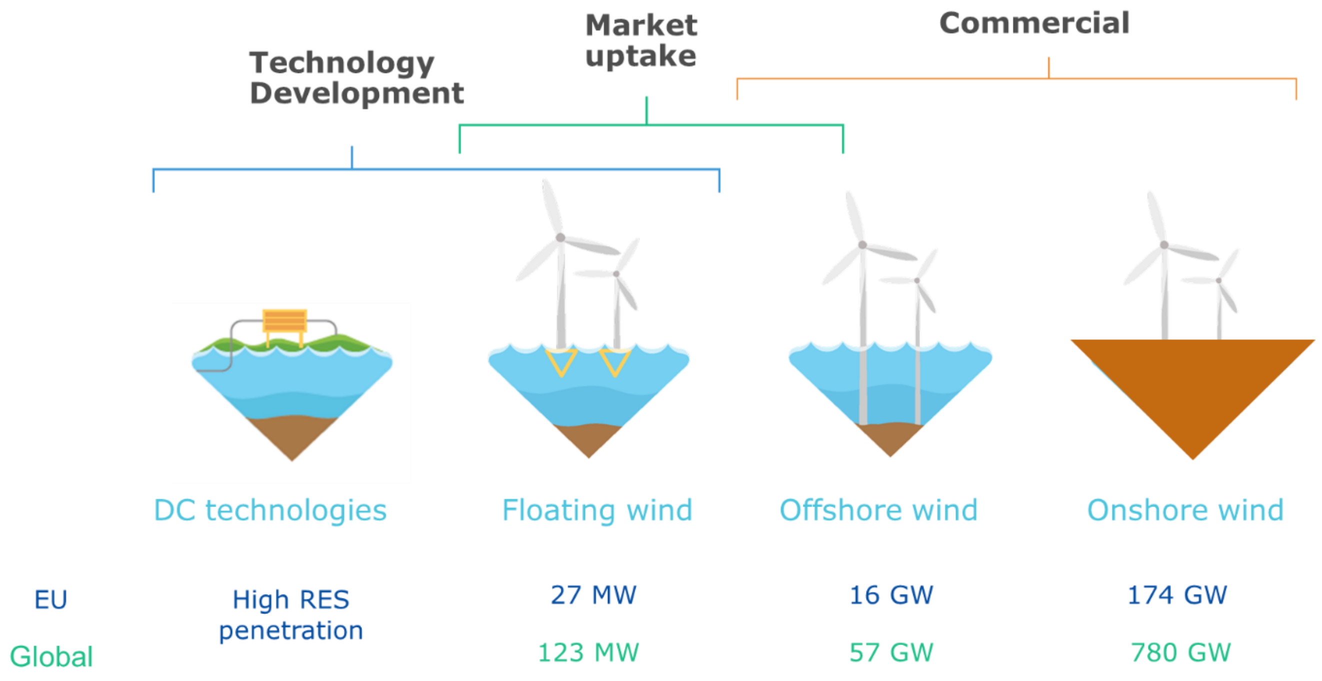
Figure 41: Evolution of EU R&I funding categorised by R&I priorities for wind energy under FP7 (2009-2013) and H2020 (2014-2020) programmes and the number of projects funded in the period 2009-2020



Source: JRC[246]

7th Framework programme and Horizon 2020

Technology readiness level of the main technologies in wind energy



Source: JRC, 2022

Note: Direct current (DC) technologies are mentioned as they are a key enabler for high offshore RES penetration rates

European Commission

Horizon Europe – cluster 5 work programme 2021 - 2022 wind-related topics

- HORIZON-CL5-2021-D3-03-04: Physics and aerodynamics of atmospheric flow of wind for power production
- HORIZON-CL5-2021-D3-03-05: Wind energy in the natural and social environment
- HORIZON-CL5-2021-D3-03-12: Innovation on floating wind energy deployment optimized for deep waters and different sea basins (Mediterranean Sea, Black Sea, Baltic Sea, North-east Atlantic Ocean)
- HORIZON-CL5-2022-D3-01-02: Demonstration of innovative materials, supply cycles, recycling technologies to increase the overall circularity of wind energy technology and to reduce the primary use of critical raw materials

(forthcoming – opening date 6.9.2022)

- HORIZON-CL5-2022-D3-03-04: Integrated wind farm control

Horizon Europe – cluster 5 work programme 2021 - 2022 wind-related topics (1)

- HORIZON-CL5-2021-D3-03-04: Physics and aerodynamics of atmospheric flow of wind for power production
  - FLOW - Atmospheric Flow, Loads and pOwer for Wind energy
  - AIRE - Advanced study of the atmospheric flow Integrating REal climate conditions to enhance wind farm and wind turbine power production and increase components durability
  - MERIDIONAL - Multiscale modelling for wind farm design, performance assessment and loading

- HORIZON-CL5-2021-D3-03-05: Wind energy in the natural and social environment
  - WENDY - Multicriteria analysis of the technical, environmental and social factors triggering the PIMBY principle for Wind technologies
  - WIMBY - Wind In My Backyard: Using holistic modelling tools to advance social awareness and engagement on large wind power installations in the EU
  - JustWind4All - Just and effective governance for accelerating wind energy

European Commission

Horizon Europe – cluster 5 work programme 2021 - 2022 wind-related topics (2)

- HORIZON-CL5-2021-D3-03-12: Innovation on floating wind energy deployment optimized for deep waters and different sea basins (Mediterranean Sea, Black Sea, Baltic Sea, North-east Atlantic Ocean)
  - BLOW - Black sea fLoating Offshore Wind
  - INFINITE - INnovative oFfshore wInd techNologies In deep waTErs
  - NEXTFLOAT - Next Generation Integrated Floating Wind Optimized for Deep Waters

- HORIZON-CL5-2021-D3-02-03: Market Uptake Measures of renewable energy systems (CSA)
  - MARINEWIND

European Commission

Horizon Europe – cluster 5 work programme 2021 - 2022 wind-related topics (3)

- HORIZON-CL5-2022-D3-01-02: Demonstration of innovative materials, supply cycles, recycling technologies to increase the overall circularity of wind energy technology and to reduce the primary use of critical raw materials
  - Blades2Build - RECYCLE, REPURPOSE AND REUSE END-OF-LIFE WIND BLADE COMPOSITES – A COUPLED PRE- AND CO-PROCESSING DEMONSTRATION PLANT
  - EoLO-HUBs - Wind turbine blades End of Life through Open HUBs for circular materials in sustainable business models

- HORIZON-CL5-2022-D3-03-04: Integrated wind farm control
  - Call closed on 10.1.2023

European Commission

Horizon Europe – cluster 5 priorities for 2023-2024 work programme

- Critical technologies for offshore wind farm
- Forecasting of power production to wind energy demand
- Lifetime improvement, efficient decommissioning and increased circularity
- Minimisation of environmental, and optimisation of socio-economic impacts
- Demonstration of innovative floating wind concepts

