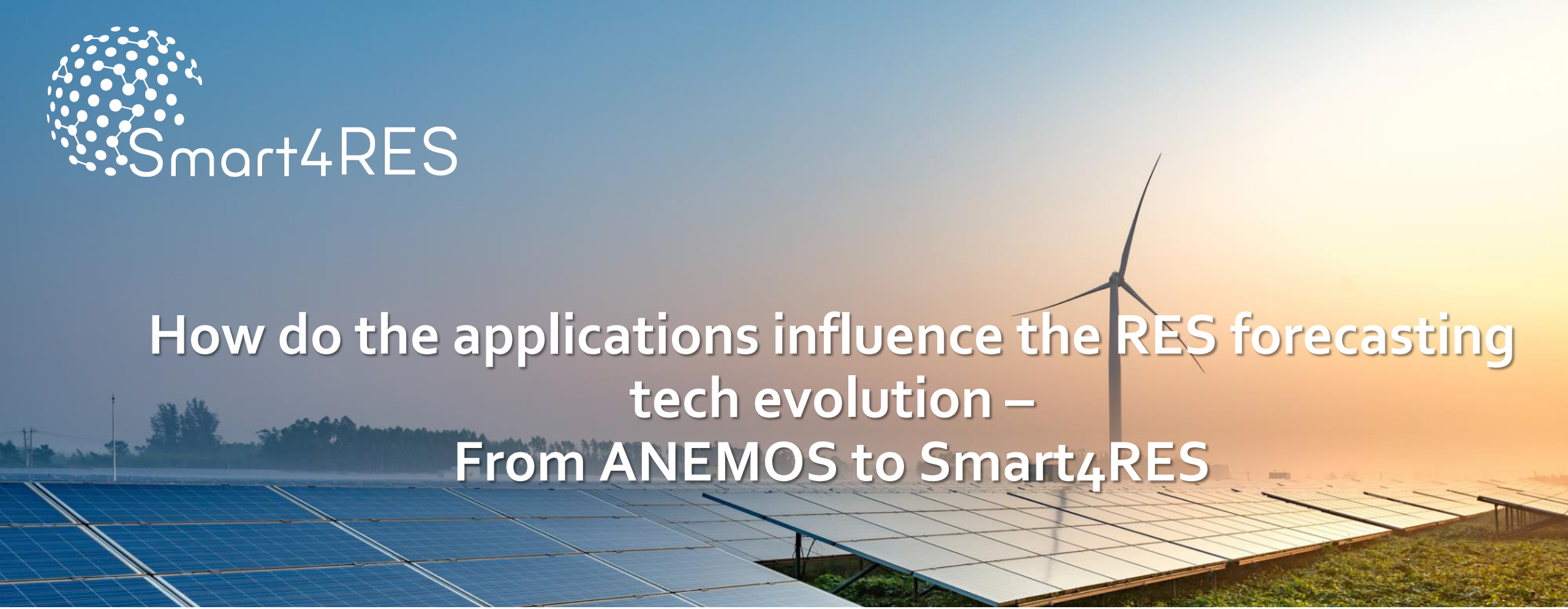


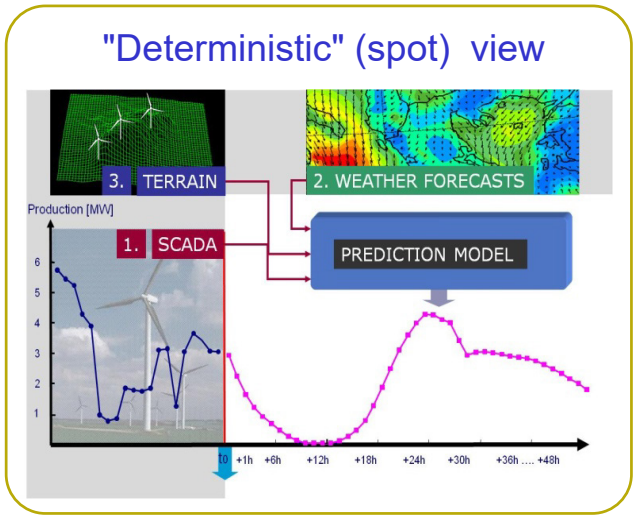
How do the applications influence the RES forecasting tech evolution – From ANEMOS to Smart4RES

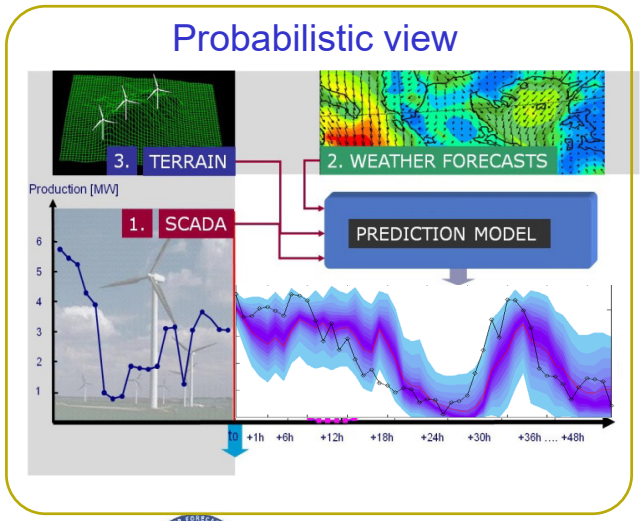
George Kariniotakis,
Prof., Head of Renewables and Smartgrids Group
MINES Paris, Centre PERSEE
Coordinator of Smart4RES
georges.kariniotakis@minesparis.psl.eu

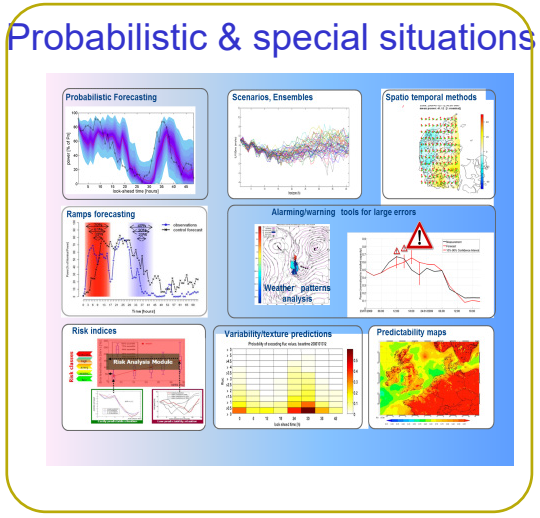
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 864337

State of the art in wind power forecasting
“Forecast then optimize”

Wind power forecasting - State of the art







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

1985 1990 2000 2010 2020

- First purely time series methods on WPF

- Statistical / time-series approaches
- Physical modelling
- NWPs considered as input
- Empiric/hybrid implementations into operational forecast tools

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

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

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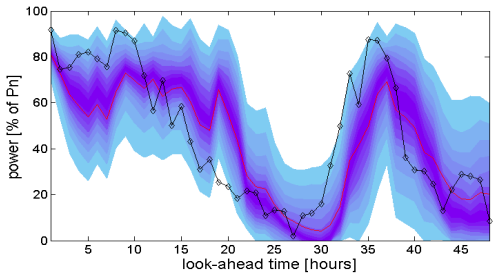
[2008-2012] SAFEWIND (FP7), http://www.safewind.eu/
[2019-2023] Smart4RES (H2020), http://www.smart4res.eu/

