

Modelling Renewable Energy Production with HPC

HiDALGO2 Clustering Event

Stuttgart, 4/11/2025



Michał Kulczewski, Piotr Kopta, Bartosz Bosak, Wojciech Szeliga, Krzysztof Kotecki

Modelling Renewable Energy Production with HPC

**HiDALGO2**
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Stuttgart, 4/11/2025

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Why renewable energy sources matter?



- EU' renewable energy directive aims for **42.5%** of the gross energy consumption from renewables **by 2030**.
- **In 2024, 46.9%** of net electricity produced in the EU came from **renewable energy sources**.

Why renewable energy sources matter?



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Wind and PV **developers** need to **identify best spots** for exploiting renewable energy sources in **the most efficient way**.

Wind and PV **plant operators** need to **estimate energy production** in future time periods and **predict potential damages to the infrastructure**.

Why renewable energy sources matter?



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Wind and PV **developers** need to **identify best spots** for exploiting renewable energy sources in **the most efficient way**.

Wind and PV **plant operators** need to **estimate energy production** in future time periods and **predict potential damages to the infrastructure**.

- **But**, with opportunities come challenges
- No wind or excessive wind ☐ no power
- No sun ☐ no power

Distribute System Operators have to **stabilise the grid**.

Yet another challenge – how to model complex physical phenomena related to Renewable Energy Sources?

- The answer is multiscale simulations models:
 - Global weather forecast
 - Mesoscale weather forecast
 - Regional/urban weather forecast
 - Energy prediction module

Yet another challenge – how to model complex physical phenomena related to Renewable Energy Sources?

- The answer is multiscale simulations models:
 - Global weather forecast
 - Mesoscale weather forecast
 - Regional/urban weather forecast
 - Energy prediction module
- **But:**
 - Modelling at different scales requires thousands of CPUs
 - How to limit uncertainties – with uncertainty quantification
 - Ensembles – hundreds of simulations each requires thousands of CPUs
 - HPDA – to efficiently process all the data
- All of these requires robust and novel HPC infrastructure, delivered by the EuroHPC-JU

- RES is a HPC suite for tackling renewable energy sources challenges
- Addressing the needs of different users and stakeholders, e.g. DSOs, RES developers and operators, individuals
- With appealing interface
- Suited for non-HPC users
- Transparent setup and execution
- With support for ensembles and uncertainty quantification

hidALGO2 CENTRE OF EXCELLENCE All applications Diana791@gmail.com

< Return to task list

RES scenario definition

RES

Start *
DD/MM/YYYY, HH:MM

Simulation time (hours) *
12

Time resolution (minutes) *
15

Domains

Select next Delete (1)

Domain 1 Delete

Horizontal resolution *
Set resolution (1-100)

Points

Starting point - X * Starting point - Y *
53.53 53.53

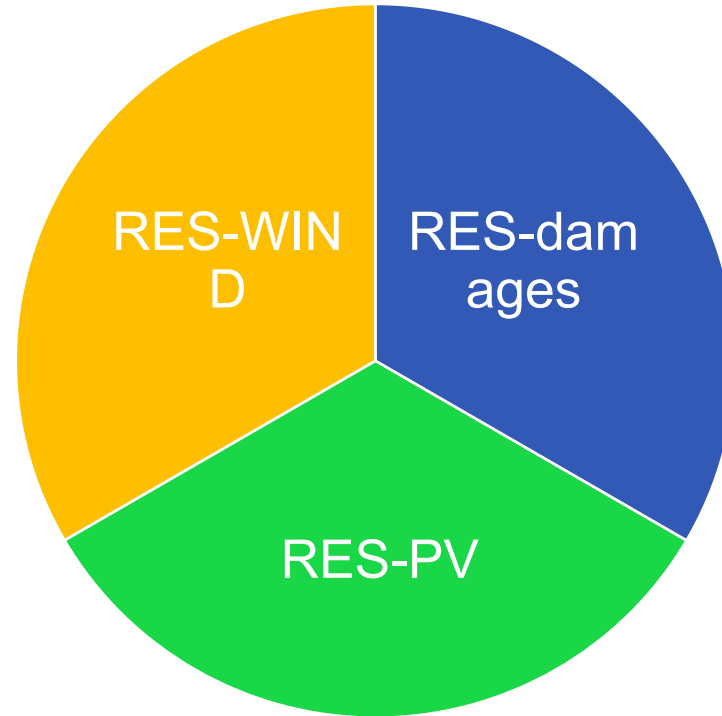
Ending point - X * Ending point - Y *
53.53 53.53

+ Add domain

Advanced options (WRF, EULAG)

