LEAP-RE

Long-Term Joint EU-AU Research and Innovation Partnership on Renewable Energy

Research & Innovation Action

August 2025

OASES

Final Report

Version N°2

Authors:
Malte Lindenmeyer (Fraunhofer IEE), Maximilian Kleebauer (University of Kassel), Tobias van Reenen (CSIR), Anni Niemi (VTT), Salim Bouchakour (CDER), Sophie Mulaudzi (University of Venda)

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Disclaimer

Document information

Grant Agreement	963530
Project Title	Development and Demonstration of a Sustainable Open Access AU-EU Ecosystem for Energy System Modelling
Project Acronym	OASES
Project Coordinator	Malte Lindenmeyer Fraunhofer IEE E-Mail: malte.lindenmeyer@iee.fraunhofer.de
Project Duration	1st July 2022 – 30st June 2025 (36 Months)
Related Work Package	WP1 – WP5
Related Task(s)	Final report: All deliverables will be aggregated to a final report with supplementary sections describing the overall project success, summary and connectivity.
Lead Organisation	Fraunhofer Institute for Energy Economics and Energy System Technology (IEE)
Contributing Partner(s)	University of Kassel (Uni KS), Centre de Developpement des Energies Renouvelables (CDER), Council for Scientific an Industrial Research (CSIR), VTT Technical Research Centre of Finland (VTT), Helwan University (HU), University of Venda (UNIVEN)
Due Date	End of project duration (M36)
Submission Date	23.07.2025
Dissemination level	Public (PU)

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Table of contents

List of tables

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Abbreviations and Acronyms

Acronym	Description
ARIMA	Autoregressive Integrated Moving Average
AU-EU	African Union - European Union
CDER	Centre de Développement des Energies Renouvelables
CSIR	Council for Scientific and Industrial Research
CSV	Comma-Separated Values
EO	Earth Observation
ERA5	ECMWF Reanalysis 5
GEE	Google Earth Engine
GIS	Geographic Information System
G-PST	Global Power System Transformation Consortium
HU	Helwan University
IEE	Fraunhofer Institute for Energy Economics and Energy System Technology
IGARSS	International Geoscience and Remote Sensing Symposium
IJGI	International Journal of Geo-Information
INES	Interoperable Energy System
IRENA	International Renewable Energy Agency
MAR	Multi-Annual Roadmap
MDPI	Multidisciplinary Digital Publishing Institute
NetCDF	Network Common Data Format

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

Acronym	Description
OSM	OpenStreetMap
PV	Photovoltaic
PyPSA	Python for Power System Analysis
RES	Renewable Energy Systems
UAV	Unmanned Aerial Vehicle
Uni KS	University of Kassel
UNIVEN	University of Venda
VTT	VTT Technical Research Centre of Finland
WP	Work Package

Summary

This final report aggregates all deliverables and highlights the success of the OASES project, which developed a sustainable AU-EU open-access ecosystem for energy system modelling. Key objectives included the creation of open-source tools for renewable energy data detection, high-resolution time series generation, and the development of user-friendly modelling workflows. Through six case studies, dissemination activities, and capacity building, OASES strengthened local capabilities and fostered long-term collaboration between Africa and Europe in renewable energy planning.

Keywords

Renewable Energy, Open Access Data, Open-Source Software, Energy System Modelling, AU-EU Collaboration, Capacity Building, Wind and Solar Energy, Satellite Imagery, Machine Learning, Resource Assessment, Time Series Generation, Scenario Analysis, Smart Grids, Off-grid Systems, Energy Transition, Sustainable Energy Systems, Energy Policy Support, Data-Driven Modelling, IRENA FlexTool, WebGIS Visualization

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

1. WP1 – Project Management and Coordination

Objectives	Description
1	Ensuring that the project reaches its objectives in a given contractual time frame and budget by managing and monitoring project resources.
2	Ensuring strategic and technical coordination, quality control and risk management.
3	Generating the project reporting internally in conjunction with the LEAP-RE secretary.

Table 1: Overview of WP1 Objectives.

To ensure the success of the OASES project, a robust coordination structure was implemented. Organisational units included the Steering Committee, composed of one representative from each partner institution. This committee served as the project's central decision-making and supervisory body, responsible for overseeing strategic direction, monitoring progress, managing risks, and ensuring quality control across all WPs.

In parallel, seven Consortium Meetings were held throughout the project to support operational alignment and foster knowledge exchange. These (virtual) meetings brought together all partners to review WP progress, present interim results, plan forthcoming activities, and conduct technical and capacity-building sessions. Two of these meetings were held in person in African partner countries – Pretoria, South Africa (2023) and Algiers, Algeria (2024) – and were combined with IRENA FlexTool workshops and dissemination activities to maximise visibility and stakeholder engagement in the regions where the research is to be implemented.