Wind power forecasting - State of the art

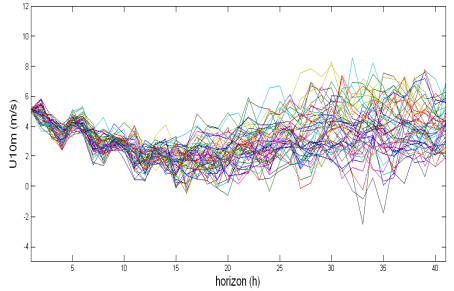
ANEMOS.plus

SafeWind

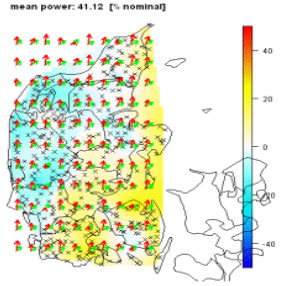
Probabilistic Forecasting



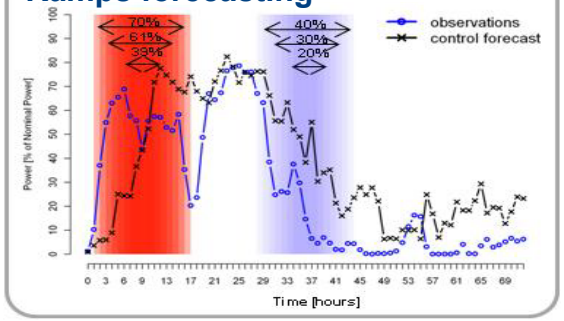
Scenarios, Ensembles



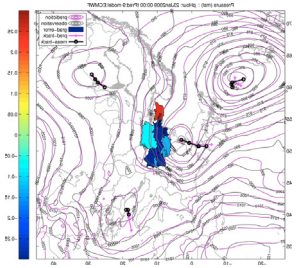
Spatio temporal methods



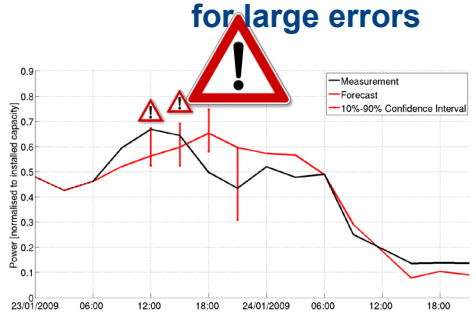
Ramps forecasting



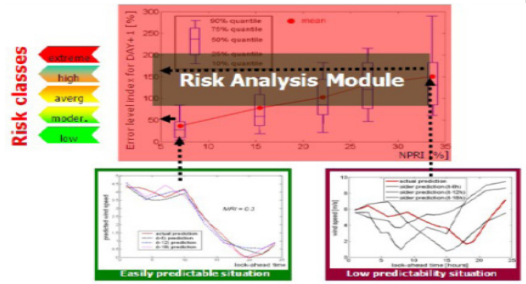
Weather patterns analysis



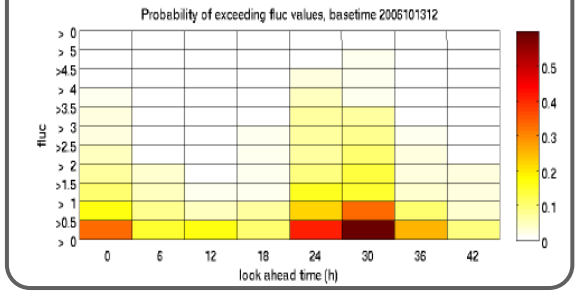
Alarming/warning tools for large errors



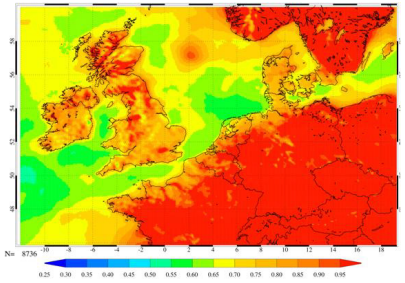
Risk indices



Variability/texture predictions



Predictability maps



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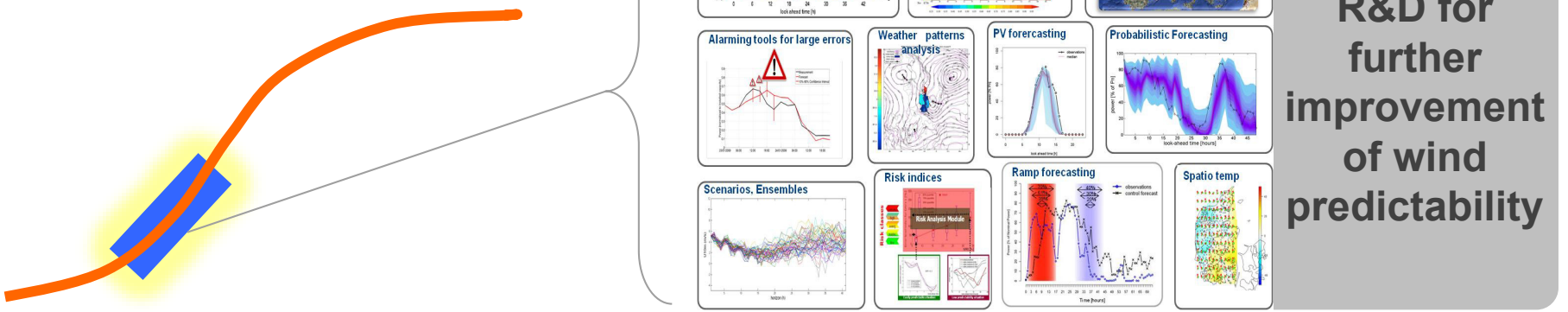
[2019-2023] Smart4RES (H2020), http://www.smart4res.eu/

A vision for R&D perspectives dated back in 2012

❖Already 10 years ago everybody was saying that **everything was already done in** wind forecasting

❖ By the end of SafeWind (2012) we supported a different vision: <u>that we were still at the first part of the technology curve.</u>



❖ Wind Power Forecasting Technology curve

A vision for R&D perspectives dated back in 2012

- Better interaction with the big weather centres, **optimised large-scale weather models** for renewable energy (wind, solar, …)
- **RES plants as sensors** and integration in the weather model, including the possibility to seamlessly extract every point or region and every time resolution
- **Improvements of wind forecasts** (marine boundary layer, combined wind/wave/ocean models, higher resolution/downscaling, ensemble predictions for better point forecasts and uncertainties, different climates, …)
- **Longer term** forecasts (week ahead for O&M of wind turbines and power system, seasonal for wind-solar-hydro matching / water value)
- **Remote sensing** (LiDARs, radars, satellites etc) for data assimilation or direct use in statistical tools)
- Upscaling/data selection and data assimilation in the context of **Big Data** (relevant for wind, even more relevant for PV)
- Improved forecasts for **extremes** (e.g. ramps / variability) and integration in business processes of end users
- **Forecasting of "everything"** (wind, pv, waves, load, DLR, and correlations between them)
- **Spatio-temporal forecasting** > European Vision for wind power forecasting (necessary due to larger TSO interaction, beneficial due to increased number of data, data exchange across nation borders)
- More integrated **use of the probabilistic forecasts** for end users (integration with business case)
- Use of different prediction products to **optimise decisions** (spot, uncertainty, ramps, cut-off, risk indices, scenario generation and reduction etc).

A vision for R&D perspectives dated back in 2012

❖Already 10 years ago everybody was saying that **everything was already done in** wind forecasting

❖ Academic literature explodes since….

ANEMOS.plus

ANEMOS

SafeWind

250 publications at conferences and journals

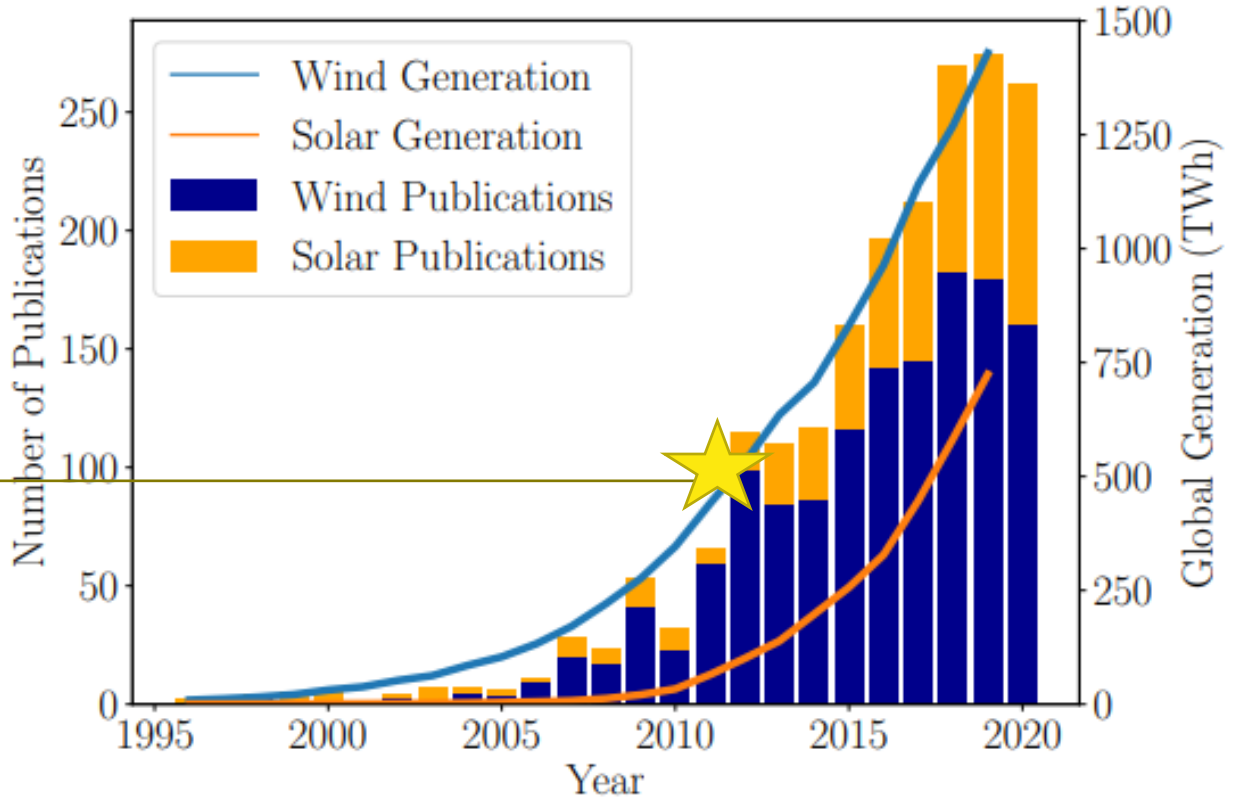


Figure 2.1: Forecasting publications broken down by wind and solar as a stacked bar chart, also plotted with global energy generation through time. Generation data provided under CC BY 4.0, Hannah Ritchie & Max Roser, `ourworldindata.org/renewable-energy`.

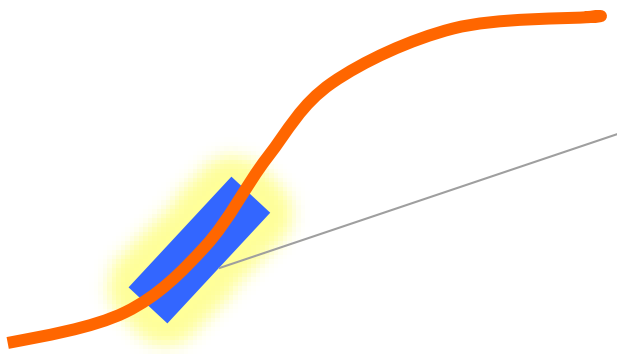
SOURCE: PhD thesis Rosemary Tawn , Strathclyde University, 2022.