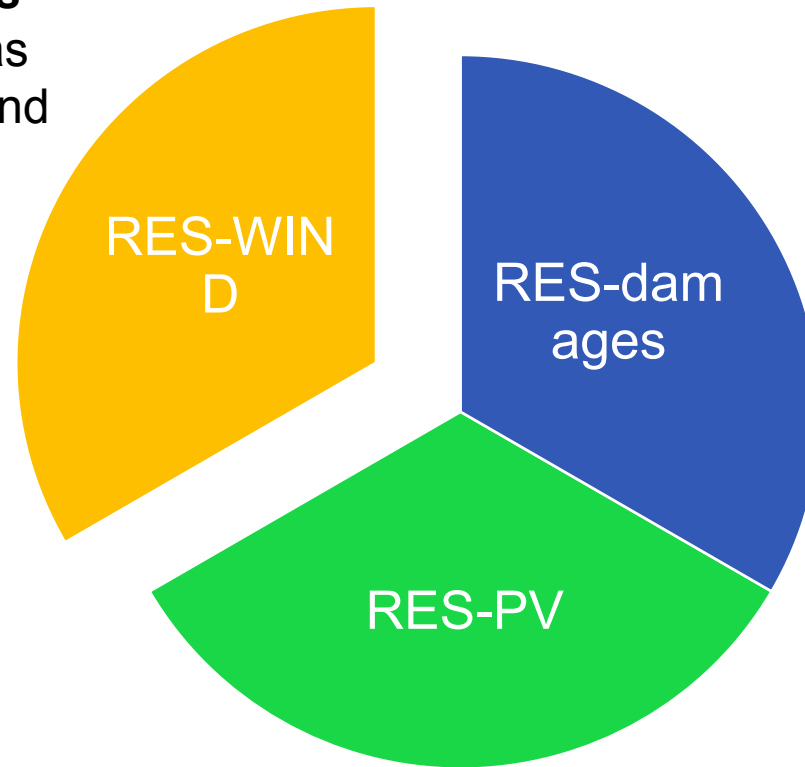
(*) required fields Cancel Submit task

RES applications

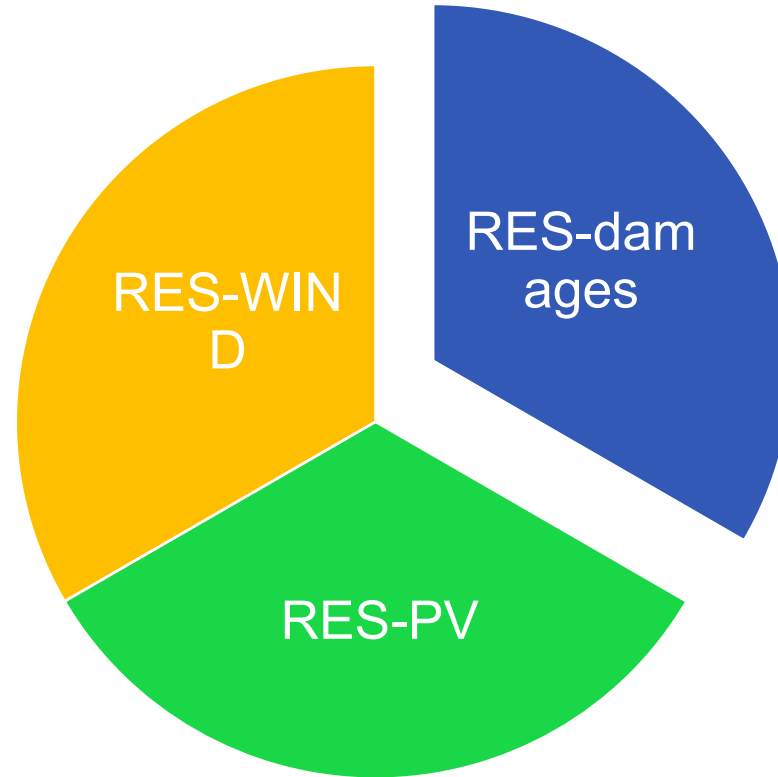


Optimising wind farms and mills

- Urban and non-urban areas
- Finding best spots from wind farms and mills

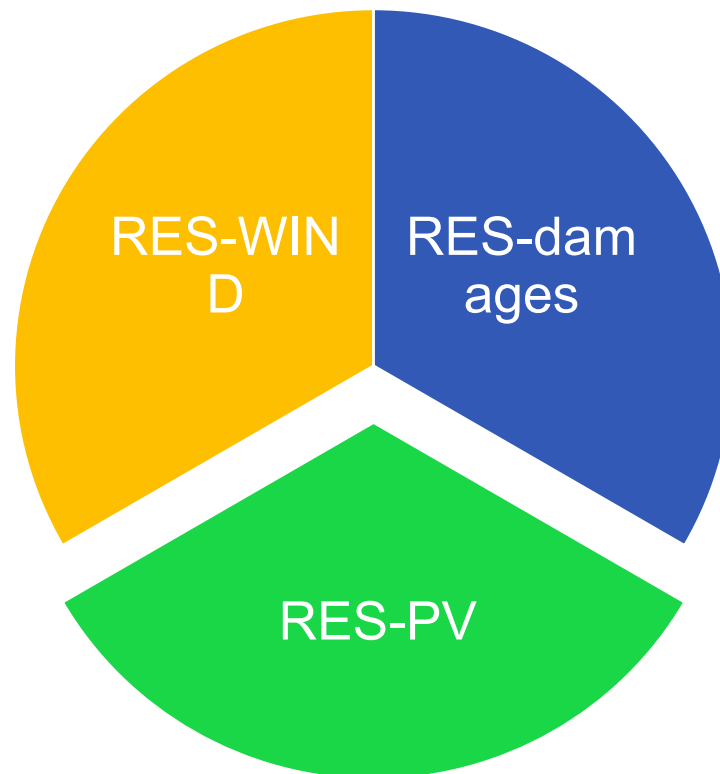


RES applications



Damages to the RES installations

- Icing
- Excessive heat
- Extreme wind



Energy production forecasts from photovoltaic systems

- Forecast of electric energy production from PV installation
- PSNC photovoltaic farm 990 kWp
- Data from OpenStreetMaps, Corine, EU-DEM, GFS, ...
- Multiscale simulation from 4km to 10m resolution



- Forecast of electric energy production from PV installation
- PSNC photovoltaic farm 990 kWp
- Data from OpenStreetMaps, Corine, EU-DEM, GFS, ...
- Multiscale simulation from 4km to 10m resolution

Why to bother?

- Increased spatial resolution to capture local variabilities
- Better accuracy in energy production forecast

Kąkolewo PV 990kWp



Basics

- Select region of interest
- Provide forecast start time, duration, and time interval
- Optionally provide details on PV infrastructure

[Return to task list](#)

RES scenario definition

RES

Start *

DD/MM/YYYY, HH:MM 📅

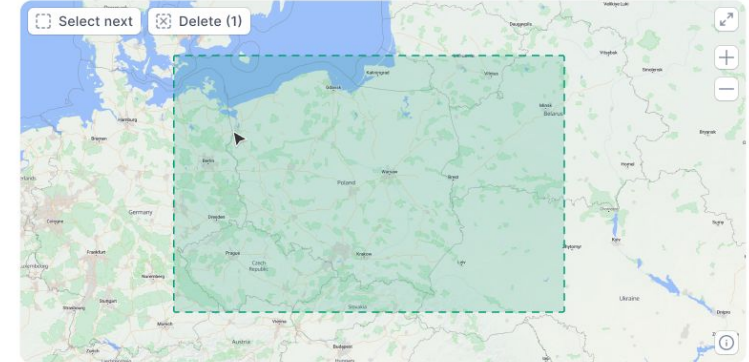
Simulation time (hours) *

12 ⌵

Time resolution (minutes) *

15 ⌵

Domains



Domain 1

Delete

Horizontal resolution *

Set resolution (1-100) ⌵

Points

Starting point - X *

53.53 ⌵

Starting point - Y *

53.53 ⌵

Ending point - X *

53.53 ⌵

Ending point - Y *

53.53 ⌵

+ Add domain

Advanced options (WRF, EULAG)

(*) required fields

Cancel

Submit task

Basics

- Select region of interest
- Provide forecast start time, duration, and time interval
- Optionally provide details on PV infrastructure

Advanced

- Select the machine, provide nodes / CPUs / GPUs configuration
- Select models, horizontal resolution, timestep, etc.