The project coordinator represented OASES at the LEAP-RE Stakeholder Forums in Kigali, Rwanda (2023) and Milan, Italy (2024), contributing to strategic dialogue within the broader program context.

To ensure continuous communication and agile project management, a monthly Jour fixe was established. This recurring format enabled timely coordination, early identification of implementation challenges, and effective steering across all work packages.

This report provides an aggregated overview and description of all project deliverables. The repository of deliverables is available in the OASES Results Archive. Each deliverable referenced in the project is visually marked in the text to ensure traceability and context.

- Deliverable Repository: https://doi.org/10.5281/zenodo.15836578

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

1.1 Overall project success

The OASES project successfully demonstrated the feasibility and value of a sustainable, open-access AU-EU ecosystem for energy system modelling. Through close cooperation between four African and three European partners, the project met its core objectives:

- EO-based Renewable Energy Detection: Innovative machine learning models were developed to detect installed PV and wind systems using open satellite data, generating high-quality georeferenced open-datasets for the African continent.

- Time Series Generation: A scalable method for high-resolution wind and solar time series generation was established, enabling accurate modelling of both current installations and future scenarios.

- Energy System Modelling Workflow: The IRENA FlexTool was improved to meet local requirements and to enable energy system modelling at multiple spatial scales. A user-friendly modular, open workflow for scenario analysis was created and tested.

- Dissemination & Capacity Building: Six case studies across different regions were executed to validate the model chain. Trainings and documentation ensured that African institutions can now independently apply and adapt the framework.

The project achieved all its milestones, published its data and results under open licenses, and ensured that code and methods are accessible to third parties. It laid the foundation for long-term AU-EU collaboration and attracted attention from IRENA, G-PST, and PyPSA meets Earth initiative, enhancing its reach and potential for impact.

1.2 Summary

OASES developed a user-friendly, open-source-based modelling framework for renewable energy systems. Combining EO-based detection of PV and wind infrastructure with RES assessment and flexible scenario modelling (via IRENA FlexTool), the project delivered both tools and capacity for evidence-based energy transition planning in Africa and Europe.

The project's outcomes include:

- Machine-learning-enhanced detection of RES from EO data (*WP2*)

- Scalable tools for wind and PV time series generation (*WP3*)

- Enhanced modelling workflows based on FlexTool, adapted to African needs (*WP4*)

- A full modelling chain tested in six diverse case studies (*WP5*)

- Open-data and code releases, integrated in a dissemination and training strategy

The project aligns with multiple MAR priorities and strengthens a long-term AU-EU research and innovation partnership in renewable energy as intended by the LEAP-RE program.

Deliverable D1.1: A deliverable template was created which served as the template for most other deliverables (except repositories and data).

Deliverable D2.1: This document constitutes the final report of the OASES project. It contains all aggregated deliverables including supplementary sections describing the overall project success, summary and connectivity.

This project has received funding from the European Union’s Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

1.3 Connectivity

OASES was designed for broad and easy integration—both technically and institutionally:

- Interoperability: Tools and data formats (e.g. NetCDF, CSV) were aligned with standards and designed to be transferable to other weather and energy system models (e.g., PyPSA, SpineOpt).
- Institutional linkages: Strong ties to IRENA, the PyPSA meets Earth initiative, and G-PST ensured technical alignment and visibility. Various letters of support from stakeholders including ministries and RE associations underscore this connectivity.
- Educational integration: Documentation and tutorials are structured to support university and other curricula as well as ongoing training, enabling lasting use.
- Future integration: The modular system and workflow templates support adoption by energy planners, ministries, and other researchers, and facilitate future integration into national energy planning strategies.

2. WP2 – Earth observation-based RES detection

Objectives	Description
1	EO-Codes for RES detection: Pre-Trained model for the spatial detection of PV and wind power sites in open-source earth observation data with documentation and application examples are available and described.
2	EO based RES data base: Site information for PV and wind turbines within South Africa, Algeria and Egypt are available as open-source data.

Table 2: Overview of WP2 Objectives.

2.1 Development of an earth observation-based RES detection

As part of OASES, a comprehensive, modular workflow for the detection of renewable energy systems from earth observation data was developed. The focus was on the automated detection and precise localization of photovoltaic (PV) systems and wind turbines based on freely available remote sensing data. State-of-the-art deep learning models were trained and validated for various spatial resolutions and image sources.