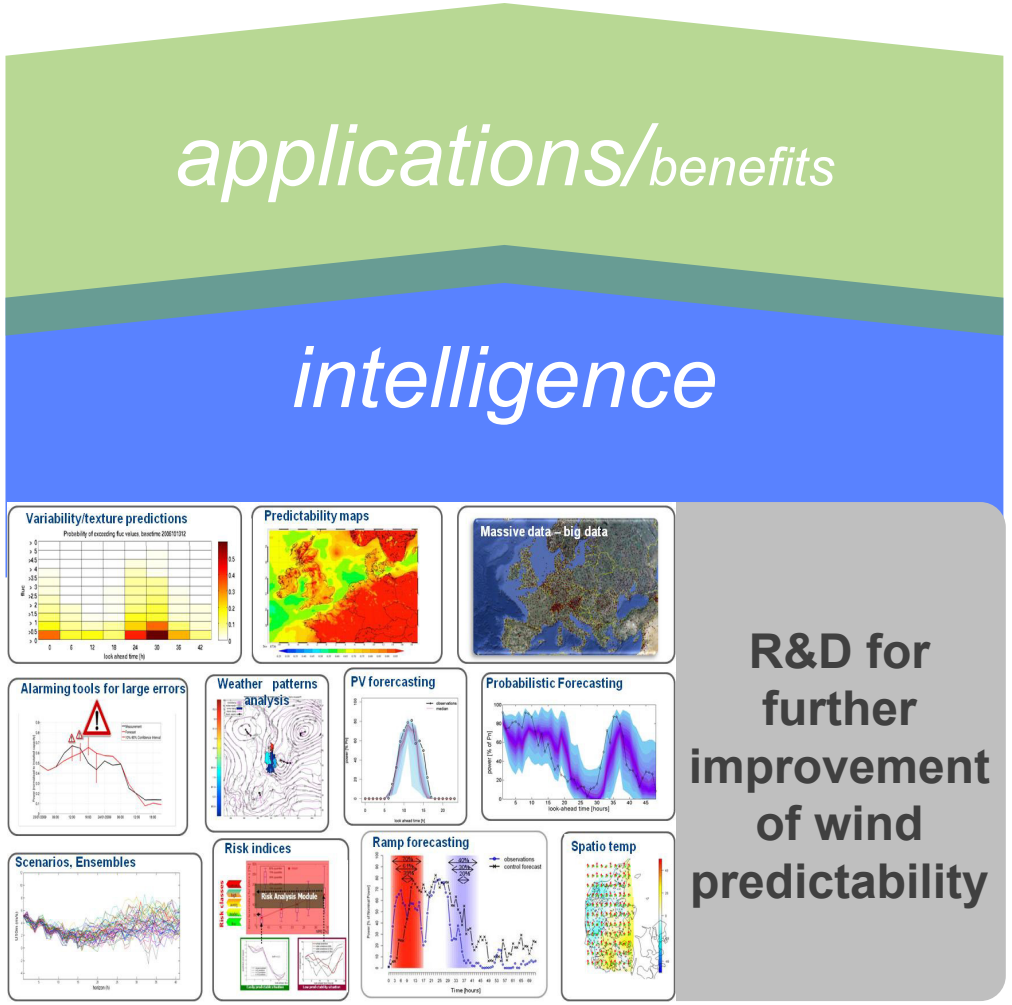
A vision for R&D perspectives dated back in 2012

« Développent of an

"intelligent" layer

able to use the most relevant information and prediction products in a situation-dependent way, for optimising **decision making** under uncertainty in different applications »

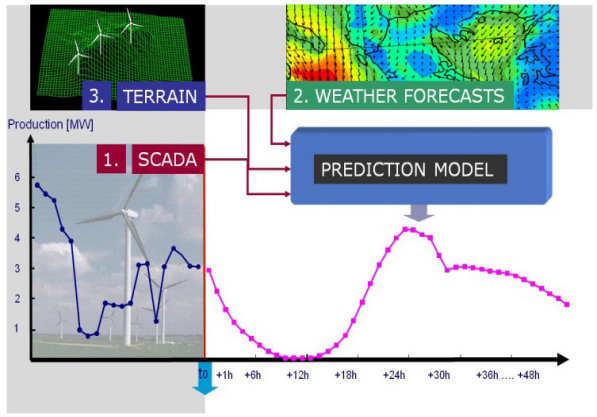




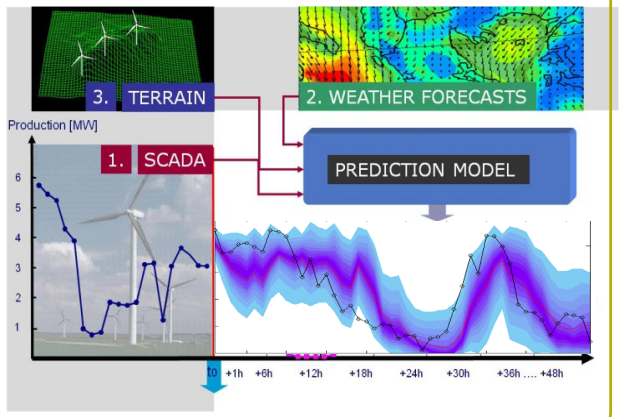
❖ Wind Power Forecasting Technology curve

Wind power forecasting - State of the art

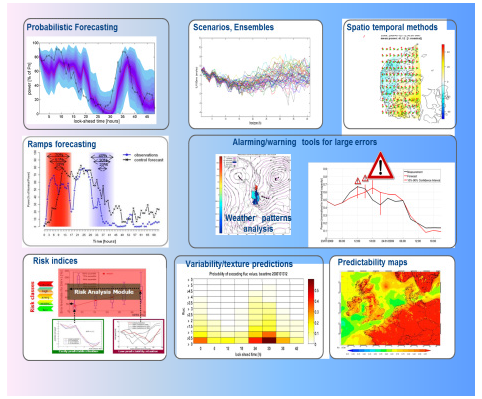
"Deterministic" (spot) view



Probabilistic view



Probabilistic & special situations



Smart4RES

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

ANEMOS ANEMOS.plus SafeWind

1985 1990 2000 2010 2020

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- Variability forecasting
- Predictability maps

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

[2002-2006] ANEMOS (FP5), http://www.anemos-project.eu/
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State of the art in wind power forecasting
Focus on applications

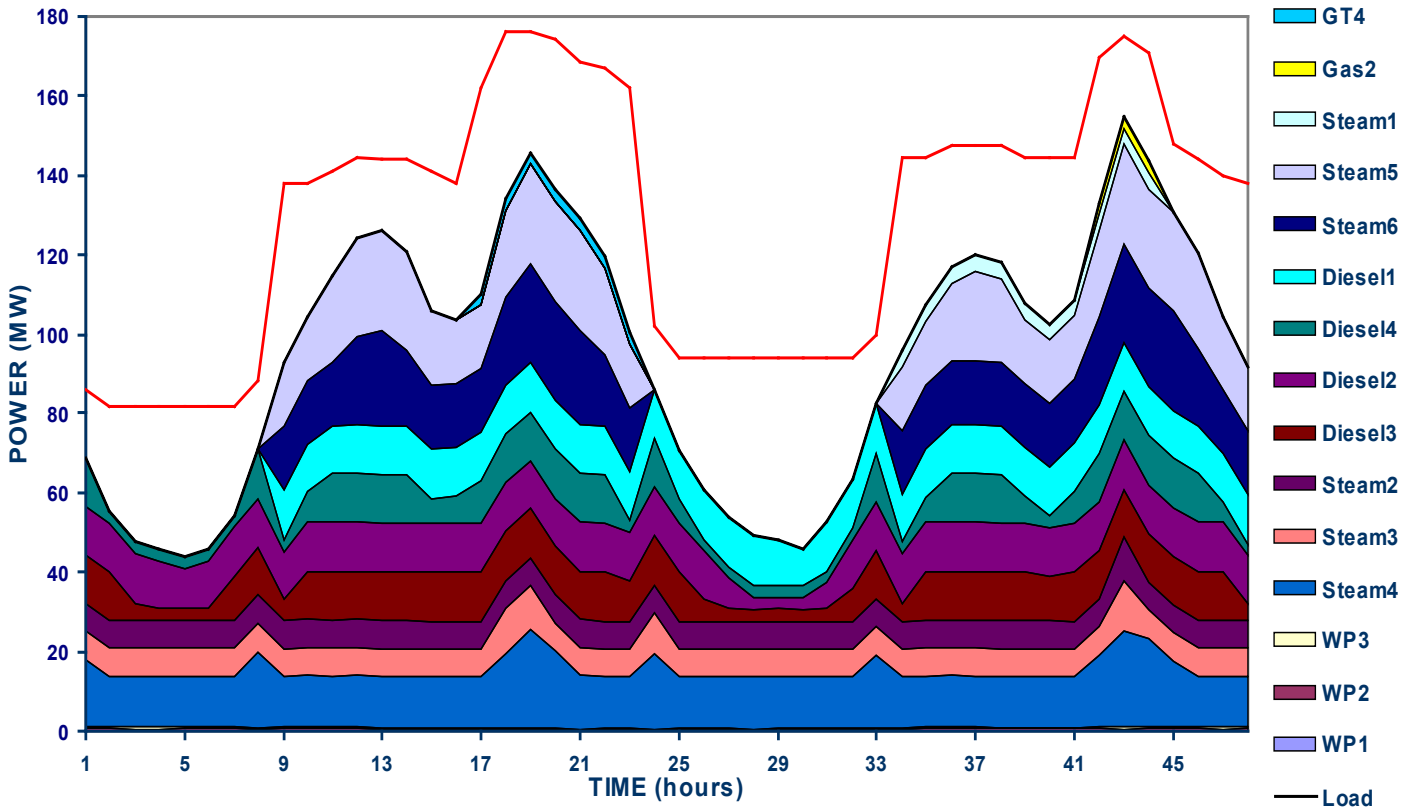
Forecasts use in applications

❖ **Applications:**

- Unit Commitment
- Economic dispatch/OPF
- Fast dynamic security assessment
- Scheduled maintenance
- Reserves setting
- Congestion management
- Wind/Storage coordination
- Storage management
- Energy trading
- Ancillary service provision

- Predictive management of:
  - Smart homes
  - Energy islands
  - Microgrids…

The base line approach in the nineties



Example: Unit commitment of an island power system using deterministic forecasts and a **adaptable margin** for spinning reserve to hedge foruncertainty (More-Care EU project. Apps: Ireland, Crete…).

Forecasts use in applications

❖ **Applications:**

- Unit Commitment
- Economic dispatch/OPF
- Fast dynamic security assessment
- Scheduled maintenance
- Reserves setting
- Congestion management
- Wind/Storage coordination
- Storage management
- Energy trading
- Ancillary service provision

- Predictive management of:
  - Smart homes
  - Energy islands
  - Microgrids…

Approaches based on **stochastic optimisation** and more lately **on robust optimisation** are extensively proposed in the power systems literature in the last 15 years.