[Return to task list](#)

RES scenario definition

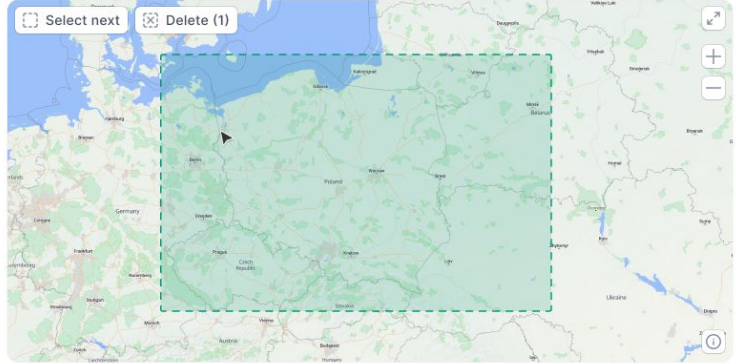


Start *

Simulation time (hours) *

Time resolution (minutes) *

Domains



Domain 1

Horizontal resolution *

Points

Starting point - X *	<input type="text" value="53.53"/>	↔	Starting point - Y *	<input type="text" value="53.53"/>
Ending point - X *	<input type="text" value="53.53"/>	↔	Ending point - Y *	<input type="text" value="53.53"/>

Advanced options (WRF, EULAG)

(*) required fields

Basics

- Select region of interest
- Provide forecast start time, duration, and time interval
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Advanced

- Select the machine, provide nodes / CPUs / GPUs configuration
- Select models, horizontal resolution, timestep, etc.

Hidden features

- Automatic domain size and nesting
- Automatic nodes / CPUs / GPUs assignment

[Return to task list](#)

RES scenario definition

 RES

Start *

DD/MM/YYYY, HH:MM 

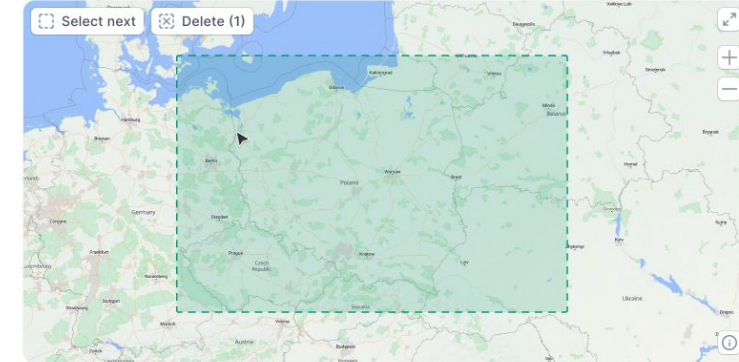
Simulation time (hours) *

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Time resolution (minutes) *

15 

Domains



Domain 1

Delete

Horizontal resolution *

Set resolution (1-100) 

Points

Starting point - X *

53.53 

Starting point - Y *

53.53 

Ending point - X *

53.53 

Ending point - Y *

53.53 

+ Add domain

Advanced options (WRF, EULAG)

(*) required fields

Cancel

Submit task

Tasks

Number of tasks: 525

SORT BY NAME ↕

- ✓ RES Energy 36
ID: 8687506
15 JUL 2025, 15:45 PM
- ✓ RES Energy 35
ID: 8687505
15 JUL 2025, 14:45 PM
- ✓ RES Energy 34
ID: 868504
15 JUL 2025, 13:45 PM
- ✓ RES Damage 21
ID: 8687503
15 JUL 2025, 13:30 PM
- ✓ RES Energy 33
ID: 8687502
15 JUL 2025, 12:45 PM
- ✓ RES Energy 32
ID: 8687501
15 JUL 2025, 11:45 AM
- ✓ RES Energy 31
ID: 8687500
15 JUL 2025, 10:45 AM
- ✓ RES Damage 20
ID: 8687499
15 JUL 2021, 10:30 AM
- ✓ RES Energy 30
ID: 8687498
15 JUL 2025, 09:45 AM


RES Energy 36

(ID: 8687506)

RUNNING ↺ ⋮

Report ✕


30 sec. ↺



Submission: 2025-07-15, 15:45

Expected finish: 2025-07-15, 18:38

Runtime: 1 h 25 min




Inited > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > Finished Follow


Corse-grained Numerical Weather Prediction (RES.WRF) ✕

Domain setup Numerical Weather Prediction


Progress: 64% (~1 min left)




29.05.2025r. - 16:47



29.05.2025r. - 16:47





29.05.2025r. - 16:47




29.05.2025r. - 16:47

Creating...

Show advanced view

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Tasks
Number of tasks: 525

Search tasks... [🔍] [📄] [🔄]

SORT BY NAME ↕

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RES Energy 36 (ID: 8687506)

RUNNING 30 sec.

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Corse-grained Numerical Weather Prediction (RES.WRF)

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29.05.2025r. - 16:47 29.05.2025r. - 16:47 29.05.2025r. - 16:47 29.05.2025r. - 16:47 Creating...

Show advanced view

Current forecast

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Coarse-grained Numerical Weather Prediction (RES.WRF) 🔗 ✕

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Creating...

Show advanced view

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Details on HPC job

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Follow


Corse-grained Numerical Weather Prediction (RES.WRF)

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Show advanced view



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Report ✕


30 sec. ↻



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Coarse-grained Numerical Weather Prediction (RES.WRF) ✕

Domain setup


Numerical Weather Prediction




Progress: 64% (~1 min left)




29.05.2025r. - 16:47




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29.05.2025r. - 16:47




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Creating...

Show advanced view

Overall progress



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Tasks

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RUNNING 30 sec.

[Report](#) | ✕

⚡

RES

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42%

Inited > Preprocessing > **RES.WRF** > RES.Eulag > RES.Analysis > Finished Follow


Corse-grained Numerical Weather Prediction (RES.WRF) ✕

Domain setup Numerical Weather Prediction


Progress: 64% (~1 min left)




29.05.2025r. - 16:47



29.05.2025r. - 16:47



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Creating...