A segmentation model based on DeepLabV3+ with ResNet101 backbone was developed for PV detection. This was trained on a wide range of UAV, aerial and satellite images with resolutions from 0.1 m to 3.2 m. The workflow, models and results were published completely open access:

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

- Publication: Kleebauer, M.; Marz, C.; Reudenbach, C.; Braun, M. Multi-Resolution Segmentation of Solar Photovoltaic Systems Using Deep Learning. Remote Sens. 2023, 15, 5687. https://doi.org/10.3390/rs15245687

- Model Download: Kleebauer, M., Marz, C., & Reudenbach, C. (2023). Multi-Resolution Segmentation of Solar Photovoltaic Systems Using Deep Learning - DeepLabV3 ResNet101 Model. Zenodo. https://doi.org/10.5281/zenodo.10036926

The publication documents the choice of hyperparameters, training strategy, and performance metrics in detail (F1-Score: 95.27%, IoU: 91.04%). The developed model outperforms conventional models that are trained on single-source data and shows high generalizability across image types.

For wind power detection, a model specialized in object localization was trained based on RetinaNet, which enables precise regression of turbine locations. This enabled the automatic correction of inaccurate coordinates, especially in OSM and register data. The method was documented in two papers:

- Publication: Enhancing Wind Turbine Location Accuracy: A Deep Learning-Based Object Regression Approach (IGARSS 2024, accepted). https://doi.org/10.1109/IGARSS53475.2024.10641018

- Publication and Data: A Wind Turbines Dataset for South Africa: OpenStreetMap Data, Deep Learning Based Geo-Coordinate Correction and Capacity Analysis (for publication at MDPI ISPRS IJGI). https://doi.org/10.3390/ijgi14060232

Both methods have been developed, documented and made openly accessible as part of the OASES model chain. They contribute significantly to the automated mapping of renewable energy infrastructure in data-poor regions.

2.2 Training of the RES detection on high resolution data

For PV segmentation, a multiscale training dataset was compiled from annotated images from various regions in Europe and Asia. Aerial images from Germany and France (0.1–0.2 m resolution), UAV data from China (0.1 m), and satellite imagery from the Gaofen-2 and Beijing-2 missions (0.3–0.8 m) were used. The Google Earth Engine (GEE) platform was also employed to extract additional training data at 0.1 m resolution in Western Europe. All training data were manually annotated and standardized into binary segmentation masks. The diversity of data sources and resolutions enabled the model to generalize well to different target images.

The training process was conducted in PyTorch on NVIDIA Tesla A100 GPUs, using 100 epochs with Binary Cross Entropy Loss and the Adam optimizer. The DeepLabV3+ architecture was optimized for the segmentation task with adjusted ASPP dilation rates and a consistent stride value of 2.

The wind turbine segmentation model was similarly trained using over 12.000 cropped aerial image tiles. After refining the training set to 7,000 examples, the model achieved high precision and generalization on independent validation sets, with an average classification accuracy of 96%.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

2.3 Transfer of the trained models

The trained PV and wind detection models were successfully deployed in accessible application environments, fulfilling Objective 1 of WP2: “EO-Codes for RES detection.” The pretrained models, along with their documentation and application examples, are publicly available and applicable to open-source Earth observation data.

As part of the project, the University of Venda conducted additional research on the detection of PV systems based on earth observation data. For this purpose, PV-related features were extracted, filtered and selected for specific case-study areas from open-source data. This ground-truth dataset from satellite imagery was used to train initial PV segmentation models. By upgrading to the models from WP 2.2, the team achieved improved segmentation performance, particularly in terms of boundary accuracy. Although the results were still in a pilot stage without final deployment, the experimental work laid the foundation for future EO-based PV detection approaches in South Africa.

To ensure practical usability, the final segmentation model from WP 2.2 PV was exported to ONNX format and integrated into the QGIS plugin Deepness, enabling GIS-based application without programming. In addition, the University of Kassel developed a browser-based Google Colab interface to apply the models to uploaded imagery.

- QGIS Plugin: Deepness (https://qgis-plugin-deepness.readthedocs.io/en/latest/main/main_model_zoo.html)

- Colab Demo: PV segmentation in satellite imagery (https://colab.research.google.com/drive/1UZmu83Os8tVaLIiGjlXRbJ_zexIJK5uX)

These efforts ensured that the pretrained EO models for PV and wind detection are not only technically available, but also practically usable by different stakeholders, including project partners in Africa. Thus, Objective 1 has been fully achieved.

Deliverable D2.1: EO-Codes for RES detection – pre-trained models for spatial detection of PV and wind power sites are available, documented, and accompanied by examples.

2.4 Application of the RES detection for the case studies

The developed detection models were successfully applied in regional case studies to generate open-source databases for renewable energy systems, thus fulfilling Objective 2 of WP2: "EO based RES data base." This objective called for the provision of site information for photovoltaic (PV) and wind systems in South Africa, Algeria, and Egypt.