- They use mainly scenarios or quantiles (pdfs) as inputs.

However, there is a **mismatch between academic research and the adoption of probabilistic approaches in business practices**.

A first **massive attempt to demonstrate the benefits** of probabilistic tools was made in the frame of ANEMOS.plus FP6 project in collaboration with several industrials (2008-2011).

However, it was probably too early to proceed to industrial deployment after the project, as RES penetration was not yet high at that time.

Forecasts use in applications

❖ The **ANEMOS.plus** experience (2008-2011)

- 15 advanced probabilistic management tools, evaluated in 6 demo cases for different decision making problems, for end-users of different types:
  - **operating reserve setting** for TSO (REN, SONI/EIGRID)
    - The tool was able to advise about reserves setting in a consistent way and outperformed deterministic decision rules in place
  - **congestion management** for TSO (REN) and for DSO (EWE)
    - TSO: Fuzzy and probabilistic power flow increased the capability of detecting possible/probable congestions and voltage violations not captured by the deterministic power flow in place
    - DSO: The tool avoided down-regulations during high and medium wind situations and transformer outages, with savings up to 1800 MWh
  - **wind power trading** tools for wind power producers (DONG, Acciona)
    - The suggested bids provided by the tool improved the economic results with total imbalance cost saving over 15% in 6 months for around 200 MW

[2008-2011] ANEMOS.plus (FP6), http://www.anemos-plus-project.eu/

Forecasts use in applications

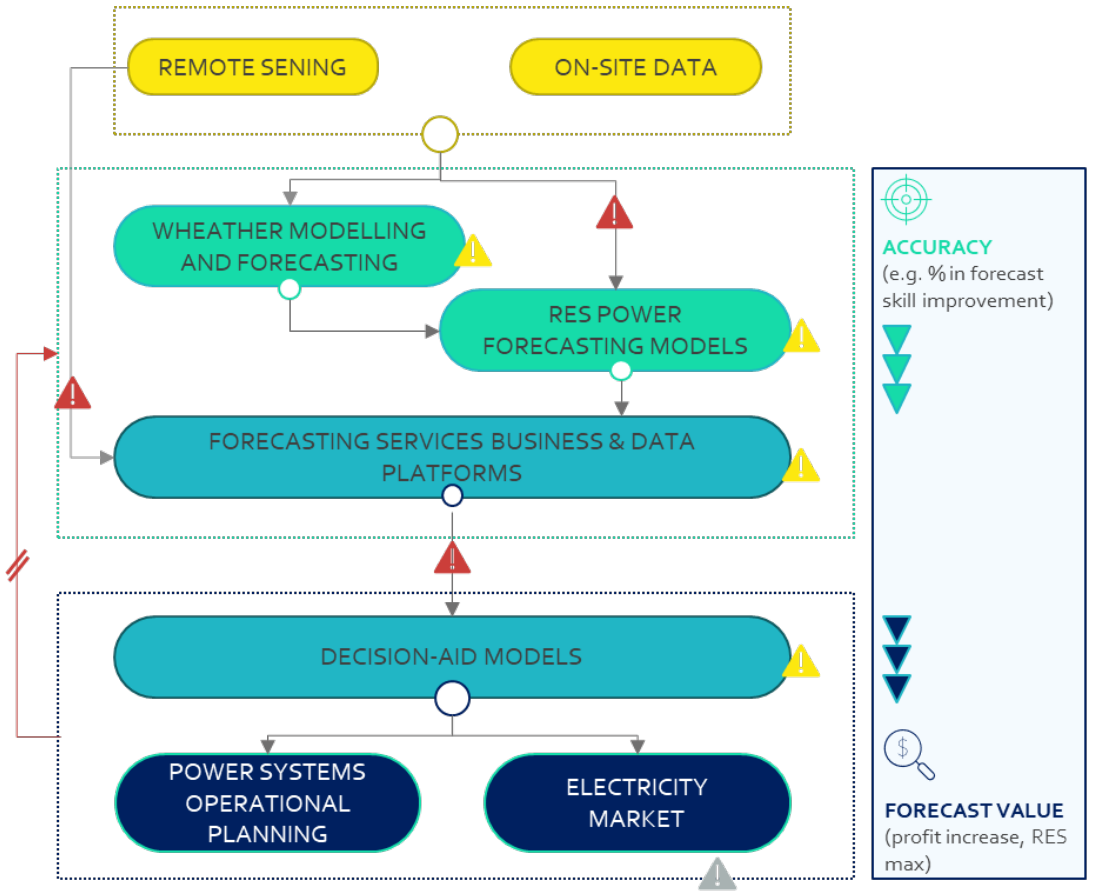
❖ The **ANEMOS.plus** experience (2008-2011)

- 15 advanced probabilistic management tools, evaluated in 6 demo cases for different decision making problems, for end-users of different types:
  - **stochastic UC for TSO** (Eirgrid/SONI)
    - The tool increased the security and reliability of the system, while contributing to a reduction of fuel costs and facilitated wind power penetration
    - Difficult to transfer this cumulated knowledge of a finetuned operational UC to anew tools. More efficient to run the deterministic tool over different forecast scenarios and then postprocess the results.
  - **stochastic UC and stochastic power flow tools for isolated systems** (PPC)
    - Stochastic tools provided early warning about possible insecure states and information about risk and the possible preventive actions. System security was improved and the workload of the operators is reduced
  - **wind-pumping storage optimization** (REN)
    - The tools allowed a profit increase between 3% and 12.4% when using storage only to mitigate forecast errors (market environment)
    - They allow a profit increase around 15% just by storing energy during low price periods for selling during high price periods (market environment)

[2008-2011] ANEMOS.plus (FP6), http://www.anemos-plus-project.eu/

State of the art in wind power forecasting
“The Smart4RES approach”

The Smart4RES project



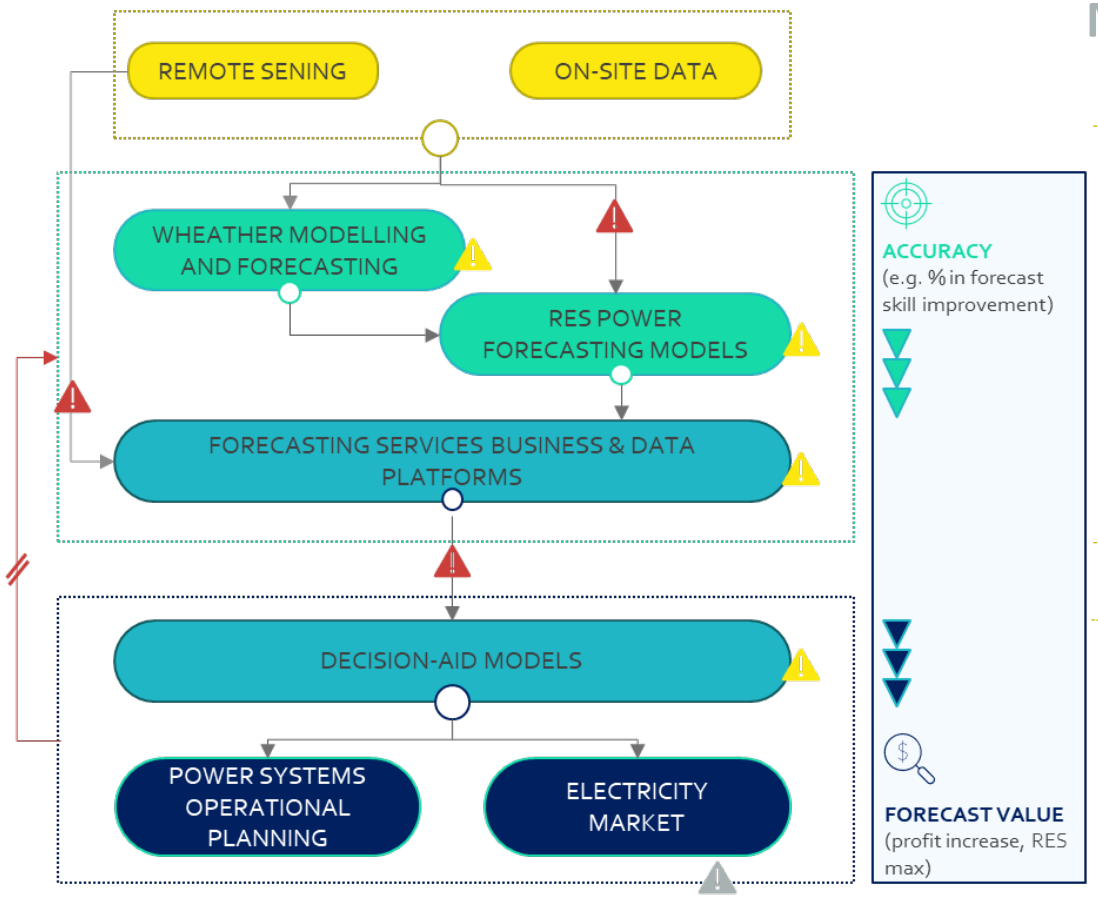
The typical RES forecasting model/value chain

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

Objectives:

1. Requirements for forecasting solutions to enable 100% RES penetration
2. RES-dedicated weather forecasting with 10-15% improvement using various sources of data and very high resolution approaches.
3. New generation of RES production forecasting tools enabling 15% improvement in performance.
4. Streamline the process of getting optimal value through new forecasting products, data market places, and novel business models
5. New data-driven optimisation and decision aid tools for power system management and market participation
6. Validation of new models in living labs and assessment of forecasting value vs remedies.