First calls already published

European Commission

Horizon Europe – cluster 5 work programme 2023-2024 Wind – related topics (1)

- HORIZON-CL5-2023-D3-01-05 Critical technologies for the offshore wind farm of the Future (18M€ - 6M€/project – call closing 30.3.23)

- HORIZON-CL5-2023-D3-02-14: Digital twin for forecasting of power production to wind energy demand (12M€ - 6M€/project – call opening: 4.5.23; call closing 5.9.23)

- HORIZON-CL5-2023-D3-02-15: Critical technologies to improve the lifetime, efficient decommissioning and increase the circularity of offshore and onshore wind energy systems (12M€ - 4M€/project – call opening: 4.5.23; call closing 5.9.23)

Search Funding & Tenders (europa.eu)

HORIZON-CL5-2023-D3-02-14: Digital twin for forecasting of power production to wind energy demand – expected outcome

Project results are expected to contribute to all of the following expected outcomes:

- Accurate and precise energy yield prediction to ease investment decisions based on accurate simulations that take into account simultaneously predictions on Renewable Energy Production, Energy Consumption and Price Predictions.
- Enhanced digital transformation of wind energy sector by delivering the next generation of digital twins.

European Commission

HORIZON-CL5-2023-D3-02-14: Digital twin for forecasting of power production to wind energy demand - scope

The objective of this topic is to develop new digital twins to optimise the exploitation of individual wind farms (onshore, bottom-fixed offshore and floating offshore) as well as wind farm clusters, in view of transforming them into virtual power plants delivering a more reliable and secure electricity system. Such a digital twin is expected to integrate [at least three of the following bullet points]:

1. Wind and weather forecast models relevant for the full wind power production system (turbines, grid, transmission) (including the effects of external physical conditions such as temperatures, rain, turbulences, waves, and currents).
2. Spatial modelling: medium (within wind farms) to long distance (between/along wind farm clusters) wake effects.
3. Interconnection optimisation via simulations to satisfy grid connection requirements and agility in grid reconfiguration and provide ancillary services.
4. Include predictive maintenance, structural health and conditional monitoring, and
5. End user location and needs.

HORIZON-CL5-2023-D3-02-14: Digital twin for forecasting of power production to wind energy demand - scope

- The digital twin will improve accurate energy yield prediction and will balance supply and demand side needs and will help to ease investment decisions based on accurate simulations. The models should incorporate other relevant parameters influencing the siting of wind farms, such as ground conditions, noise impacts and environmental impacts as well as representing the complex system in a map view format while considering time series data of each and every asset. Infrastructure modelling of each and every asset should be executed via independent profiling based on past performance data and contextual data in view to deliver prediction at the level of each and every asset with as much accuracy as possible".

- The project should focus on offshore or on onshore wind power systems and make optimal use of previously developed models. Validation should be carried out with data of existing wind farms. Cooperation with wind energy suppliers, OEM's, developers and O&M services can make the available data more accurate, resulting in better, more sustainable and eventually circular products and sector. The project should also sufficiently invest in delivering a cyber-secure system. The projects is expected to build also on the digital twins developed under Destination Earth, which envisage to develop a high precision digital model of the Earth to model, monitor and simulate natural phenomena and related human activities.

- For the offshore digital twin projects the impact of other blue economy sectors, islands, different land-sea interactions for near shore wind farms should be considered.

- For onshore digital twin projects, the build environment and different landscapes should be considered, and cooperation is envisaged with the selected projects under topic HORIZON-CL5-2021-D3-03-05 Wind energy in the natural and social environment.

- It is expected that one project on offshore digital twin will be funded and one on onshore digital twin.

- To support rapid market uptake, widespread application and further innovation based on the developed solutions, projects are invited to use Open-Source solutions when appropriate and clarify in case they choose not to use Open Source, so that they can support the planning of future large scale offshore wind installations. Free licensing is also a possibility to consider to support rapid market uptake.

Horizon Europe – cluster 5 work programme 2023-2024 Wind – related topics (2)

- HORIZON-CL5-2024-D3-02-08: Minimisation of environmental, and optimisation of socio-economic impacts in the deployment, operation and decommissioning of offshore wind farms (10M€ - 5M€/project – call opening: 7.5.24; call closing 5.9.24)

- HORIZON-CL5-2024-D3-02-09: Demonstrations of innovative floating wind concepts (30M€ - 15M€/project – call opening: 7.5.24; call closing 5.9.24)

EU funding for [offshore] renewables

- + Horizon Europe Cluster 5
- + EU Innovation Council
- + LIFE – Clean Energy Transition sub-programme
- + European Maritime Fisheries and Aquaculture Fund
- + BlueInvest
- + Innovation Fund
- + Cohesion policy funds
- + Connecting Europe Facility - Transport
- + Connecting Europe Facility - Energy
- + InvestEU Fund
- + Modernisation Fund
- + Renewable Energy Financing Mechanism

- Overview of EU funding programmes relevant to finance offshore renewable energy projects
- Information about eligible investments
- Previously funded offshore projects
- How different EU programmes can be combined

Thank you

European Commission

Smart4RES

Final conference
14 April 2023

Evolution of the state of the art & The Smart4RES project in a nutshell

Georges Kariniotakis

Prof., Head of RES & Smart Energy Systems Group,
Mines Paris, Centre PERSEE
Coordinator of Smart4RES
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MINES PARIS PSL PERSEE ARMINES

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864337

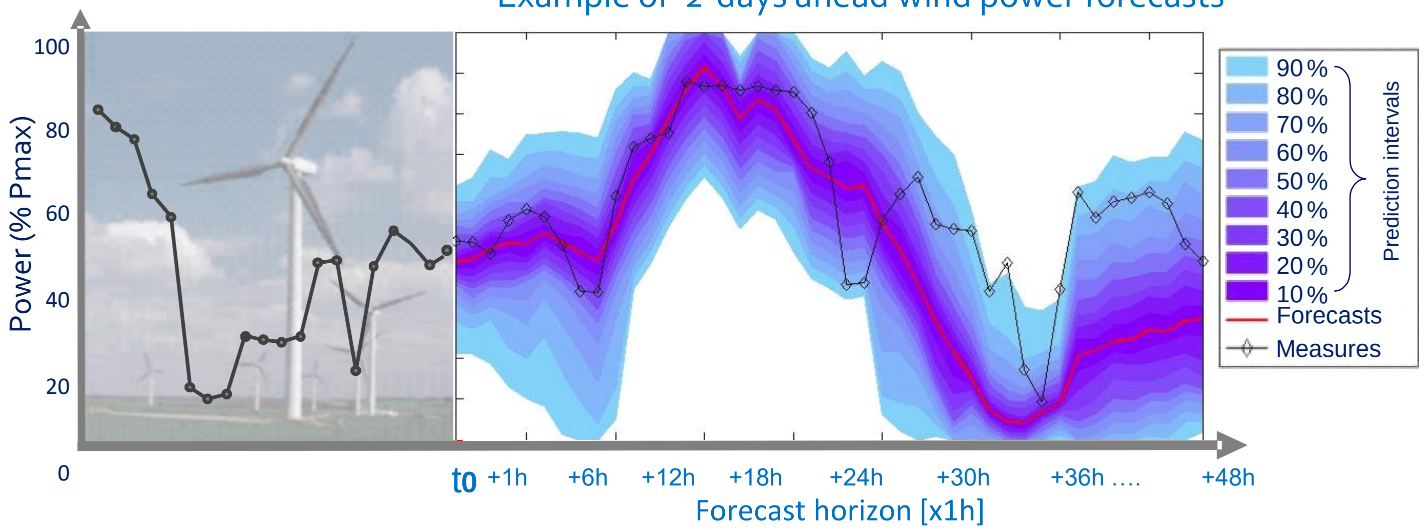
OUTLINE

1. Context
2. Evolution of the State of the Art in RES forecasting
3. The Smart4RES project in a nutshell
4. Program presentation