Show advanced view

Stages (models)



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Tasks

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[Report](#) | ✕



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42%

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Corse-grained Numerical Weather Prediction (RES.WRF) ✕

Domain setup


Numerical Weather Prediction




Progress: 64% (~1 min left)




29.05.2025r. - 16:47




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Creating...

Show advanced view

Stage progress



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Tasks

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[Report](#) X

⚡
RES

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Inited > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > Finished Follow


Corse-grained Numerical Weather Prediction (RES.WRF) [X](#)

Domain setup Numerical Weather Prediction


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29.05.2025r. - 16:47



29.05.2025r. - 16:47



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29.05.2025r. - 16:47

Creating...

Show advanced view

Stage results



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Tasks

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RES Energy 36

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RUNNING

Report

⚡ RES

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42%

Initiated > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > Finished


Follow

Corse-grained Numerical Weather Prediction (RES.WRF)


Domain setup

Numerical Weather Prediction


Progress: 64% (~1 min left)




29.05.2025r. - 16:47



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29.05.2025r. - 16:47

Creating...

Show advanced view

- Details on HPC job
- Overall progress
- Stages (models)
- Stage progress
- Stage results



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RES.WRF

- Mesoscale to regional weather forecast
- Use of GFS / other global data as an input
- Details weather forecast up to 100m

RES.WRF

- Mesoscale to regional weather forecast
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RES.EULAG

- City-to-street scale weather and flows forecast
- Use of RES.WRF output data
- Details weather forecast up to 1m

RES.WRF

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RES.ENERGY

- Energy production forecast

RES.WRF

- Mesoscale to regional weather forecast
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- Details weather forecast up to 100m



Single run

$10^2 - 10^3$ CPUs

RES.EULAG

- City-to-street scale weather and flows forecast
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- Details weather forecast up to 1m

RES.ENERGY

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RES.WRF

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Single run

$10^2 - 10^3$ CPUs

RES.EULAG

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- Details weather forecast up to 1m



$10^2 - 10^4$ CPUs

RES.ENERGY

- Energy production forecast

RES.WRF

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- Use of GFS / other global data as an input
- Details weather forecast up to 100m



Single run

$10^2 - 10^3$ CPUs

RES.EULAG

- City-to-street scale weather and flows forecast
- Use of RES.WRF output data
- Details weather forecast up to 1m



$10^2 - 10^4$ CPUs

RES.ENERGY

- Energy production forecast



$10^0 - 10^1$ GPUs

RES.WRF

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Single run

$10^2 - 10^3$ CPUs

Ensembles,
uncertainty
quantification

RES.EULAG

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$10^2 - 10^4$ CPUs

RES.ENERGY

- Energy production forecast



$10^0 - 10^1$ GPUs

RES.WRF

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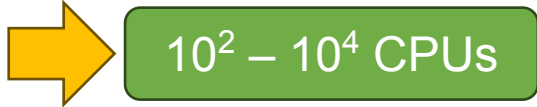
Single run

Ensembles,
uncertainty
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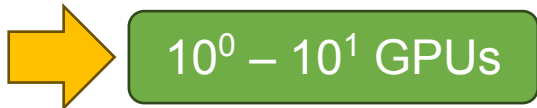
RES.EULAG

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RES.ENERGY

- Energy production forecast



RES.WRF

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Single run

Ensembles,
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RES.EULAG

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- Use of RES.WRF output data
- Details weather forecast up to 1m



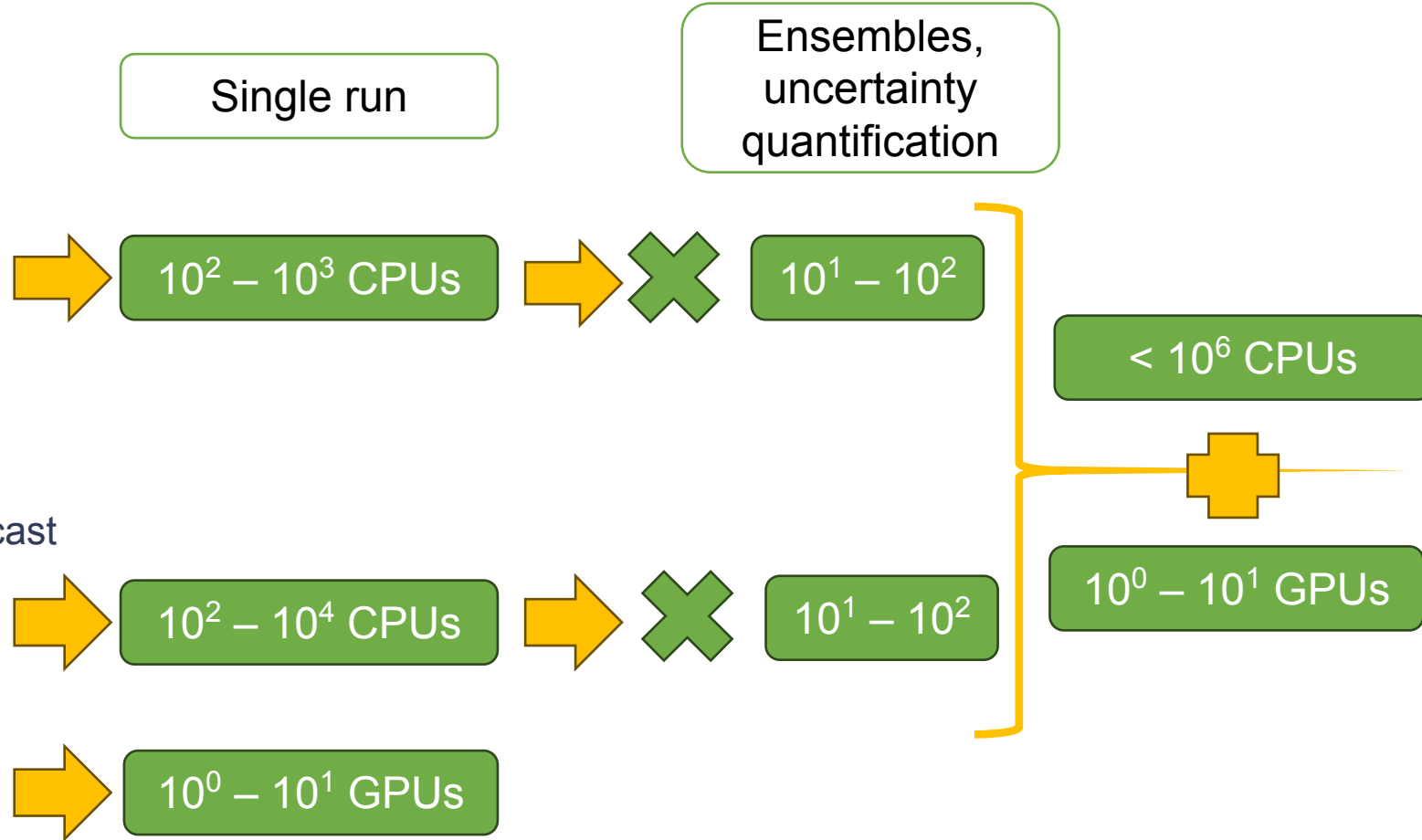
RES.ENERGY

- Energy production forecast



RES.WRF

- Mesoscale to regional weather forecast
- Use of GFS / other global data as an input
- Details weather forecast up to 100m