The RES forecasting model/value chain



The typical RES forecasting model/value chain

May decline into different versions as a function of the use case

Predictive analytics

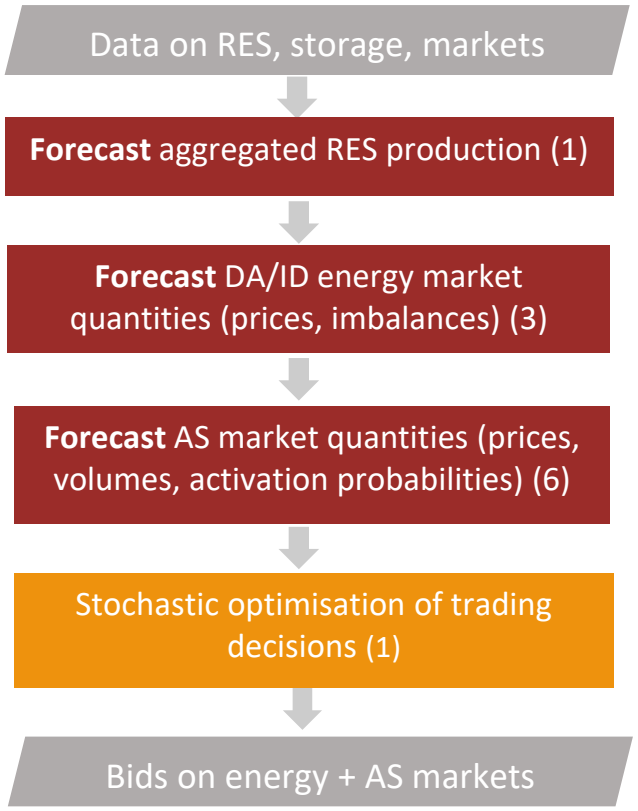
- **Forecasting models** for: weather variables, wind/solar or aggregations, dynamic line rating, demand, market prices….
- Different **forecasting products**: probability distributions, scenarios/ensembles, extremes (ramps, low quantiles etc).
- Tuned to minimize a proxy loss without considering downward costs. This raises some issues:
  - Increased forecast accuracy ≠ increased forecast value.
  - Impact of forecast errors on realized costs varies with the specific task.
  - Deploying multiple tools obfuscates the impact of data on decisions…

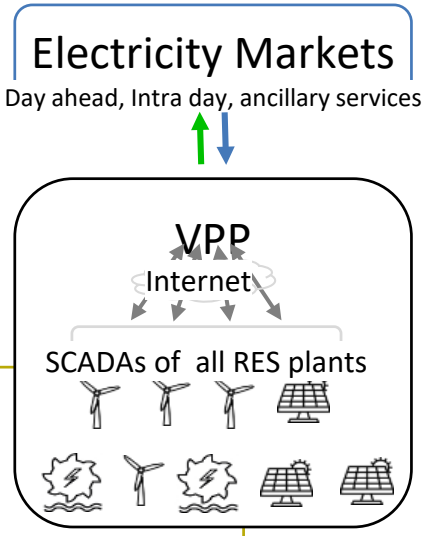
Decision support/optimisation tools

- Solutions tailored for different actors (aggregators, producers, energy communities, TSOs, DSOs,…)
- and for a multiplicity of problems (trading, smart home management, grid management,….)
- Optimisation taking into account uncertainties (stochastic/robust)

Let's dive into a concrete use-case: market participation of RES

The generic model chain for the case of a Virtual Power Plat (VPP) trading in day ahead, (DA) Intraday (ID) and Ancillary Service (AS) markets:
(in parenthesis the number of models: 11 in total)





Challenges

- High quantities of flowing data (dimensionality)
- Data reliability
- Evolving "physical" system (VPP)
- Evolving market rules due to structural changes of markets
- Multiple uncertainties (RES, market quantities,…)
- Forecasting models dependability on data
- Computational time
- Human in the loop
- ….

Let's dive into a concrete use-case: market participation of RES

The generic model chain for the case of a Virtual Power Plat (VPP) trading in day ahead, (DA) Intraday (ID) and Ancillary Service (AS) markets:
(in parenthesis the number of models: 11 in total)

Data on RES, storage, markets

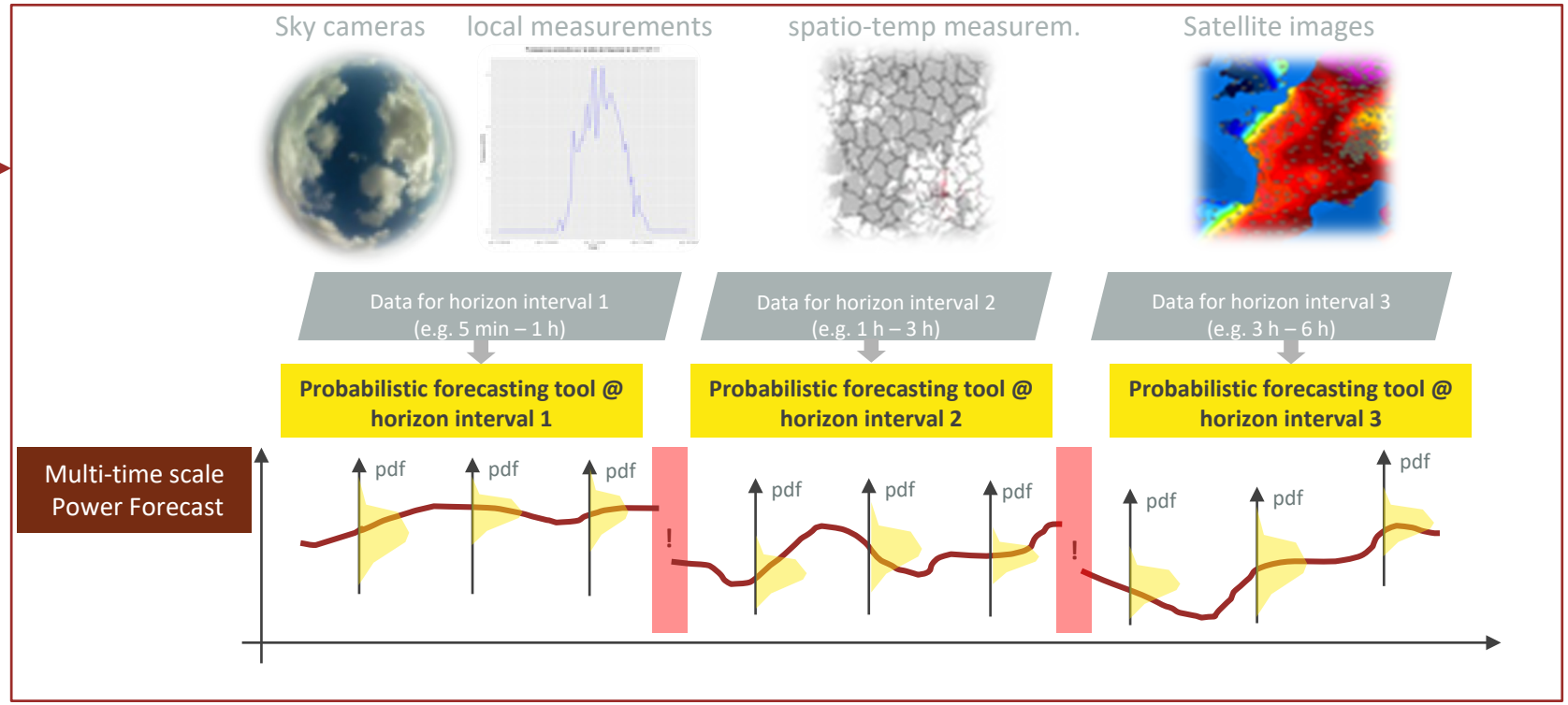
Forecast aggregated RES production (1+

Forecast DA/ID energy market quantities (prices, imbalances) (3)

Forecast AS market quantities (prices, volumes, activation probabilities) (6)

Stochastic optimisation of trading decisions (1)

Bids on energy + AS markets



Focus on RES forecasting models: multiple models may be needed to derive forecasts for different time scales as a function of the avaiable data