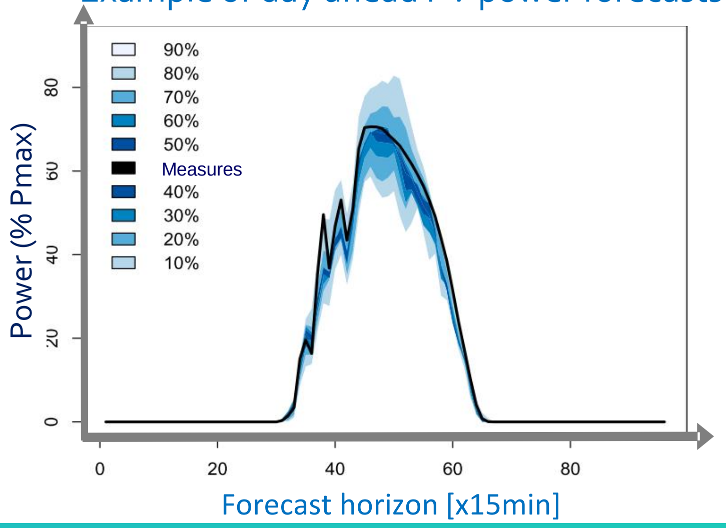
Context

- Short-term (minutes-days ahead) forecasts of renewable generation (wind, solar) (RES) are necessary for a secure and economic operation of power systems.
- Forecasting solutions are used operationally by all stakeholders.
- However, large forecast errors may occur with a high financial/technical impact.
- Improving forecasting accuracy has been a continuous requirement by end users.

Example of 2-days ahead wind power forecasts

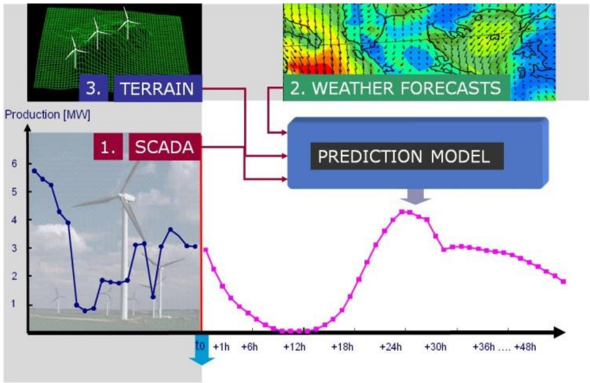


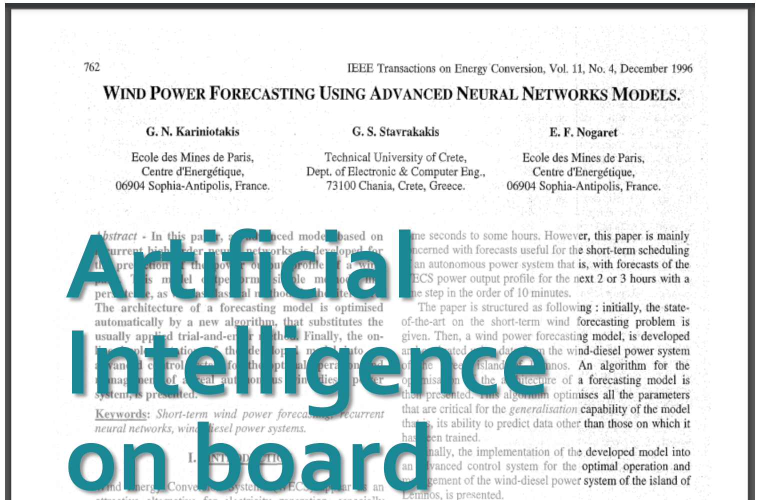
Example of day ahead PV power forecasts



The history of RES forecasting

"Deterministic" view





762 IEEE Transactions on Energy Conversion, Vol. 11, No. 4, December 1996

WIND POWER FORECASTING USING ADVANCED NEURAL NETWORKS MODELS.

G. N. Kariniotakis
Ecole des Mines de Paris,
Centre d'Energétique,
06904 Sophia-Antipolis, France.

G. S. Stavrakakis
Technical University of Crete,
Dept. of Electronic & Computer Eng.,
73100 Chania, Crete, Greece.

E. F. Nogaret
Ecole des Mines de Paris,
Centre d'Energétique,
06904 Sophia-Antipolis, France.

❖ (1996) 1st journal paper ever with AI applied in RES

1985 1990 2000 2010 2020

- First purely time series methods on WPF

- Statistical / time-series approaches
- First AI-based approaches
- NWPs considered as input
- Empiric/hybrid implementations into operational forecast tools

[2002-2006] ANEMOS (FP5), http://www.anemos-project.eu/
[2008-2011] ANEMOS.plus (FP6), http://www.anemos-plus-project.eu/
[2008-2012] SAFEWIND (FP7), http://www.safewind.eu/
[2019-2023] Smart4RES (H2020), http://www.smart4res.eu/

The history of RES forecasting

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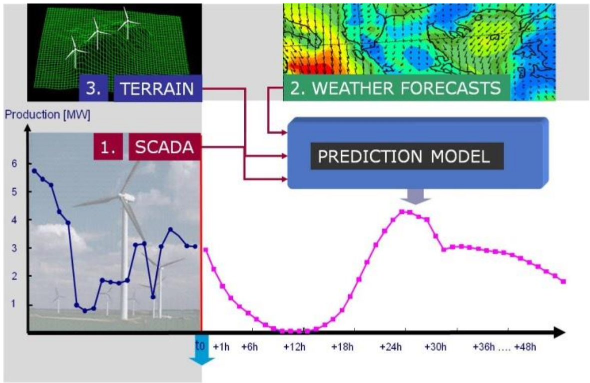
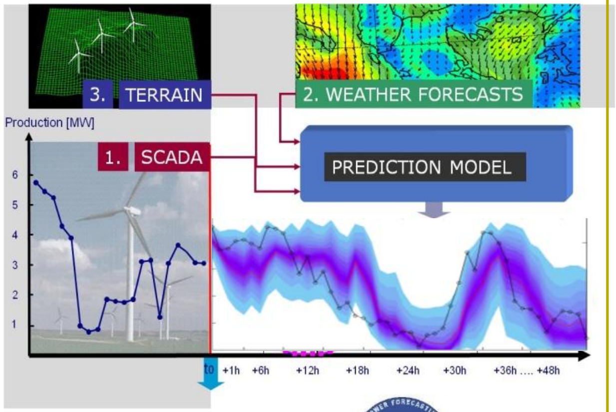