In Algeria, the trained PV segmentation model was applied to the region of PIAT. A post-processing routine was used to calculate installed capacities based on detected surface area. The generated dataset was validated against official operator data and published as an open-access geospatial resource. The work has been accepted for presentation at IGARSS 2025, demonstrating its scientific relevance and robustness.

In South Africa, the wind detection model was applied in combination with a coordinate correction network and manual post-processing. The final dataset contains 1.493 wind turbines across 42 wind farms. All turbines were validated, and additional attributes such as turbine type, manufacturer, and estimated capacity were added. The dataset is openly available and has been submitted as part of a scientific publication to ISPRS IJGI.

This project has received funding from the European Union’s Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

Although a full application in Egypt was not realized due to access and data constraints, the developed methodologies and models are fully transferable and ready for use in the Egyptian context when imagery becomes available. As a result, comprehensive EO-based RES datasets have been created, validated, and published for two of the three targeted countries. This directly meets the requirements of Deliverable 2 and ensures the usability of Earth observation data for energy planning purposes.

Deliverable D2.2: EO-based RES database – Site information for PV (Algeria) and wind turbines (South Africa) has been compiled, validated, and made openly available. As the Egyptian partners were unable to participate in the project, no additional results were achieved for Egypt.

Pending publications and resources:

- PV in Algeria: Kleebauer et al. (2025), accepted at IGARSS
- Wind in South Africa: Kleebauer et al. (2025), submitted to ISPRS IJGI

Open Datasets:

- Kleebauer, M. (2025). PIAT Solar Photovoltaic Systems, Algeria [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15294535
- Kleebauer, M. (2025). Dataset according to "A Wind Turbines Dataset for South Africa: Open Street Map Data, Deep Learning Based Geo Coordinate Correction and Capacity Analysis. Zenodo. https://doi.org/10.5281/zenodo.15221465

Interactive Maps:

- PV systems in PIAT, Algeria: https://www.google.com/maps/d/edit?mid=1mJtANHKUGB81otvNTuTCEah_QbvybtU&usp=sharing
- Interactive map: Wind turbines in South Africa: https://www.google.com/maps/d/edit?mid=1q9Dg6tvfvpRqEQAneWj732UkFmAfIjQ&usp=sharing

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

3. WP3 – RES potential analysis

Objectives	Description
1	Creating an overview of the relevant meteorological reanalysis data and methods to produce wind and solar resource data sets with a temporal resolution of 1-hour and an appropriate spatial resolution (e.g. 1km x 1km).
2	Developing a generalized model for wind and PV time series data set generation with focus on future energy scenarios.
3	Generation of time series for relevant energy scenarios within the African Partner countries.

Table 3: Overview of WP3 Deliverables.

3.1 Survey of existing data sets and methods

The work completed for WP3 focused on developing high-resolution time series data for renewable energy resources, specifically wind and solar. Efforts in work package 3.1 included identifying relevant datasets, software, and methodologies, with an emphasis on processes for statistical downscaling to overcome computational limitations. The scope of the work involved assessing available global and local datasets, exploring methodologies for time series generation, such as forecasting and energy system modelling techniques, and utilizing statistical clustering and downscaling methods to refine coarse data for finer spatial resolutions. Additionally, workflows were developed to integrate renewable energy system analysis into regional case studies. Atlite was used as the software of choice for time series generation, leveraging datasets like ERA5 and Sarah-2.

The work included surveys of various global datasets, such as NASA's POWER dataset, the Global Solar Atlas, and the Global Wind Atlas, along with local datasets like the Solar Atlas of Egypt and the Wind Atlas of South Africa. Research into methodologies for time series generation explored forecasting techniques, such as ARIMA, and clustering methods like k-means. ERA5 was identified as a reliable global dataset, providing high-resolution reanalysis data for weather variables, while Sarah-2 offered solar radiation data ideal for PV energy yield calculations.

Deliverable 3.1: A report was published on the currently available datasets for wind and solar resources, as well as on software, methodologies, and techniques for wind power and PV time series generation. The report aims to provide a comprehensive overview of the resources and tools available for renewable energy system modelling and initial workflows for time series generation were prepared using open-source tools, ensuring adaptability for user-supplied downscaled datasets.

Publication and resources:

- Grobler, J.-H., Malatji, D., Karamanski, S., & Wessels, G. (2025). OASES WP3: Literature & Data Report. Zenodo. https://doi.org/10.5281/zenodo.15372696

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

3.2 Generation of high-resolution meteorological time series

The work completed under Work Package 3.2 primarily focused on generating high-resolution time series data for renewable energy resources, specifically wind and solar power. The methodology involved downloading meteorological datasets, refining the data through statistical downscaling, and employing advanced interpolation techniques like bilinear interpolation and kriging to achieve finer spatial resolutions. Atlite software was utilised as the primary tool for time series generation, leveraging datasets such as ERA5 and Sarah-2. This approach enabled the creation of time series data with a spatial resolution of 1 km x 1 km and a temporal resolution of 1 hour, which is suitable for power generation scenarios. The work culminated in the refinement and validation of downscaled datasets and their integration into energy system models outlined in WP4.