Let's dive into a concrete use-case: market participation of RES

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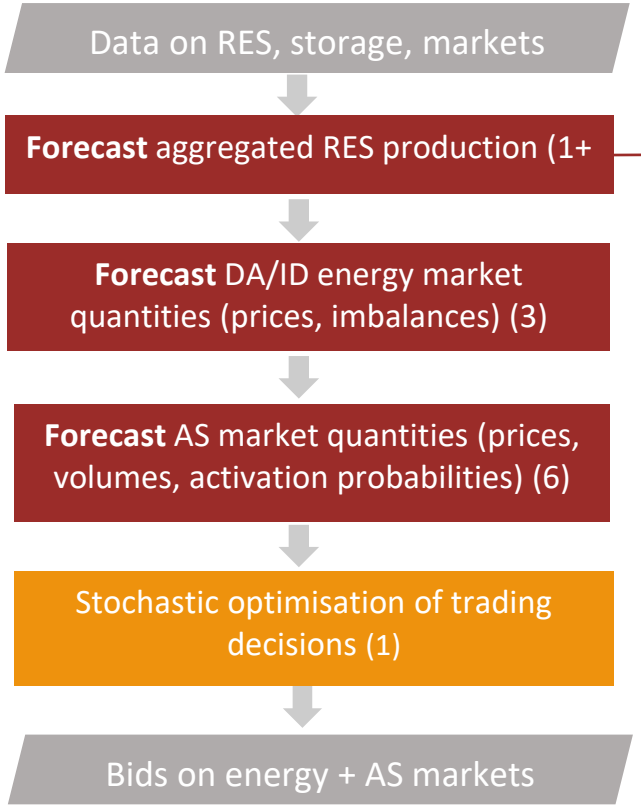
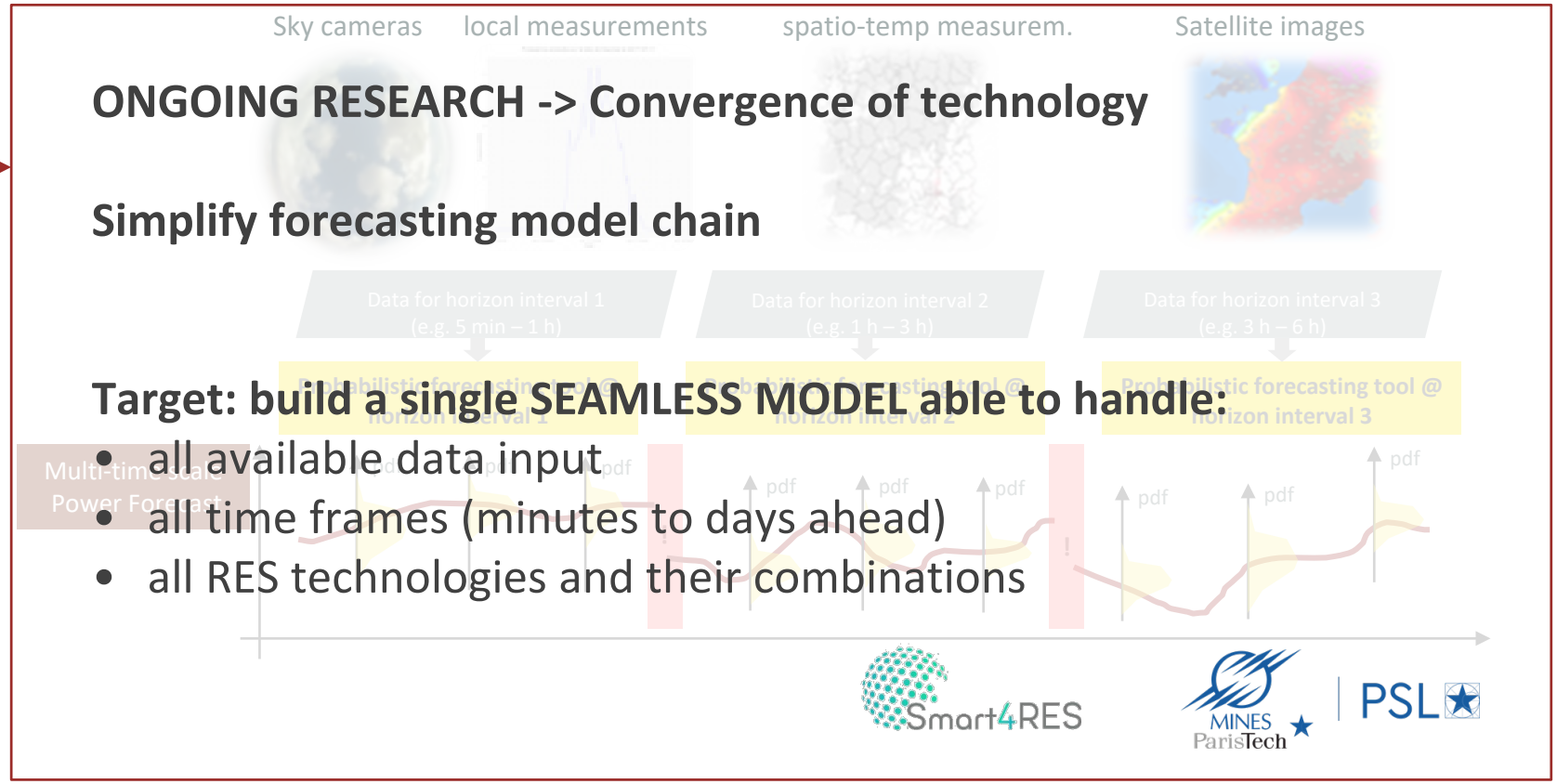
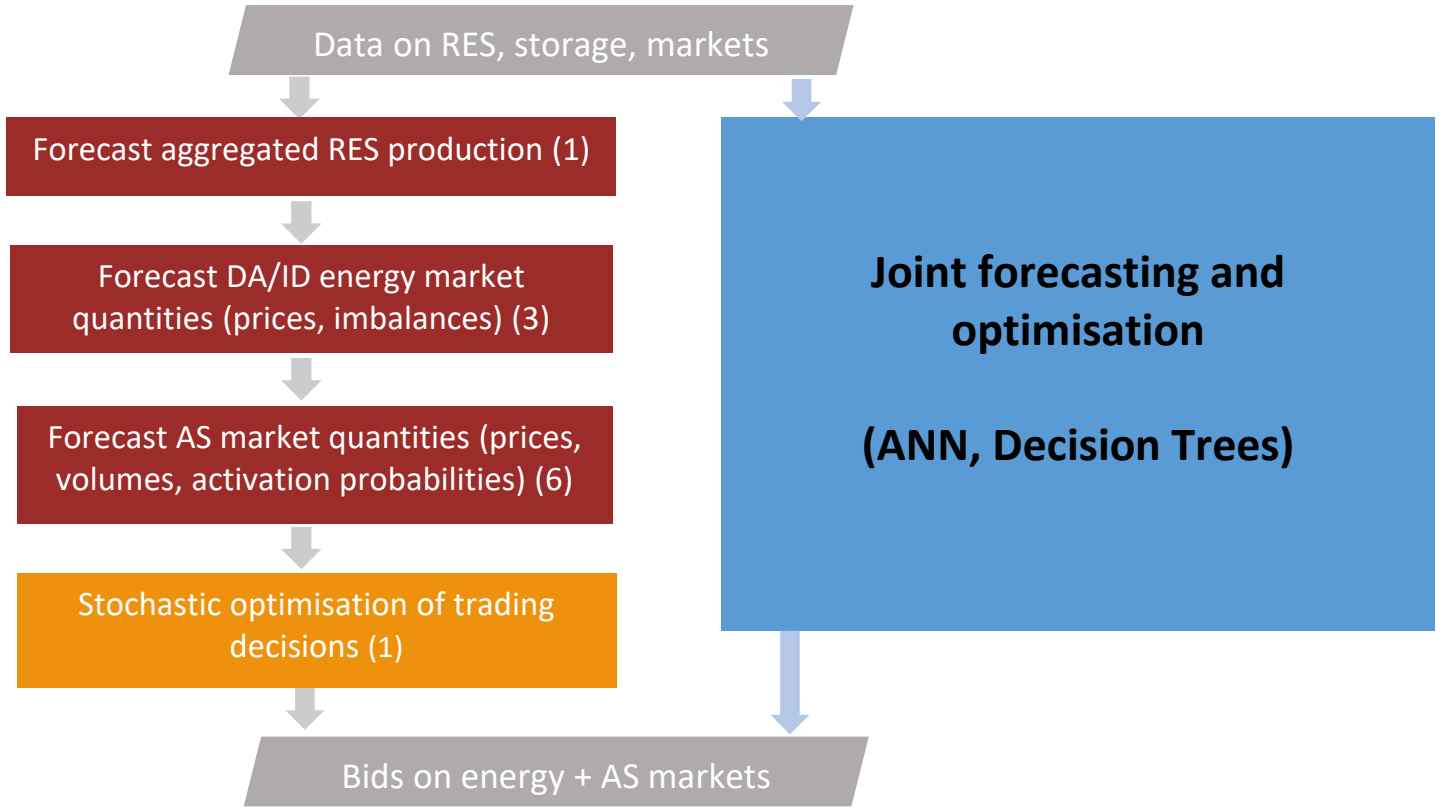




A. C. Stratigakos, S. Camal, A. Michiorri and G. Kariniotakis, "Prescriptive Trees for Integrated Forecasting and Optimization Applied in Trading of Renewable Energy," in *IEEE Transactions on Power Systems*, doi: 10.1109/TPWRS.2022.3152667.

Let's dive into a concrete use-case: market participation of RES

Prescriptive analytics: An alternative paradigm where forecasting and optimisation are **merged into a single step**.
The objective is to **simplify the model chain** through data-driven decision making



ONGOING RESEARCH

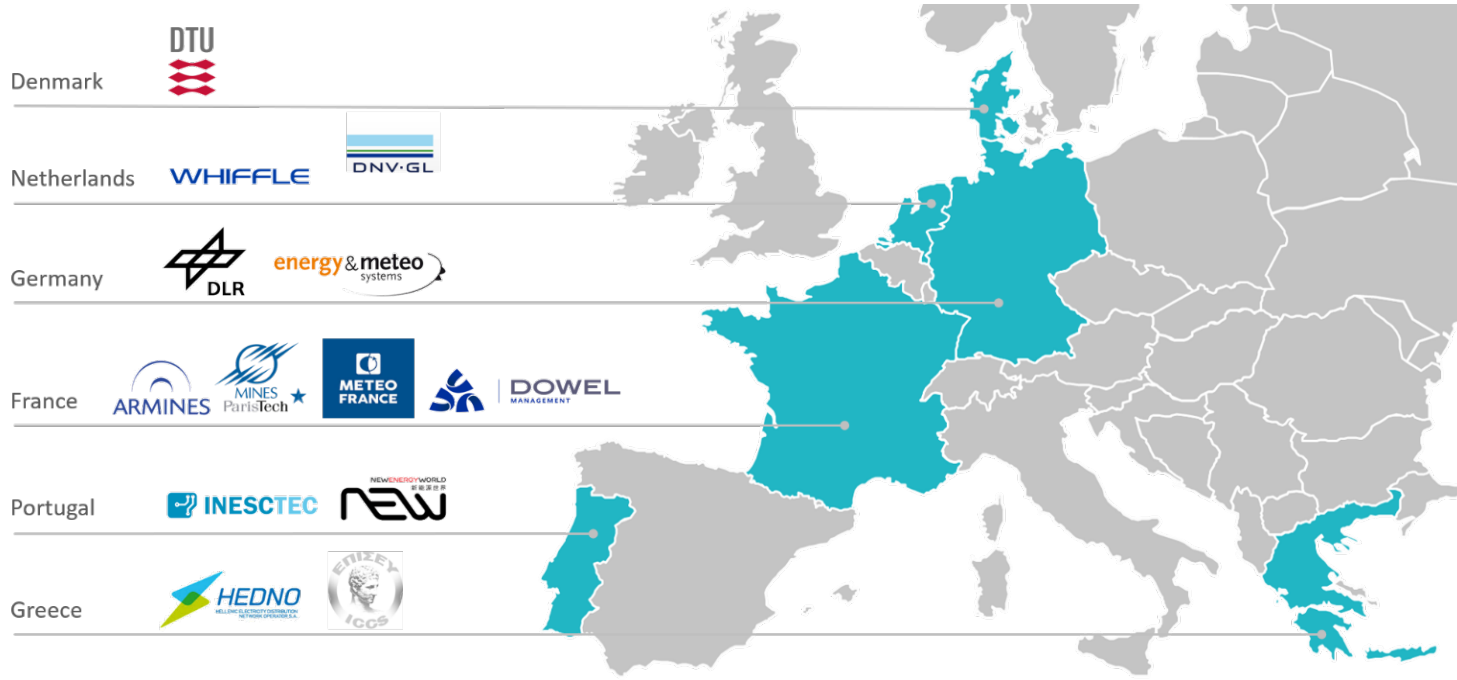
- Learn a policy conditioned on explanatory data.
- Comparable results to the full chain
- Skip probabilistic forecasts… !!!!
- Skip stochastic optiisation !!!!
- Framework to assess impact of data on decisions.
- Good interpretability (optimal DTs)
- Enhanced resilience through a robust approach that handles missing features.
- Human in the loop

Conclusions – some big directions

- **New forecasting products** will be requested by emerging applications (see: Smart4RES Deliverable).
- **Simplification of the model/value** chain will remain a challenge.
- **Automatisation** of the model chain needed.
- Integration of **multiple forecasting products in the optimisation/decision-making** tools
- Integration of the **human in the loop** – operator-centric solutions.
- The RES forecasting and related decision making tools should become **resilient** (robust to missing data, cyberattacks…)
- The existence of solutions is not adequate for the adoption of probabilistic optimisation/decision-making tools by industyry. **Human-centric innovation adoption policies** needed inside the companies.
- …

Smart4RES

THANK YOU !