Probabilistic view



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- 1st benchmarking (Anemos competition)
- Physical modelling
- Statistical models, AI, Data mining,…
- Combination of models
- First probabilistic approaches/ensembles
- Upscaling
- Evaluation standardisation
- International collaboration

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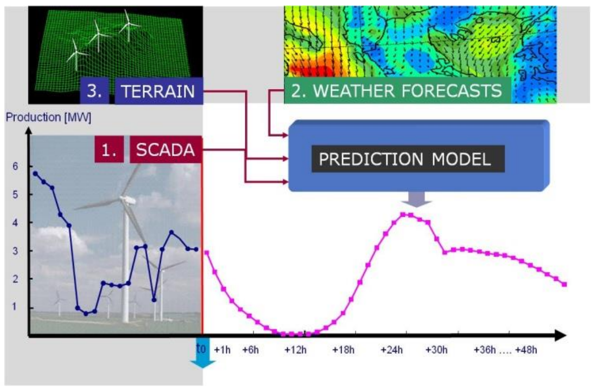
The history of RES forecasting

"Deterministic" view



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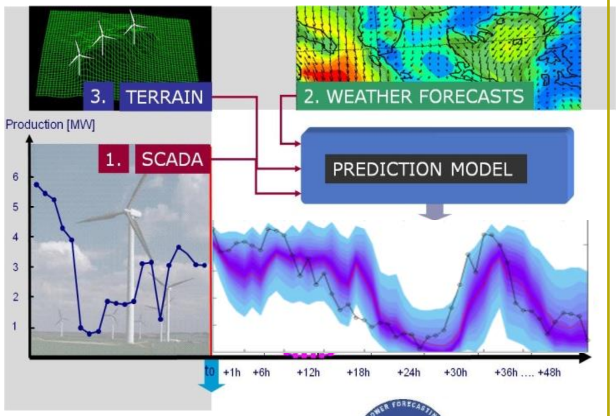
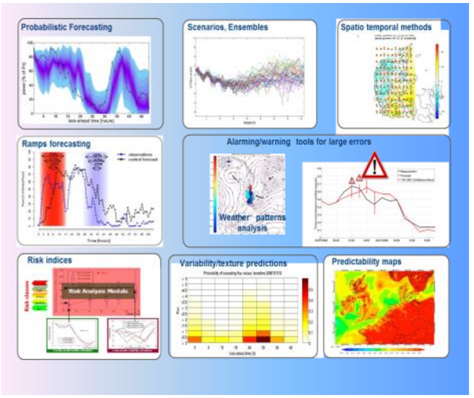


Probabilistic & special situations



1985 | 1990 | 2000 | 2010 | 2020

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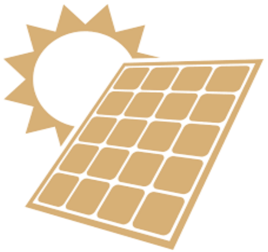
- Dedicated NWPs for RES
- Direct probabilistic predictions
- Ramps forecasting
- Scenarios, Ensembles,
- Risk indices
- Large errors warning/alarming
- Spatiotemporal forecasting
- Variability forecasting
- Predictability maps



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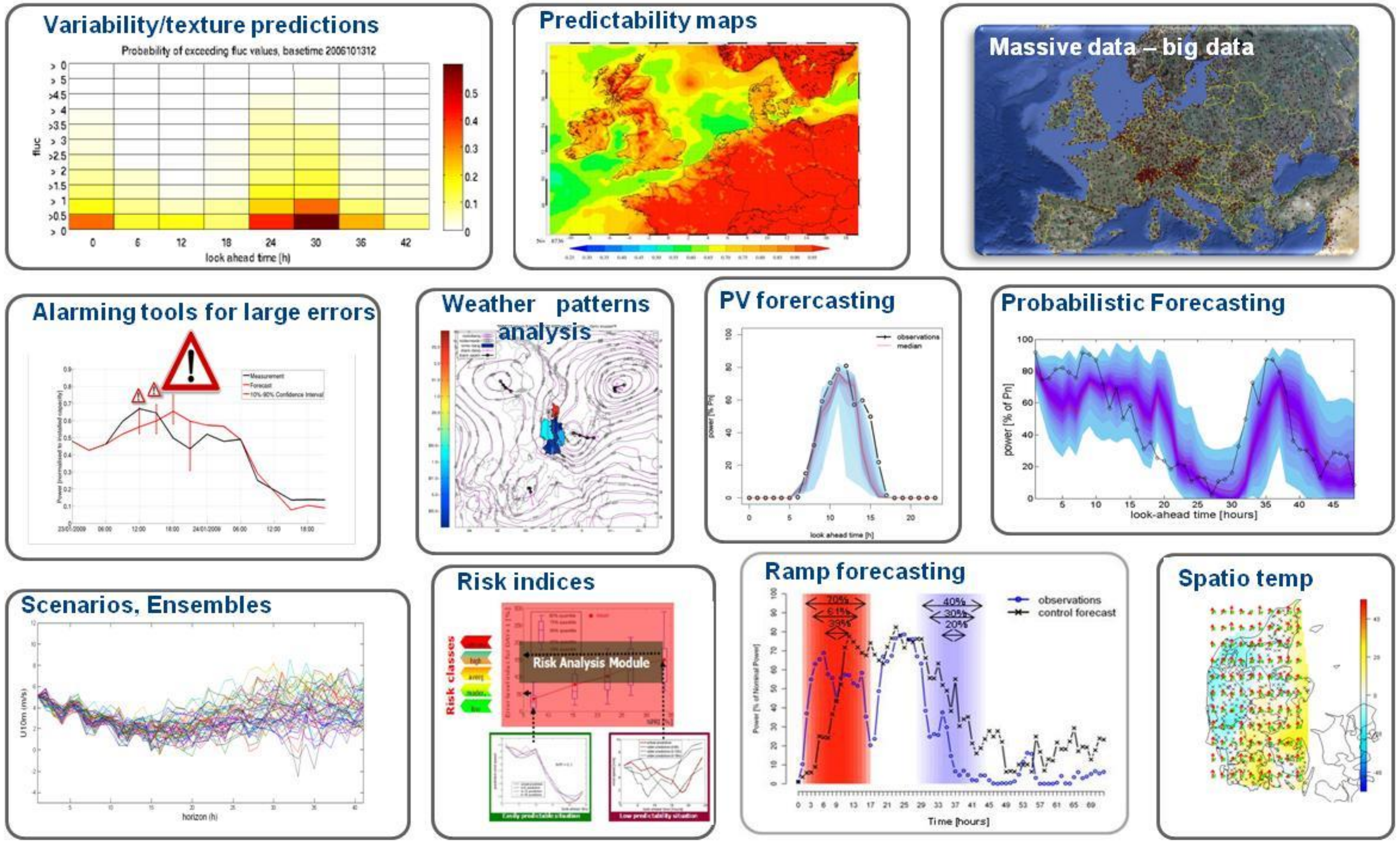
The history of RES forecasting

- Major developments in wind forecasting in the period 2002-2012.