Deliverable 3.2: A report was published on the resources and tools available for renewable energy system modelling. The report includes workflows for a general model for meteorological time series generation, prepared using open-source tools, ensuring adaptability for user-supplied downscaled datasets.

Publication and resources:

- Wessels, G., Botha, N., Karamanski, S., Malatji, D., & Coleman, T. (2025). OASES WP 3.2 RES Potential Analysis. Zenodo. https://doi.org/10.5281/zenodo.15372732

3.3 Distribution of wind and PV plants

The spatial distribution of future wind and PV plants was determined through a structured three-step process. First, a high-resolution GIS-based potential analysis was conducted. This included applying exclusion criteria such as nature conservation areas, residential zones, water bodies, and buffer zones. Additional land constraints – such as projected urban or agricultural expansion and unsuitable soil types (e.g. highly sandy soils) – were also considered to refine the technically available areas.

In the second step, the identified potential areas were evaluated and prioritised in close consultation with partners from the involved countries – Algeria, Egypt, and South Africa. This process included the definition of relevant evaluation criteria, the classification of these into quality intervals, and the assignment of weighting factors to reflect their relative importance. A composite suitability score was then calculated for each location by aggregating the weighted criteria. This multi-criteria assessment enabled the identification of areas most suitable for renewable energy development, taking into account not only resource availability but also broader spatial planning and socio-environmental factors.

Finally, in the third step, wind and PV installations were allocated to the highest-ranking areas. National renewable energy targets and political ambitions were derived from national strategies in each focus country. These targets were then spatially distributed using the Fraunhofer IEE renewable placing module, which iteratively places power plants in the most suitable locations until the specified capacity targets are met.

The outcome provides a scenario-based projection of how wind and solar capacities might be geographically distributed over the coming years.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

3.4 Generation of wind power and PV time series

Within WP3.2 the report published includes workflows for a general model for power time series generation, prepared using the meteorological timeseries previously prepared, ensuring adaptability for user-supplied downscaled datasets.

The report outlines the use of key meteorological variables such as wind speed, solar irradiance, and temperature to facilitate detailed energy generation modelling. Atlite is an open-source Python software package designed for retrieving global historical weather data and converting it into power generation potentials and time series for renewable energy technologies like wind turbines and solar photovoltaic panels. forms the cornerstone of this methodology, enabling the transformation of raw meteorological data into specific power generation profiles.

The methodology also included capacity factor calculations to assess energy production potential and the creation of hourly power generation profiles, adhering to defined spatial and temporal resolutions. This approach was rigorously refined and validated, ensuring adaptability across diverse scenarios and providing a solid foundation for integrating these power time series into broader energy system modelling frameworks.

Publication and resources:

- Wessels, G., Botha, N., Karamanski, S., Malatji, D., Coleman, T., & Boodhraj, K. (2025). Potential Analysis. Zenodo. https://doi.org/10.5281/zenodo.15372631

3.5 Preparation of time series for the case studies

Deliverable 3.3: Wind and solar power time series data was generated and prepared for relevant case studies within partner countries, regional and continental.

Publication:

- Botha, N.; Coleman, T.; Wessels, G.; Kleebauer, M.; Karamanski, S. Power Generation Time Series for Solar Energy Generation: Modelling with Atlite in South Africa. Solar 2025, 5, 8. https://doi.org/10.3390/solar5010008

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

4. WP4 – Energy System Modelling for different spatial scales

Objectives	Description
1	Introduce IRENA FlexTool and its modelling methodology to new partners.
2	Build the modelling workflows for the different spatial scales (including new data sources from WP3).
3	Further improvement of IRENA FlexTool according to the requirements of local conditions in African and European countries.

Table 4: Overview of WP4 Deliverables.

4.1 Documentation and workflow

Task 4.1 focused on creating reusable and well-documented modelling workflows to support energy system scenario analysis at different spatial scales: local, national, regional, and continental. These workflows are based on the IRENA FlexTool, a modelling framework optimised during the project to suit both African partner countries and third-party users. Objective 1 was achieved by successfully introducing IRENA FlexTool and its modelling methodology to all project partners and local stakeholders through IRENA FlexTool workshops online, in person in South Africa in 2023 and in Algeria in 2024, monthly IRENA FlexTool support calls and collaboratively building case studies with local partners. A result of the successful introduction of IRENA FlexTool to new users is how partners previously unfamiliar with IRENA FlexTool are now able to understand, adapt, and apply the tool within their contexts, including new case studies beyond the project tasks.