RES.EULAG

- City-to-street scale weather and flows forecast
- Use of RES.WRF output data
- Details weather forecast up to 1m

RES.ENERGY

- Energy production forecast

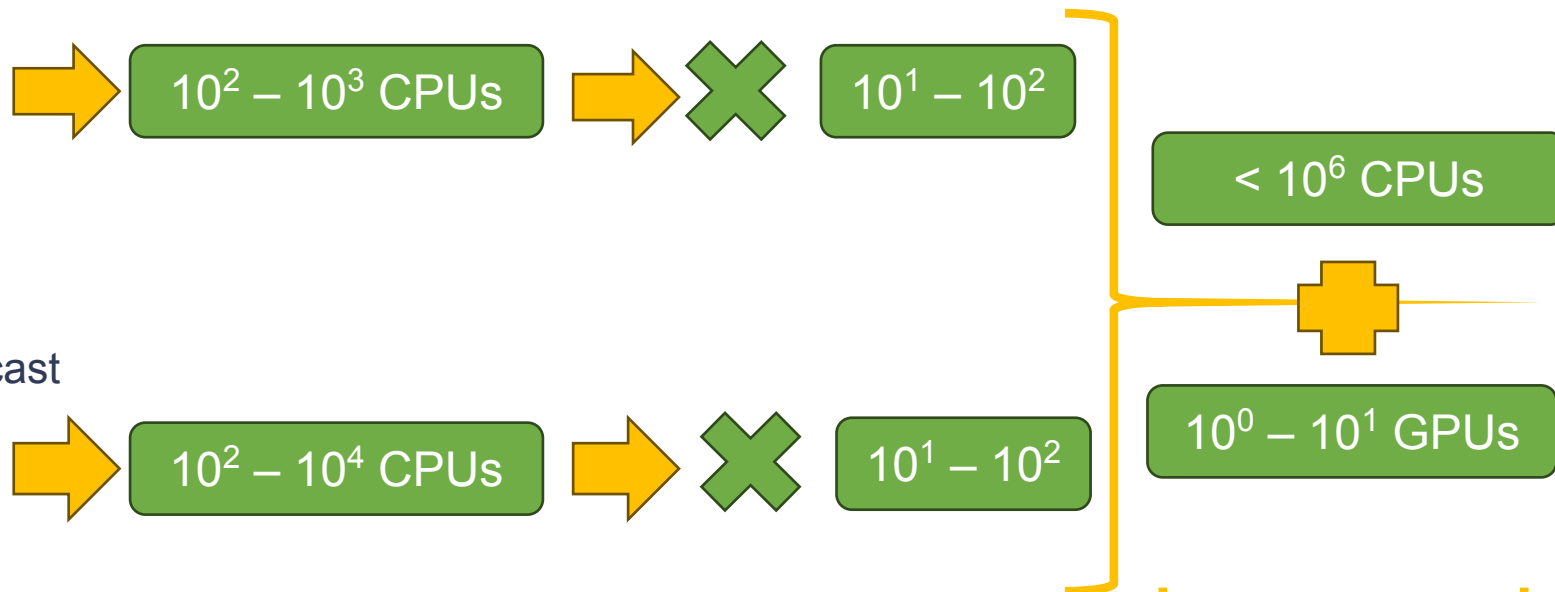
RES.WRF

- Mesoscale to regional weather forecast
- Use of GFS / other global data as an input
- Details weather forecast up to 100m



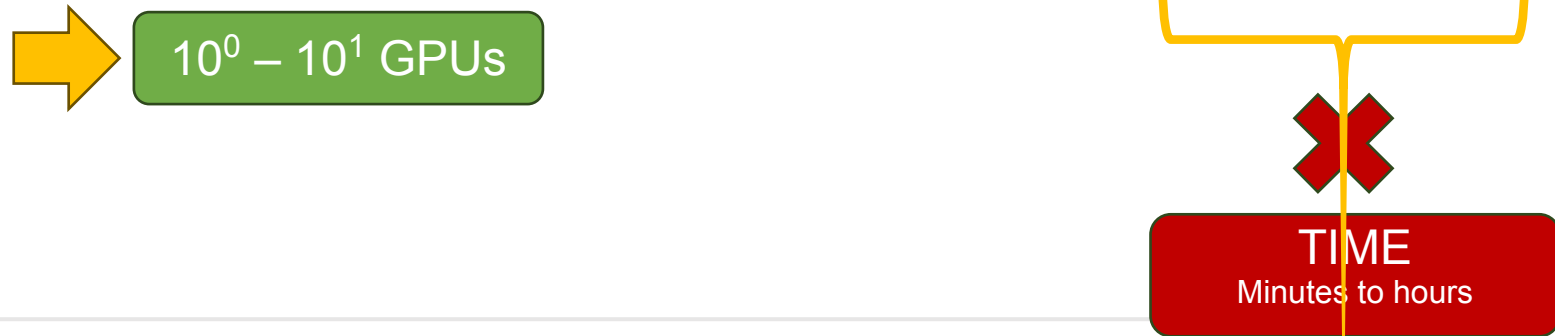
RES.EULAG

- City-to-street scale weather and flows forecast
- Use of RES.WRF output data
- Details weather forecast up to 1m