The history of RES forecasting

Smart4RES

- Major developments in wind forecasting in the period 2002-2012.
- Exponential growth of academic works.
- Solar forecasting followed a much faster learning curve that started around 2004.

ANEMOS.plus

ANEMOS

SafeWind

250 publications at conferences and journals

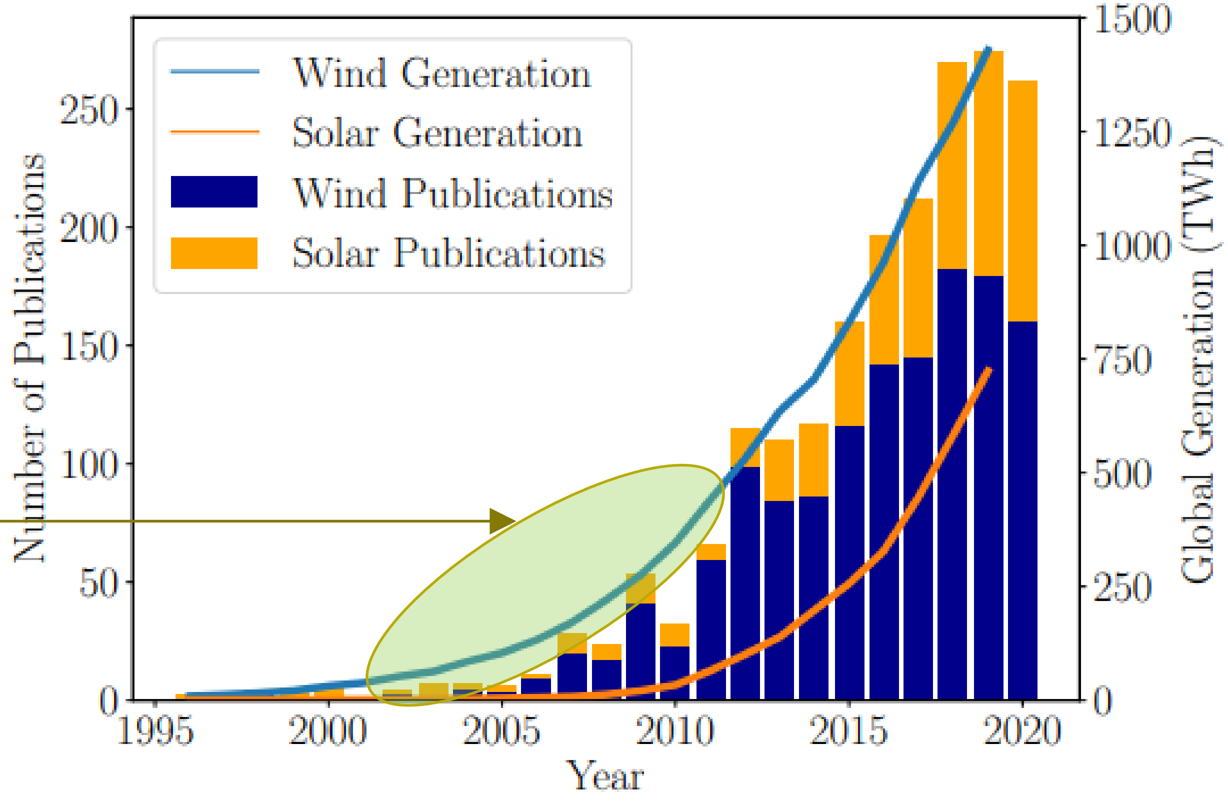
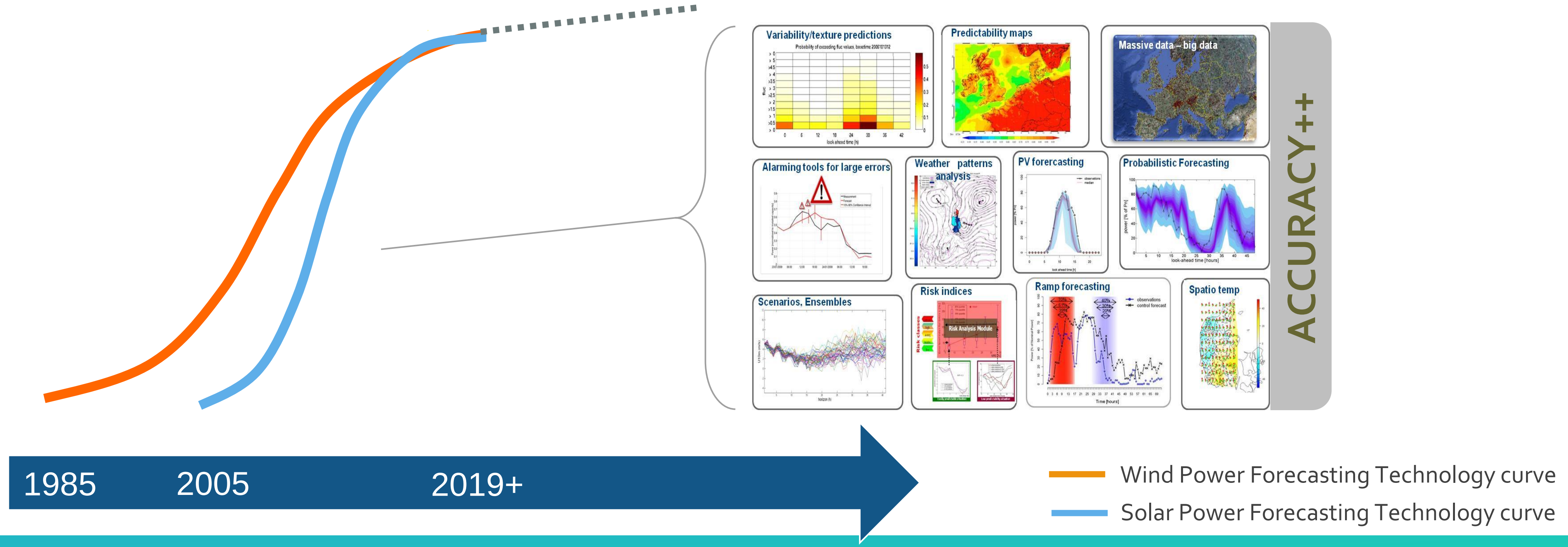


Figure 2.1: Forecasting publications broken down by wind and solar as a stacked bar chart, also plotted with global energy generation through time. Generation data provided under CC BY 4.0, Hannah Ritchie & Max Roser, `ourworldindata.org/renewable-energy`.