- Get in touch on our social media

https://twitter.com/Smart4RES

https://www.linkedin.com/company/30726283

https://www.smart4res.eu/

Smart4RES

APPENDIX

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PROJECT COORDINATOR & CONTACTS

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georges.kariniotakis@minesparis.psl.feu, simon.camal@minesparis.psl.eu

1. Smart4RES in a nutshell

- A multi-disciplinary consortium

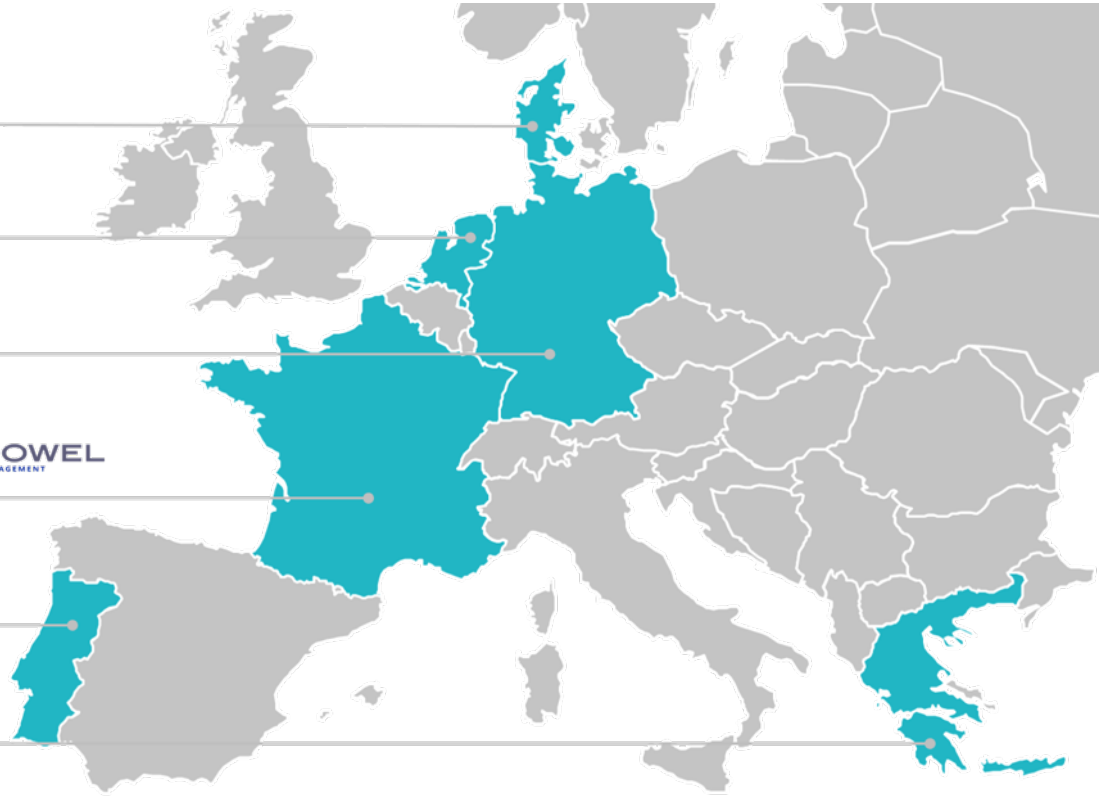
6 countries
12 partners

End-users
Industry
Research
Universities
Meteorologists

Funds: H2020 programme
Budget: 4 Mio€
Duration: 3.5 years

11/2019-4/2023

Denmark
Netherlands
Germany
France
Portugal
Greece

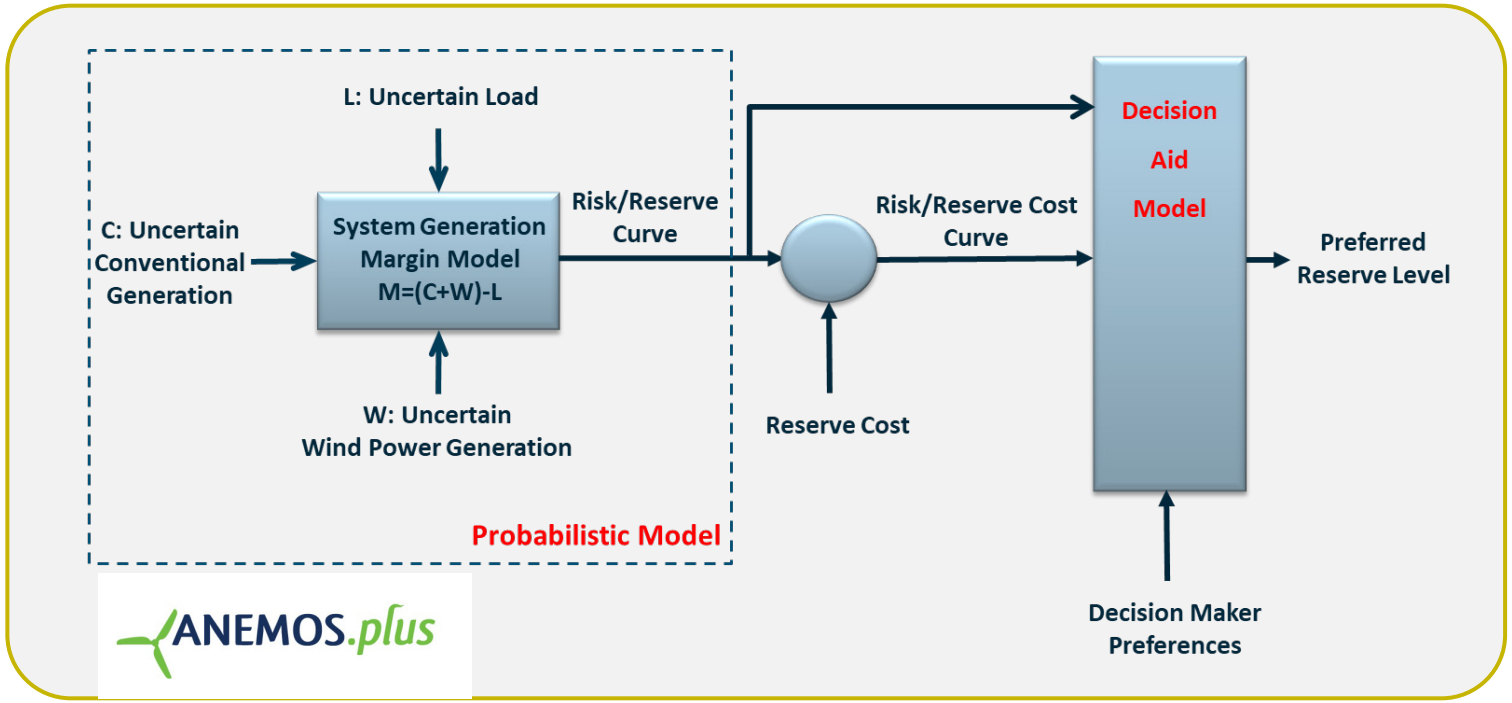


Forecasts use in applications

❖ Applications:

- **Unit Commitment**
- **Economic dispatch/OPF**
- Fast dynamic security assessment
- Scheduled maintenance
- **Reserves setting**
- Congestion management
- Wind/Storage coordination
- Storage management
- **Energy trading**
- Ancillary service provision

- Predictive management of:
  - Smart homes
  - Energy islands
  - Microgrids…



Probabilistic Robust Reserve Setting tool to support TSO in defining the operating reserve needs for the daily and intraday markets. INESC TEC (2011). Later deployed at REN (TSO of PT).