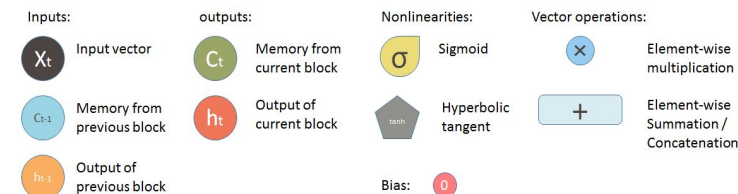
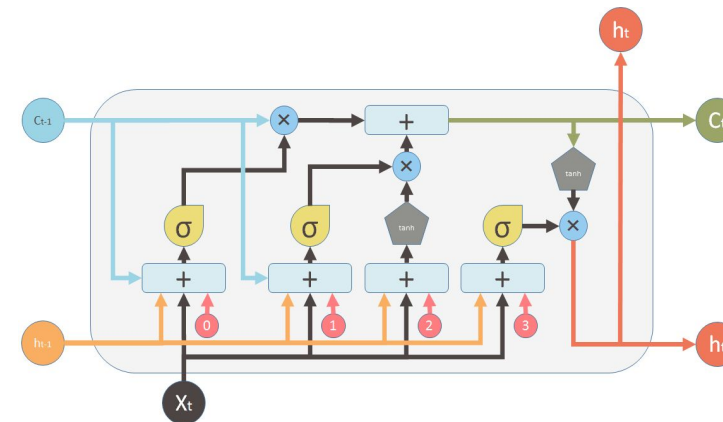


RES.ENERGY

- Energy production forecast



- Data with a 15 minute timestamp
- Weather features including : direct radiation, visibility, temperature and 9 more
- Ongoing process of data gathering
- Each use-case needs a specific model and data gathered for it
- Modelling done in PyTorch, using Recurrent Neural Network with LSTM cells
- With more data, come more opportunities e.g. incorporating new architectures :
Transformers or Mamba.



Current architecture - RNN with LSTM cells



Tasks
Number of tasks: 525

SEARCH BY NAME

- RES Energy 36
ID: 8687506
15 JUL 2025, 15:45 PM
- RES Energy 35
ID: 8687505
15 JUL 2025, 14:45 PM
- RES Energy 34
ID: 868504
15 JUL 2025, 13:45 PM
- RES Damage 21
ID: 8687503
15 JUL 2025, 13:30 PM
- RES Energy 33
ID: 8687502
15 JUL 2025, 12:45 PM
- RES Energy 32
ID: 8687501
15 JUL 2025, 11:45 AM
- RES Energy 31
ID: 8687500
15 JUL 2025, 10:45 AM
- RES Damage 20
ID: 8687499
15 JUL 2021, 10:30 AM
- RES Energy 30
ID: 8687498
15 JUL 2025, 09:45 AM
- RES Energy 29
ID: 8687497
15 JUL 2025, 18:45 AM

Search tasks...

Energy Energy 36

(ID: 8687506)

Report

FINISHED

30 sec.

RES

Submission: 2025-07-15, 15:45
Expected finish: 2025-07-15, 18:30
Runtime: 2 h 45 min

Initiated > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > Finished

Overview Period: 01.05 - 07.05.2024r.

ENERGY PRODUCTION ESTIMATION
1233 MWh 7 days ↑ +1%

CONFIDENCE
85%

EXPECTED INCOME (7 DAYS) **2000 \$**
EXPECTED INCOME (1 DAY) **190 \$**
EXPECTED INCOME (1 HOUR) **25 \$**

Energy Temperature Pressure Last 7 days

Wind Temperature Pressure

Tasks
Number of tasks: 525

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Search tasks... [icon] [icon]

Energy Energy 36

(ID: 8687506)

Report [icon]

FINISHED [icon] [icon]

30 sec. [icon]

RES Submission: 2025-07-15, 15:45
Expected finish: 2025-07-15, 18:30
Runtime: 2 h 45 min

Initiated > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > Finished [icon] Follow [toggle]

Overview Period: 01.05 - 07.05.2024r. [icon] [icon]

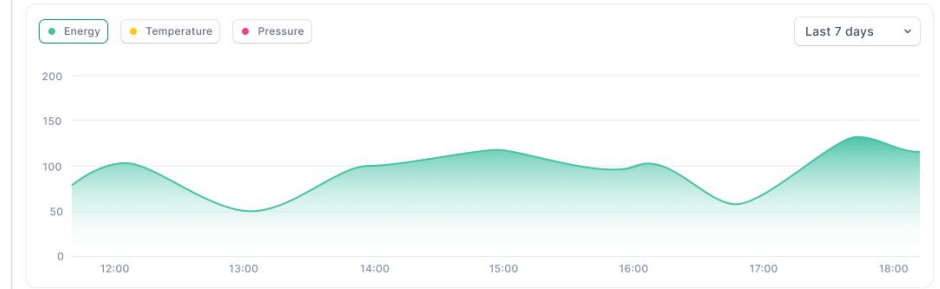
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Wind Temperature Pressure

Application (workflow) stage

Tasks

Number of tasks: 525

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Energy Energy 36 (ID: 8687506)

● FINISHED 30 sec.

Report

RES

Submission: 2025-07-15, 15:45
Expected finish: 2025-07-15, 18:30
Runtime: 2 h 45 min

Initd > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > **Finished**

Follow

Overview Period: 01.05 - 07.05.2024r.

ENERGY PRODUCTION ESTIMATION

1233 MWh

7 days ↑ +15%

CONFIDENCE

85%

EXPECTED INCOME (7 DAYS)

2000 \$

EXPECTED INCOME (1 DAY)

190 \$

EXPECTED INCOME (1 HOUR)

25 \$

Energy Temperature Pressure

Last 7 days

Wind

Temperature

Pressure

Forecasted energy production

1 2 ... 8
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41

Tasks

Number of tasks: 525

SORT BY NAME ▾

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Energy Energy 36 (ID: 8687506)

● FINISHED 30 sec.

Report

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Initd > Preprocessing > RES.WRF > RES.Eulag > RES.Analysis > **Finished**

Overview Period: 01.05 - 07.05.2024r.