SOURCE: PhD thesis Rosemary Tawn , Strathclyde University, 2022.

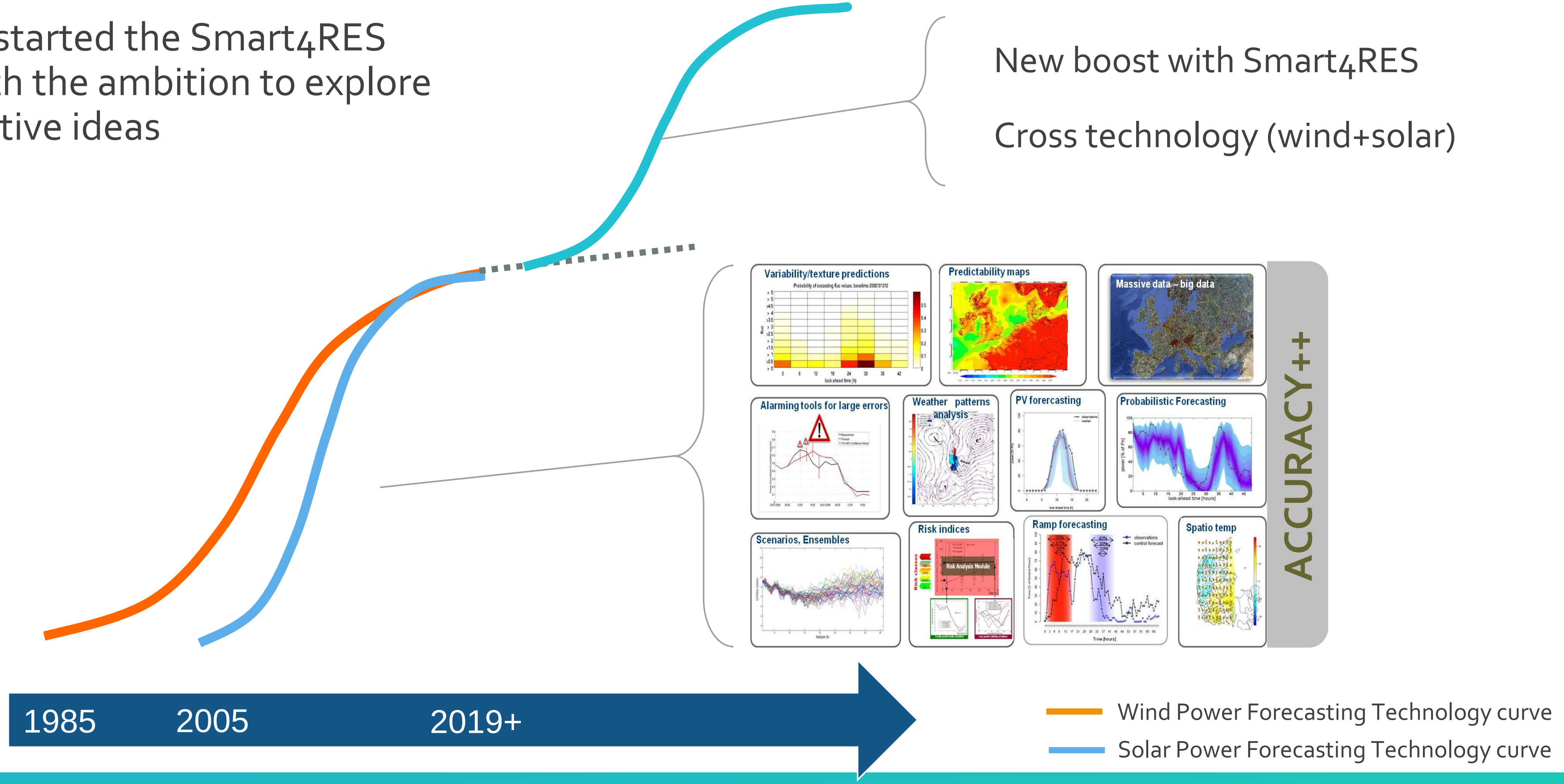
The history of RES forecasting

- So… what is next??



The history of RES forecasting

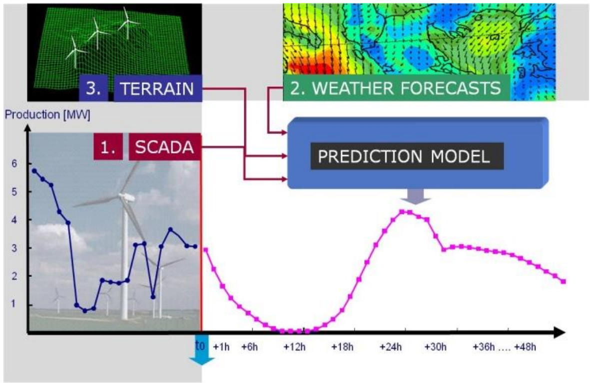
- So… what is next??
- By 2019 we started the Smart4RES initiative with the ambition to explore some disruptive ideas



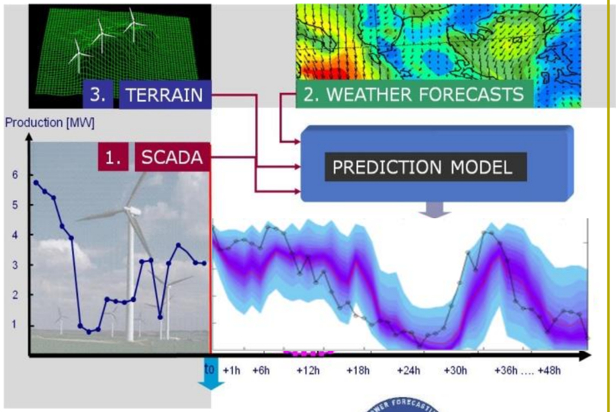
Evolution of the state of the art & the Smart4RES project in a nutshell

The history of RES forecasting

"Deterministic" view

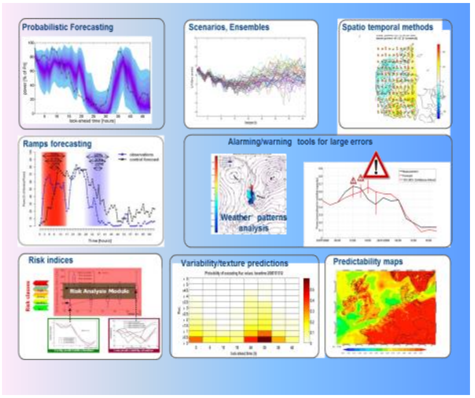


Probabilistic view



ANEMOS

Probabilistic & special situations



ANEMOS.plus

SafeWind

Smart4RES

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- Predictability maps

- Seamless forecasting
- Ultra high resolution (LES)
- Advanced NWPs
- Prescriptive analytics
- Extremes
- Data sharing/Data markets
- New forecasting products
- Resilience in forecasting
- Optimal use in applications