The task's Objective 2 was successfully achieved by delivering a comprehensive, modular modelling workflow including a tool to integrate wind and PV time series data from WP3 to IRENA FlexTool.

Deliverable 4.1: The modelling workflows for different spatial scales are openly available and ready to be used for modelling purposes.

GitHub IRENA FlexTool code repository:

- https://github.com/irena-flextool/flextool

For integration of the wind and PV timeseries, all code repositories can be found on GitHub. The main repository is under VTT's repository as it is used for integration into FlexTool:

- https://github.com/vttresearch/OASES_wind_power_data.git

The following two repositories are embedded into the main repository but contain the modules needed for the capacity factor generation and for the capacity factor tiers generation respectively:

- https://doi.org/10.5281/zenodo.15363899
- https://doi.org/10.5281/zenodo.15363917

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

The FlexTool-based workflow proved flexible and scalable, successfully supporting local models (e.g., solar pumping in rural Egypt), national models (e.g., coal transition planning in South Africa), and even continent-wide models (e.g., fully renewable Africa using PyPSA-Earth data). Six case studies for different spatial scales are openly published via Zenodo, each including a spreadsheet documentation, IRENA FlexTool model and a report. Detailed instructions are provided on how to run the models with IRENA FlexTool 3, ensuring accessibility for future users beyond the immediate project team. The workflows serve as a foundation for current and future modelling activities in Africa and Europe, supporting informed decision-making and broader capacity building. More detailed descriptions of the case studies are provided in 5.5, the links for the models on Zenodo are:

Documentation and workflow for case studies:

- Egypt (local): Putkonen, N. (2024). Model and dataset for combined irrigation and electricity operation of a solar water pump in Egypt for IRENA FlexTool 3 (OASES project case study) (v. 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.13318686

- Algeria (local): Niemi, A. (2025). Model and dataset for isolated PIAT grid in Algeria for IRENA FlexTool 3 (OASES project case study) (v 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15275481

- Egypt (national): N. (2024). Model and dataset for national electricity system of Egypt 2018 for IRENA FlexTool 3 (OASES project case study) (v. 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.13304369

- South Africa (national): Niemi, A. (2025). Model and dataset for national electricity system of South Africa for IRENA FlexTool 3 (OASES project case study) (v. 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15222894

- Northern Africa (regional): Niemi, A. (2025). Model and dataset for regional electricity system of Northern Africa and Europe for IRENA FlexTool 3 (OASES project case study) (v. 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15341304

- Africa (continental): Tupala, A. (2025). Model and dataset for continental energy system case study in Africa for IRENA FlexTool 3 (OASES project case study) (v.3.9.0). Zenodo. https://doi.org/10.5281/zenodo.14843471

4.2 Development of the modelling tools

Task 4.2 aimed at ensuring that the IRENA FlexTool is capable of addressing the diverse local conditions present across African partner countries. The goal was to identify and implement improvements to both the core tool and supporting data-processing utilities, guided by the modelling requirements of different contexts. The task successfully delivered numerous improvements to the IRENA FlexTool, leading to a significantly more accessible and powerful modelling environment and achievement of Objective 3.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

Key improvements included:

- Mixed-integer optimisation capabilities, allowing complex investment decisions.
- Pathway investment modelling: Users can now model multi-period investment scenarios, supporting longer-term planning horizons.
- Solve-time enhancements to improve the performance of large-scale models.
- Improvements in user documentation, time settings as ready database and new ”how-to” sections.
- Enhanced error messages and parameter validation.
- Pre-set default values for common parameters (e.g., penalties, efficiencies).
- Loss-of-load allocation between nodes.
- Stochastic capabilities were introduced to support uncertainty modelling.
- More user-friendly entity structure.
- A fully updated and comprehensively documented version of the IRENA FlexTool, including ready-to-use template datasets and a detailed tutorial, was released: https://irenaflextool.github.io/flextool/
- Training materials and tutorials were published online and revised based on feedback from consortium partners and stakeholders.
- Improving the usability by fixing issues based on user feedback.

Deliverable 4.2: A detailed documentation of new features in IRENA FlexTool can be found in the corresponding document in the deliverable repository and is published as part of the existing training material.

4.3 Comparing modelling results with established models

Task 4.3 was originally designed to improve the credibility and flexibility of energy system modelling in the project by developing a data conversion tool that would transfer input data from IRENA FlexTool workflows into formats compatible with more complex models such as PyPSA, SpineOpt, or Backbone. This would allow for cross-model verification and the possibility to expand analysis using tools that offer greater modelling granularity.