ENERGY PRODUCTION ESTIMATION

1233 MWh ↑ +1% 7 days

CONFIDENCE

85%

EXPECTED INCOME (7 DAYS)

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EXPECTED INCOME (1 DAY)

190 \$

EXPECTED INCOME (1 HOUR)

25 \$

Energy Temperature Pressure Last 7 days ▾

Wind

Temperature

Pressure

Expected income

1 2 ... 8
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42

Tasks

Number of tasks: 525

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1233 MWh ↑ +1% (7 days)

CONFIDENCE

85%

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EXPECTED INCOME (1 HOUR)

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Energy ● Temperature ● Pressure

Last 7 days

Wind

Temperature

Pressure

Detailed energy production per 15 minutes

EuroHPC Joint Undertaking
www.hidalgo2.eu

Powered by QCG
About application | www.penc.pl

43

Tasks
Number of tasks: 525

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Search tasks... [icon] [icon]

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(ID: 8687506)

Report [icon]

FINISHED [icon] [icon]

30 sec. [icon]

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Overview Period: 01.05 - 07.05.2024r. [icon] [icon]

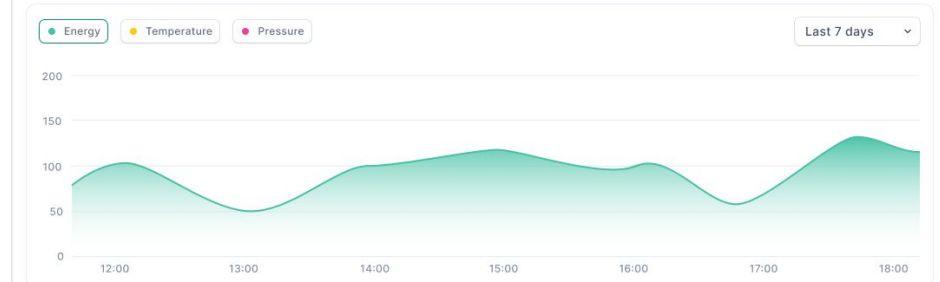
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Wind Temperature Pressure

Weather forecast

Tasks

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ENERGY PRODUCTION ESTIMATION

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CONFIDENCE

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Energy Temperature Pressure

Wind

Temperature

Pressure

Application (workflow) stage

Forecasted energy production

Expected income

Detailed energy production per 15 minutes

Weather forecast

EuroHPC
Joint Undertaking

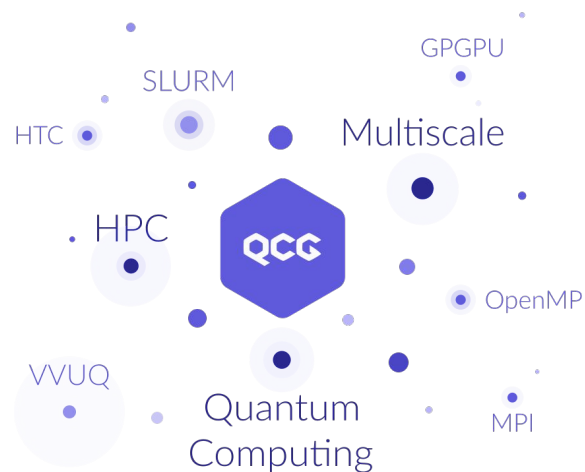
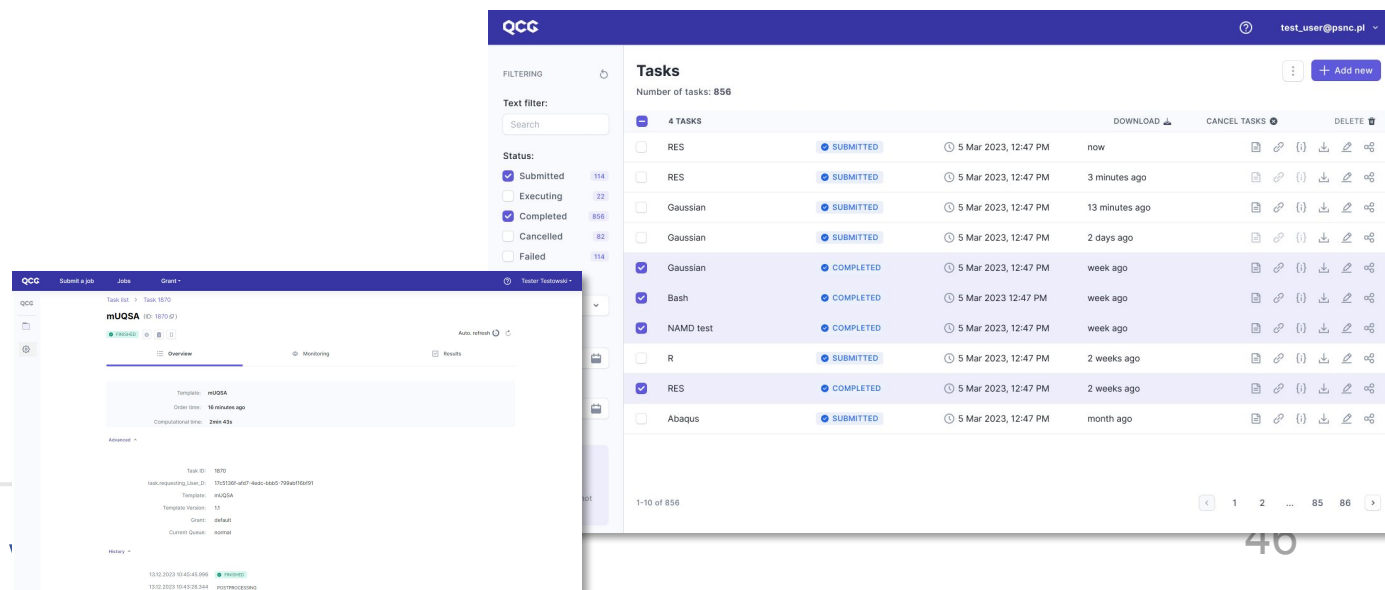
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Leveraging HPC with GUI for energy services