[2002-2006] ANEMOS (FP5), http://www.anemos-project.eu/
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[2019-2023] Smart4RES (H2020), http://www.smart4res.eu/

OUTLINE

1. Context
2. Evolution of the State of the Art in RES forecasting
3. **The Smart4RES project in a nutshell**
4. Program presentation

The Smart4RES project in a nutshell

Smart4RES

- A multi-disciplinary consortium

7 countries
13 partners

End-users
Industry
Research
Universities
Meteorologists

Funds: H2020 program
Budget: 4 M€
Duration: 3.5 years

11/2019-4/2023

France — MINES PARIS | PSL | ARMINES | METEO FRANCE | Dowel innovation

Germany — energy & meteo systems | DLR

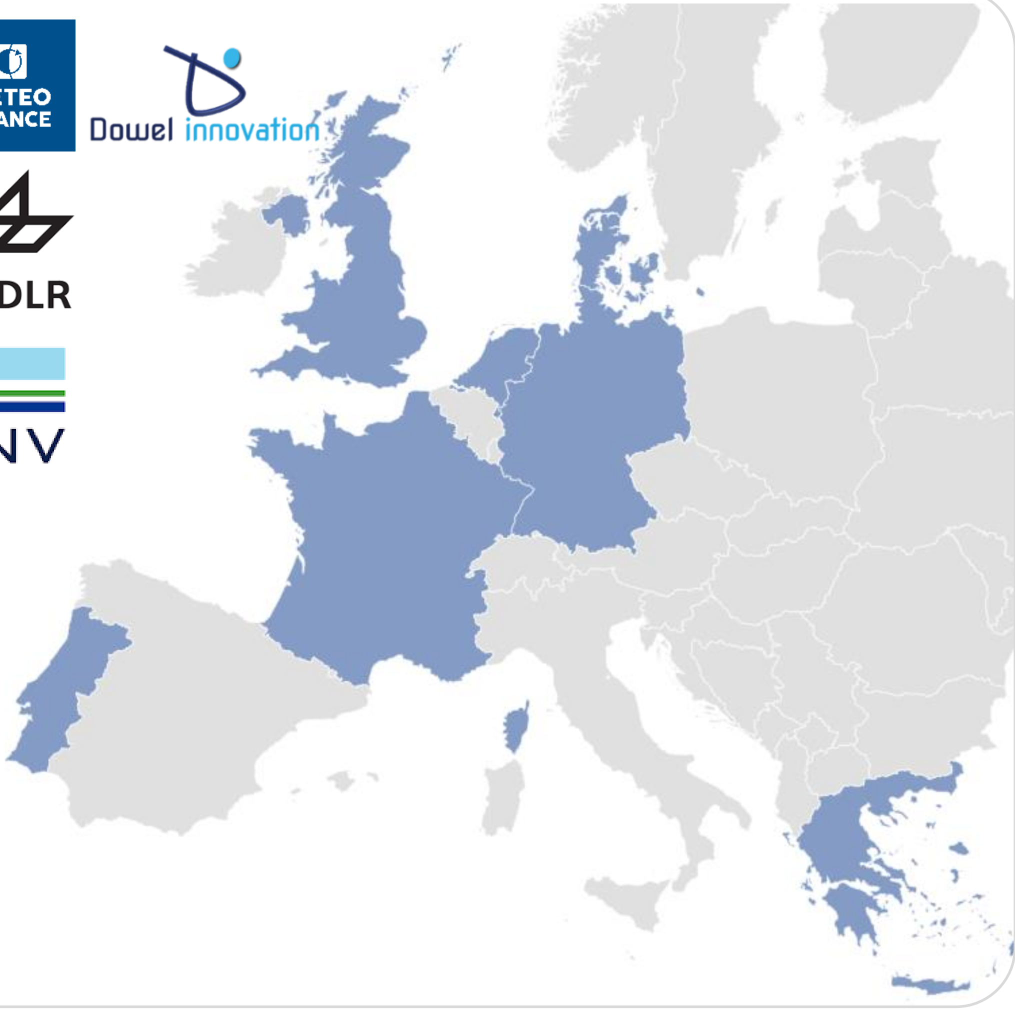
Netherlands — whiffle precision weather forecasting | DNV