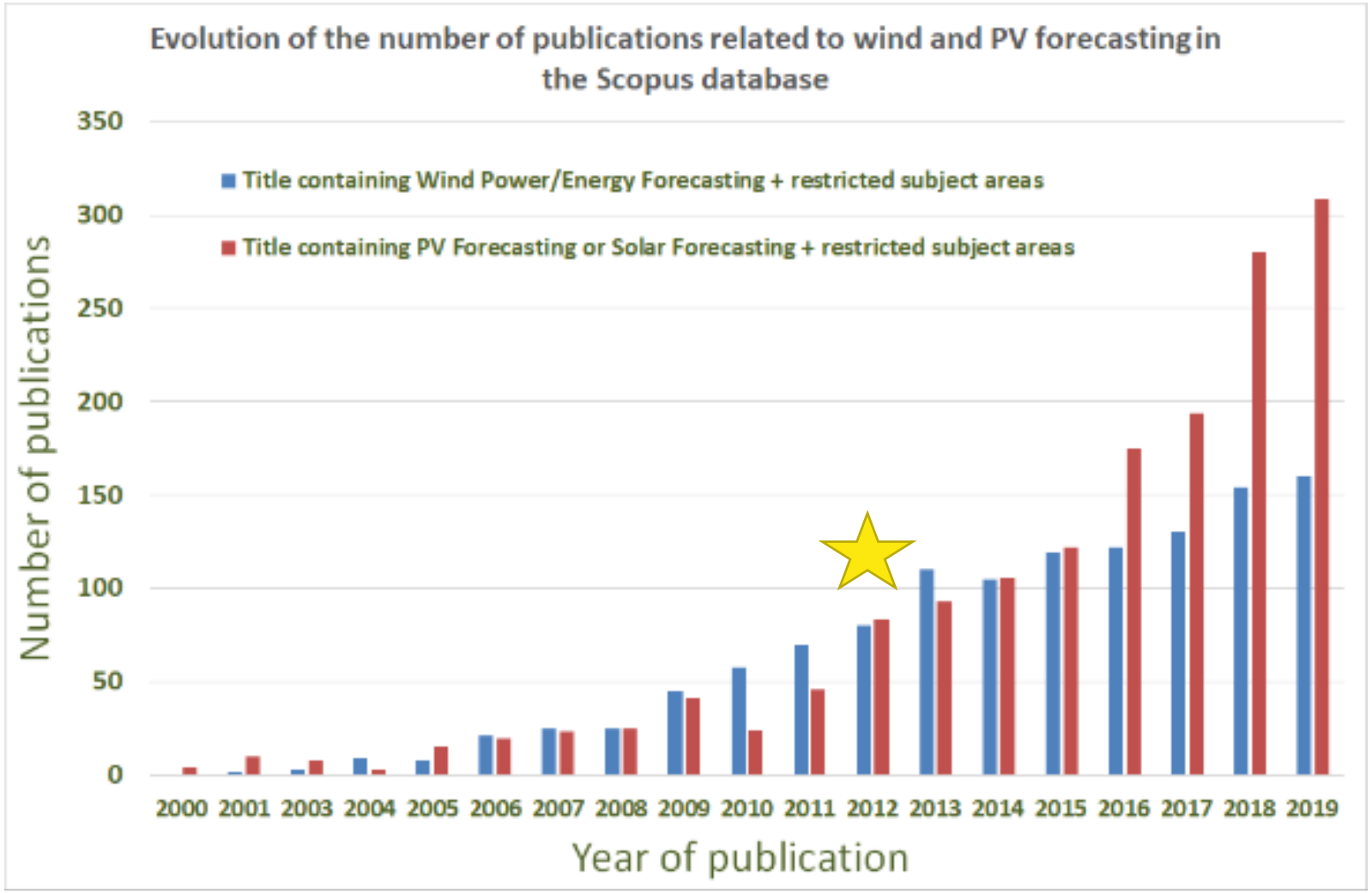
- showed advantages over deterministic rules.

A vision for R&D perspectives dated back in 2012

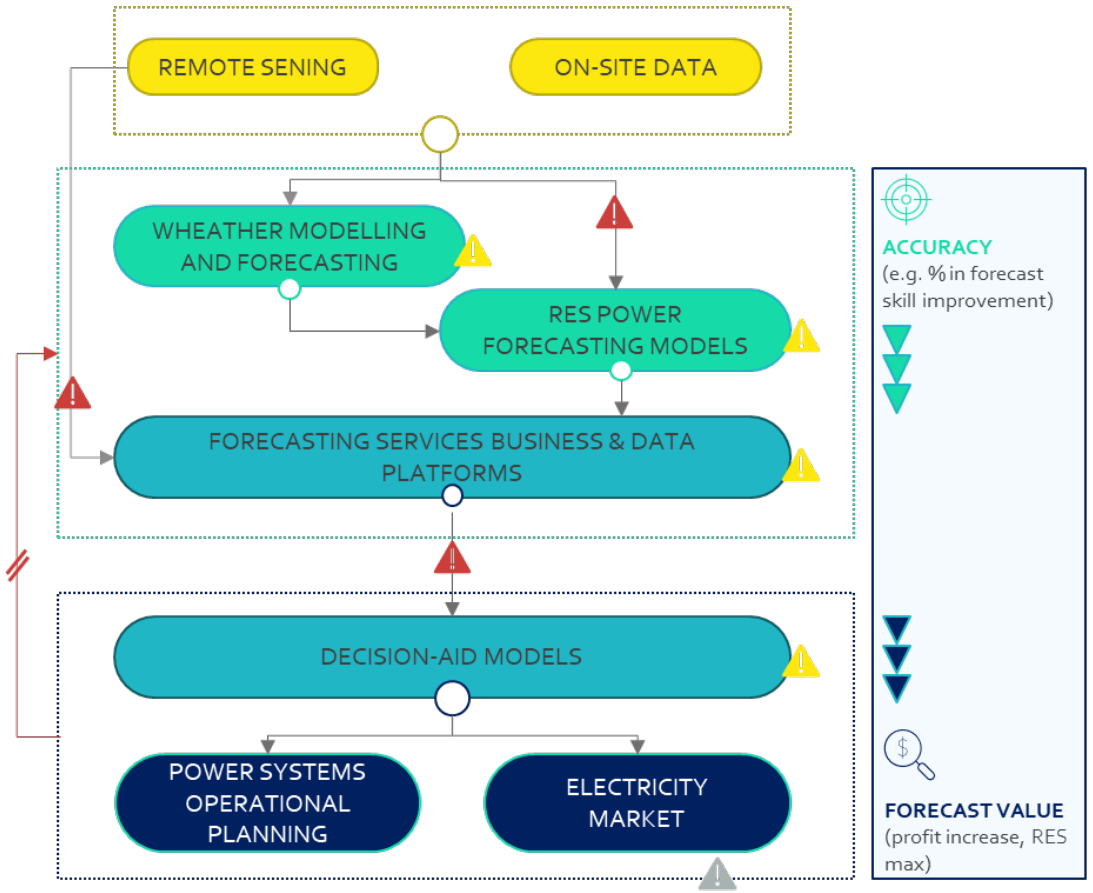
ANEMOS.plus

SafeWind

250 publications at conferences and journals



The Smart4RES project



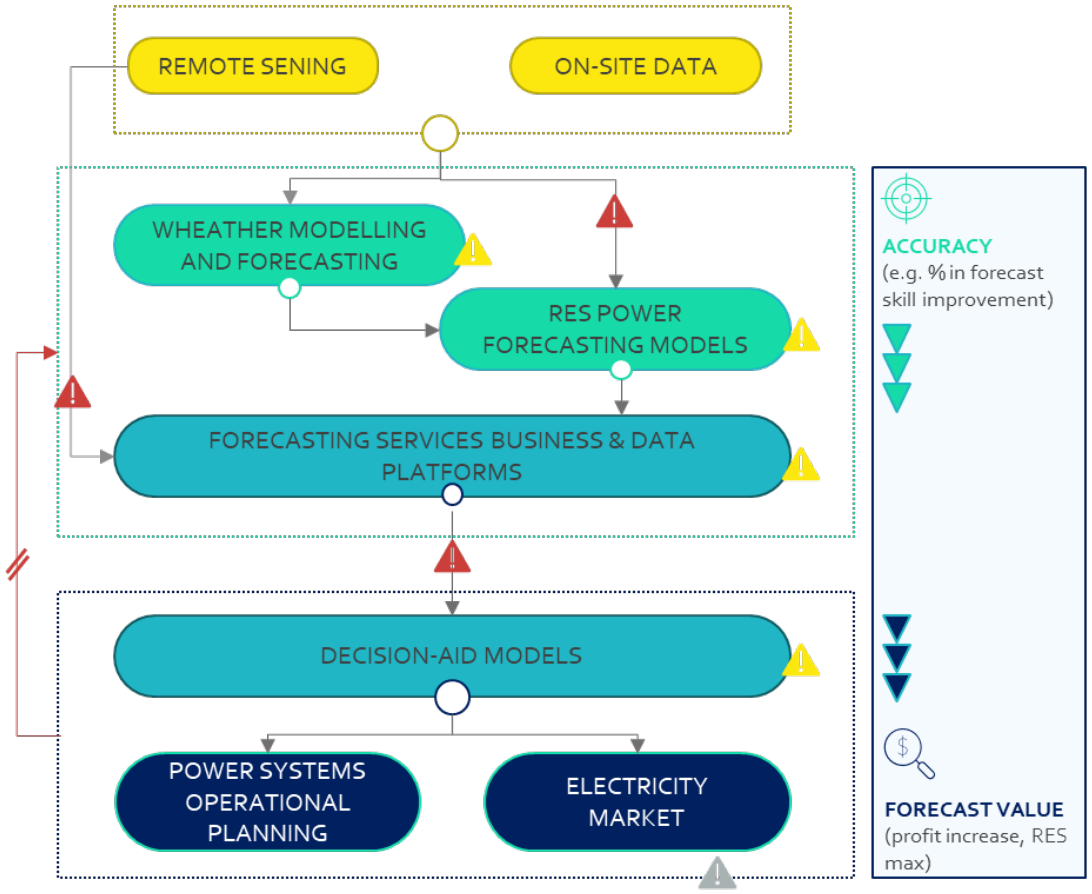
The typical RES forecasting model/value chain

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

Objectives:

1. Requirements for forecasting solutions to enable 100% RES penetration
2. RES-dedicated weather forecasting with 10-15% improvement using various sources of data and very high resolution approaches.
3. New generation of RES production forecasting tools enabling 15% improvement in performance.
4. Streamline the process of getting optimal value through new forecasting products, data market places, and novel business models
5. New data-driven optimisation and decision aid tools for power system management and market participation
6. Validation of new models in living labs and assessment of forecasting value vs remedies.

Smart4RES: vision



The typical RES forecasting model/value chain

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

Generic model/value chains:

- **Power systems branch:** Multiple use cases like reserves estimation, congestion management, scheduling, microgrids/smarthomes/energy communities management, predictive maitenance, etc.
- **Electricity markets branch:** Mainly trading. Variants depending on assets combination and markets.

Time frames:

- All tools that aim to optimise operational decisions in time frames of a few minutes to afew days ahead are concerned.
- Not concerned: real time control and long term multi-annual planning (investements).