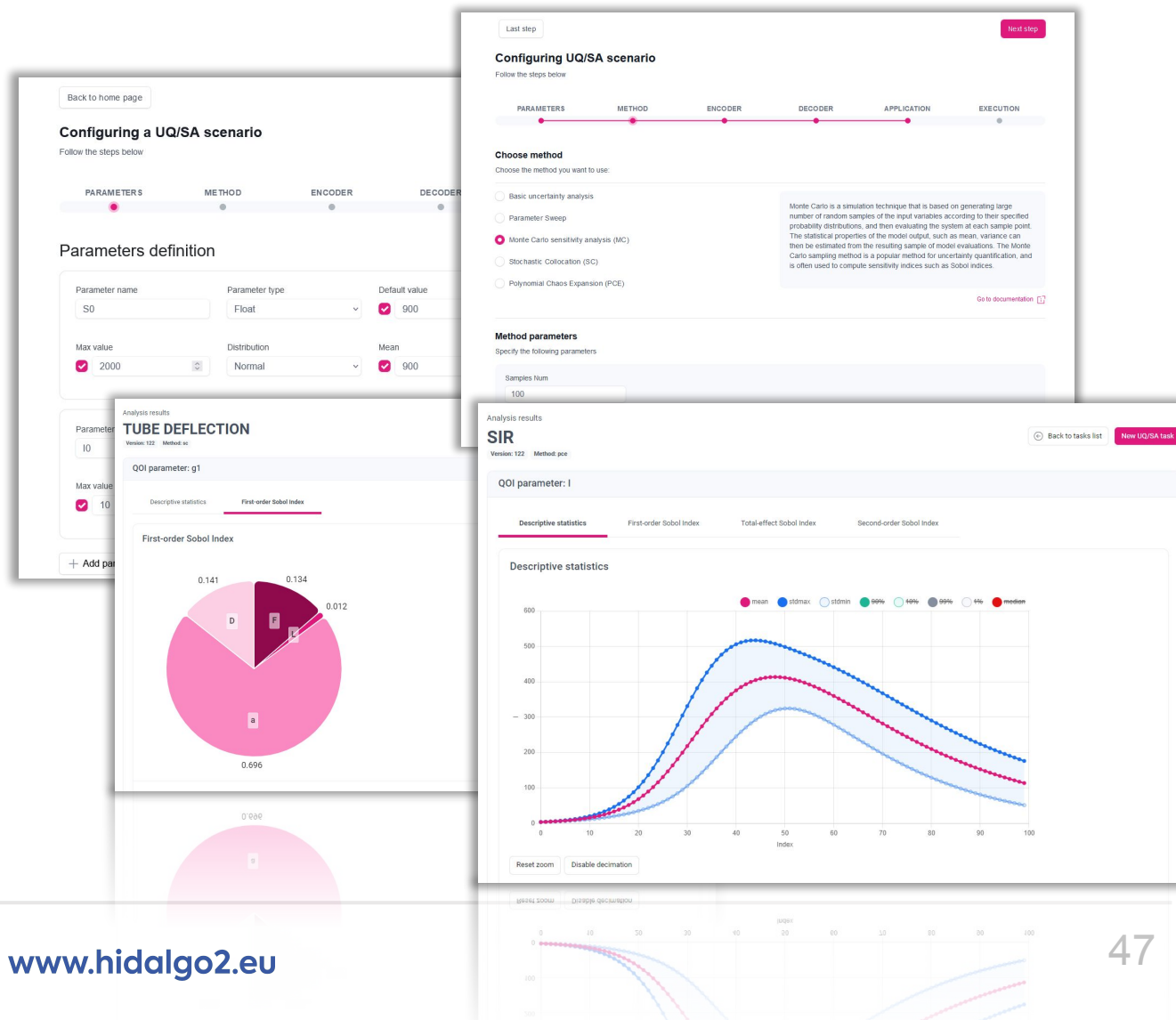
- QCG delivers a set of highly efficient services and access tools for remote application execution in large-scale computing environments, including both classical HPC and Cloud systems, and emerging Quantum Computers

- QCG-Portal is an adaptable portal for execution of various computational scenarios on remote resources.
- Graphical definition, submission, management and monitoring of tasks.
- Customisable interface
- Integrated data management and automated data stage-in & stage-out (IBIS).
- Authentication/Authorisation based on modern SSO technologies (OAuth2 / OIDC, Keycloak).

The screenshot displays the QCG web interface. The top navigation bar shows the user 'test_user@psnc.pl'. The main area is titled 'Tasks' and shows a list of 856 tasks. A filter sidebar on the left allows filtering by status: Submitted (114), Executing (22), Completed (856), Cancelled (82), and Failed (114). The task list includes columns for status, name, submission time, and age. An inset window shows the details for a task named 'mUQSA', including its ID, template, and computational time.

- mUQSA provides solution for uncertainty quantification, sensitivity analysis, and ensembles
- Supports different UQ methods: SC, PCE, MC, ...
- Integrated with QCG and QCG-Portal for seamless analysis



The screenshots illustrate the workflow in mUQSA:

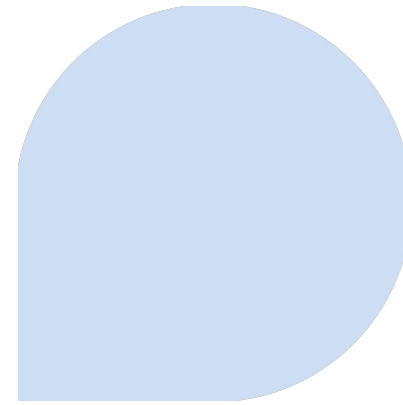
- Configuring a UQ/SA scenario:** A step-by-step interface for setting up an analysis. It includes a progress bar with steps: PARAMETERS, METHOD, ENCODER, DECODER, APPLICATION, and EXECUTION. The 'METHOD' step is currently active.
- Parameters definition:** A form for defining input parameters. For 'TUBE DEFLECTION', parameter 'S0' is defined as a Float with a default value of 900 and a maximum value of 2000. The distribution is set to Normal with a mean of 900.
- Method selection:** A screen where the user chooses a method. 'Monte Carlo sensitivity analysis (MC)' is selected. A text box explains that Monte Carlo is based on generating random samples and evaluating the system at each point to estimate statistical properties like mean and variance.
- Method parameters:** A screen to specify parameters for the chosen method. For MC, the 'Samples Num' is set to 100.
- Analysis results (TUBE DEFLECTION):** Shows the 'First-order Sobol Index' as a pie chart. The parameter 'a' is the most influential, contributing 0.696 to the variance. Other parameters 'D', 'F', and 'E' contribute 0.141, 0.134, and 0.012 respectively.
- Analysis results (SIR):** Shows 'Descriptive statistics' as a line plot. The x-axis is 'Index' (0-100) and the y-axis is the output value. The plot displays the mean (red dashed line), standard deviation (blue shaded area), and various percentiles (99%, 95%, 50%, 5%, 1%).



**Thank you for your
attention**

www.hidalgo2.eu

e-mail: office@hidalgo2.eu



Michał Kulczewski

**Poznanskie Centrum
Superkomputerowo-Sieciowe**

e-mail: michal.kulczewski@pcss.pl