Denmark — DTU

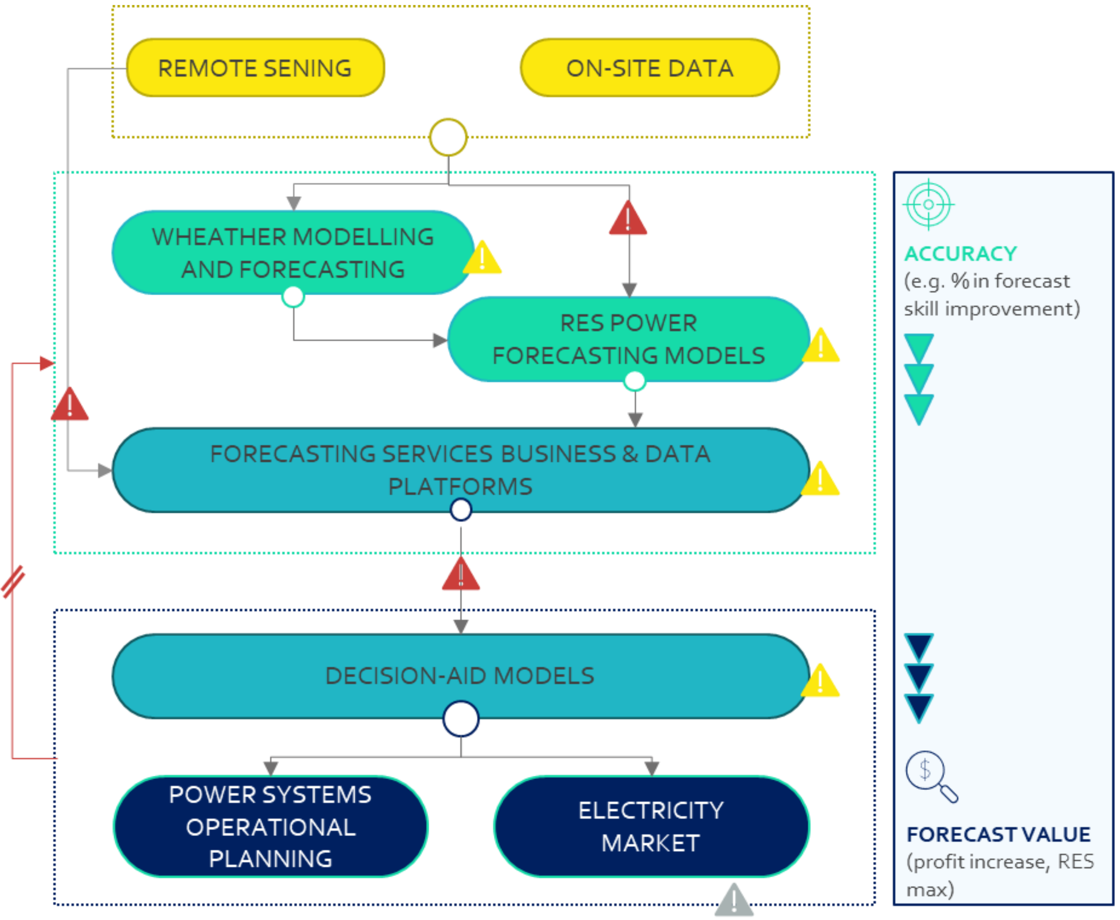
UK — Imperial College London

Portugal — INESCTEC | NEW by EDP & CTG

Greece — ΕΠΙΣΕΥ ICCS | HEDNO HELLENIC ELECTRICITY DISTRIBUTION NETWORK OPERATOR S.A



The Smart4RES project



The typical RES forecasting model/value chain

<u>Project vision:</u> Achieve outstanding improvement in RES predictability through a **holistic approach,** that covers the whole model and value chain related to RES forecasting

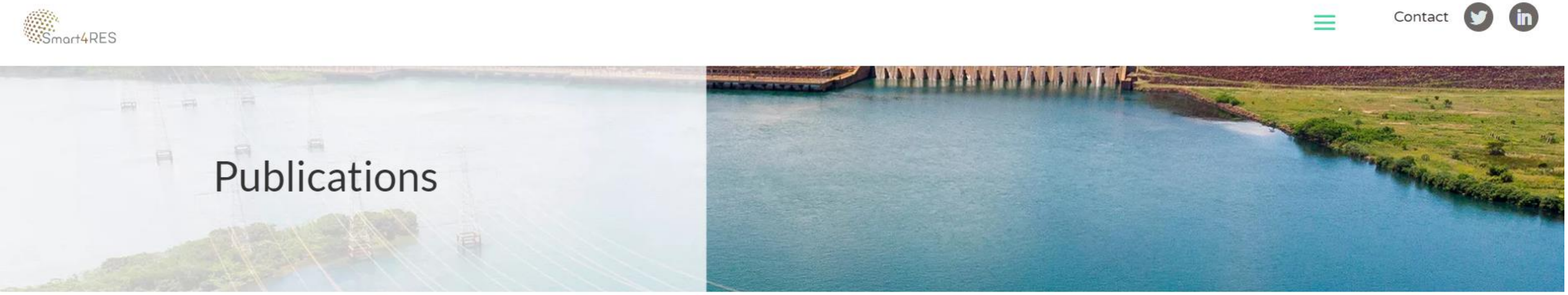
<u>Objectives (& key take aways):</u>

- Methods to extract the value out of data through data sharing and data market concepts
- Advanced weather modelling & forecasting adapted to the energy sector
- New RES forecasting tools which, by design, are not only optimized to maximize accuracy, but also other properties, like simplicity, resilience, robustness, value in applications.
- A new generation of AI-based tools to simplify decision making of operators like meta-forecasting and prescriptive analytics .

Challenges & Smart4RES solutions and impacts

Challenge	Smart4RES solutions	Impact
REDUCED KNOWLEDGE OF THE PHYSICAL SYSTEM	• Ultra/high resolution modeling of weather conditions • Weather forecasts adapted to the energy sector • Modelling based on multiple sources of data	HIGHER MODELLING ACCURACY
VULNERABILITY	• Solutions that permit operators to take optimal decisions under situations with lacking information	RESILIENCE
COMPLEXITY	• Convergence of the technology through seamless solutions • Joint forecasting and optimisation prescriptive approach • Reduction of information for human operators	SIMPLICITY
UNCERTAINTIES	• Reduce uncertainties especially in extreme siituations • Optimisation tools to manage uncertainties	ROBUSTNESS
SUBOPTIMALITY	• Value-oriented vs accuracy-oriented forecasting • Privacy/confidentiality preserving data sharing & data markets	VALUE MAXIMISATION

35 + publications and conference papers



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2023

- Lindberg O, Lingfors D, Arnqvist J, van der Meer D, Munkhammar J. Day-ahead probabilistic forecasting at a co-located wind and solar power park in Sweden: Trading and forecast verification. *Advances in Applied Energy*. 2023 https://doi.org/10.1016/j.adapen.2022.100120.
  Download the pre-proof.

https://www.smart4res.eu/publications/

OUTLINE

1. Context
2. Evolution of the State of the Art in RES forecasting
3. The Smart4RES project in a nutshell
4. **Program presentation**

09:15 -10:00	**SESSION 1: GENERAL OVERVIEW** Moderator: Stéphanie Petit, Dowel Innovation - **Welcoming words**, A. Laboudigue (Deputy Director of Research of Mines Paris and Director of operation Carnot M.I.N.E.S) - **Keynote speech 'EU's research and innovation priorities on renewable energy'**, M. Soede (DG Research and Innovation, European Commission) - **Evolution of the state of the art and The Smart4RES project in a nutshell** G. Kariniotakis (MINES Paris)
10:00-11:00	**SESSION 2: ADVANCES IN WEATHER MODELLING** Moderator: Laure Raynaud, Météo France - **RES-dedicated weather forecasting models** Q. Libois (Météo France) - **High-resolution weather models - Large Eddy Simulation (LES): the future** R. Verzijlbergh (Whiffle) - **Improvement of solar forecasting through the use of multi-source observations** J. Lecaza (DLR)
11:00-11:25	COFFEE BREAK
11:25-12:25	**SESSION 3: NEXT-GENERATION RES FORECASTING** Moderator: Simon Camal; MINES Paris - **Improved RES models in particular weather conditions** M. Lange (EMSYS) - **Data driven methods for minute-scale wind power and structural load forecasts using Lidars** T. Göçmen (DTU) - **How to simplify RES forecasting using a seamless approach** D. van der Meer (MINES Paris)
12:25-13:30	LUNCH BREAK

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MORNING SESSIONS

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	SESSION 4: FORECASTING SERVICES AND APPLICATIONS Moderator: João Gonçalo Maciel, EDP NEW
13:30-15:20	▪ **Towards data markets** P. Pinson (DTU/ Imperial College of London) ▪ **Privacy-preserving data-sharing for energy forecasting** C. Gonçalves (INESC TEC) ▪ **Uncertainty-aware booking of flexibilities in electrical grids** R. Bessa (INESC TEC) ▪ **Optimisation of operation and security assessment of isolated power systems with high RES penetration** D. Lagos (NTUA) ▪ **Trading strategies for RES production** S. Camal (MINES Paris) ▪ **Resilient energy forecasting and prescriptive analytics** A. Stratigakos (MINES Paris)
15:20-15:35	**COFFEE BREAK**
15:35-16:30	**PANEL – FUTURE CHALLENGES IN RES FORECASTING** Moderator: Gregor Giebel & Georges Kariniotakis
16:30	**END OF THE CONFERENCE**

AFTERNOON SESSIONS

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Thank you!

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