During the course of the project, based on stakeholder feedback and practical engagement with partners, it became clear that a more valuable and impactful approach would be to develop conversion tools in the reverse direction; from more complex models (e.g., PyPSA and OSeMOSYS) into the IRENA FlexTool format. This shift was based on two key observations:

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

1. Many stakeholders, especially those newer to modelling, found widely used tools like PyPSA or OSeMOSYS challenging to use and interpret.

2. IRENA FlexTool's simpler structure and user-friendly interface makes it ideal for broader dissemination and for training purposes among partners and less-experienced users.

By enabling data and model conversion from complex systems into FlexTool, we provided a valuable bridge: users could leverage existing detailed models, but engage with them through a more accessible, transparent, and easy-to-use platform. This approach better served the project's objectives of capacity building, accessibility, and rapid deployment of modelling capability. Based on a joint decision of the consortium, this task was reversed, and conversion tools were developed. The conversions were done though INES (Interoperable Energy System) specification. It is a standardized data format for energy system modelling. This allows not only the conversions to IRENA FlexTool from tools used in this project, but any tool that has a conversion to the INES specification. These currently include OSeMOSYS and Backbone. The conversions made here included:

- INES to IRENA FlexTool conversion tool

- PyPSA to INES conversion tool

The conversion process was published, demonstrating how high-complexity datasets can be mapped into IRENA FlexTool's simplified structure without losing essential scenario information.

Deliverable 4.3: Conversion tools to convert input data from two other energy system models to IRENA FlexTool. The tools can be found under INES Github.

INES GitHub: INES database to FlexTool conversion tool:

- https://github.com/ines-tools/ines-flextool

INES GitHub: PyPSA to INES conversion tool:

- https://github.com/ines-tools/ines-pypsa

While Task 4.3 diverged from its original plan, the revised approach better aligns with the project's overarching goals of accessibility, stakeholder engagement, and practical usability. By enabling downward conversion from complex models into IRENA FlexTool, the project results empower users to engage with robust datasets and scenarios in a simplified environment.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

5. WP5 – Dissemination, Demonstration and Capacity Building

Objectives	Description
1	Coordination of all dissemination activities.
2	Development and implementation of a sustainable open source and data strategy.
3	Implementation of capacity building actions based on 6 example case studies.
4	Development of strategies for long-term AU-EU collaborations in energy system modelling.

Table 5: Overview of WP5 Deliverables.

5.1 Dissemination activities

The communication and dissemination strategy of the OASES project was designed to ensure both visibility and long-term accessibility of its results across scientific, policy, and practitioner communities. A central element of this strategy was the maintenance of a dedicated project website, hosted by Fraunhofer IEE, which was regularly updated with news, publications, open-source tools, and key project milestones.

In addition, OASES actively contributed to the LEAP-RE programme newsletter, providing periodic updates on progress, outcomes, and upcoming events to the wider community. Stakeholder involvement was another important pillar of the dissemination effort. All consortium partners contributed to the creation of a shared stakeholder list, which was updated on an annual basis. Stakeholders received yearly information E-Mails highlighting the latest project developments and, upon project completion, a final update with access to results and links to the deliverable archive.

Beyond digital communication, the project engaged in direct scientific dissemination through participation in several international conferences and symposia, including IGARSS and other domain-specific events. Multiple peer-reviewed publications were produced as part of the project, further enhancing its scientific value.

Finally, the project was represented at the LEAP-RE Stakeholder Forums held in Kigali, Rwanda (2023) and Milan, Italy (2024). These forums provided valuable opportunities to present results, engage with policy actors, and connect with other AU-EU researchers.

Main website hosted by IEE:

- https://www.iee.fraunhofer.de/en/research_projects/search/2022/oases.html

Deliverable 5.3: This section outlines all dissemination activities undertaken throughout the OASES project. In addition, a comprehensive communication and dissemination strategy was developed and is included in the full deliverable repository.

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

5.2 Open-source data and software dissemination

A key objective of the OASES project was to develop and implement a sustainable open-source and open-data strategy that ensures that all project results are transparent, accessible and usable in the long term. This strategy encompasses all three main areas of the project: the detection of renewable energy systems (RES), the generation of high-resolution time series and the energy system modelling. A consistent approach for the publication of data, models and software components has been developed that complies with both the FAIR principles (Findable, Accessible, Interoperable, Reusable) and the requirements of the LEAP-RE initiative. The OASES consortium relies on established open science platforms for the structured dissemination of project results:

- GitHub: Is used as a central platform for publishing and maintaining source codes, workflows and application scripts. The repositories contain reproducible workflows for the automatic detection of wind and PV systems in satellite images, the creation of meteorologically based feed-in time series and the integration of this data into energy modelling tools. Open licenses and structured documentation promote reuse by third parties.

- Zenodo: Serves as an archiving platform for stable and citable versions of data sets, models, publications and reports. The connection to the LEAP-RE community on Zenodo enables a thematic embedding of the project content in a larger research context within the African-European energy cooperation. All key results - such as training data, derived time series, published modelling scenarios and the final open-source strategy report - are permanently accessible there.

- LEAP-RE: The LEAP-RE online platform and the newsletter are regularly used to provide information on project progress, disseminate findings and reach targeted stakeholders in the African-European region. Involvement in the LEAP-RE Stakeholder Forum and regular contributions at scientific conferences strengthen the visibility and networking of the project.

- Websites: Websites of the project partners such as Fraunhofer IEE, University of Kassel and VTT also offer dedicated information pages that link to central content, present relevant publications and simplify access to open-source resources.

Deliverable 5.1: Development and implementation of a sustainable open-source and data strategy. This deliverable was fulfilled through the creation of a comprehensive strategy report that describes in detail the central principles, platforms used and concrete implementation measures for the use of open source and open data in the OASES project. The report forms the basis for sustainable reuse of the project results by the scientific community, political decision-makers and industrial users and is openly accessible.

Open-Source and Data Strategy Report:

- Kleebauer, M., Niemi, A., Putkonen, N., Kiviluoma, J., Boodhraj, K., van Reenen, T., Lindenmeyer, M., Dobschinski, J., & Braun, M. (2024). OASES: Open-Source and Data Strategy Report. Zenodo. https://doi.org/10.5281/zenodo.13365309

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

5.3 Capacity building

The capacity-building initiatives within the African-European cooperation aim to enhance the skills and empower stakeholders from diverse sectors, including scientific communities, policymakers, and industrial users. The capacity-building initiatives have enhanced skills across various sectors.

Deliverable 5.1 (Section 5.2) presents a foundational strategy report outlining the principles and measures for integrating open-source code and open data into the OASES dissemination framework. This approach supports sustainable capacity building, best practices, and long-term growth in the renewable energy sector.

In addition, the project team organized targeted workshops and training sessions for key stakeholders, fostering direct and impactful engagement. One such event was the IRENA FlexTool and energy modelling workshop held in Algiers in November 2024. According to post-event feedback from 15 participants, the average satisfaction rating was 4.3 out of 5. Notably, 7 respondents indicated they were 'not at all familiar' with energy modelling prior to the workshop, yet all participants reported that the session was insightful and that they felt confident applying the IRENA FlexTool in their own work thereafter. We regard this as a clear indicator of the effectiveness of our capacity-building efforts.

By promoting innovative practices, offering accessible resources, and fostering inclusive partnerships, these activities have upheld the principles of sustainability and inclusivity within the African-European partnership.

5.4 Stakeholder’s involvement

Stakeholder engagement played a central role in the OASES dissemination and capacity-building strategy. To support this, a stakeholder E-Mail list was systematically compiled by all partner institutions. This mailing list was used to distribute annual updates on the project’s progress and to invite stakeholders to key events and training opportunities.

Dedicated stakeholder workshops were organised in conjunction with the in-person consortium meetings held in Pretoria, South Africa (2023) and Algiers, Algeria (2024). These workshops focused on hands-on training for the IRENA FlexTool and enabled direct interaction with representatives from government agencies, research institutions, and the renewable energy sector in the respective regions.

In addition, OASES was represented at the LEAP-RE Stakeholder Forums in Kigali, Rwanda (2023) and Milan, Italy (2024), further strengthening ties with broader AU-EU research and policy communities.

While stakeholder engagement was successful in the regions represented by active partners, additional activities were initially planned for Egypt and other regions. However, due to early-stage financial challenges, the Egyptian partner responsible for WP5 was unable to continue in the consortium, which limited engagement in that regard.

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Program under Grant Agreement 963530.

5.5 Example case studies

Task 5.5 demonstrated the application of the framework developed, particularly IRENA FlexTool, to facilitate energy system optimization across diverse scenarios and regions. This tool proved instrumental in representing scenarios of energy systems by incorporating multiple energy balance nodes, enabling precise analysis of energy sources and storage capacities, making it suitable for both simple and complex modelling environments. The activities under this work package included models and datasets such as optimising solar pump operations with small battery storage and comprehensive component sizing for renewable energy systems, including solar panels, batteries, and transmission lines. The importance of the tools lies in its ability to assess and visualise the integration of renewable technologies like solar and wind energy into existing grids, highlighting reductions in fossil fuel dependency, lower system costs, and improved sustainability.

VTT lead the case study work by building the first versions of models. Case studies were then demonstrated to local partners from Algeria, South Africa and Egypt who helped to gather the local data, shape the model scope and analyse the results. The case studies were also demonstrated to third parties in IRENA FlexTool trainings in South Africa in 2023 and Algeria in 2024. The final versions of the case studies are available open-source and are free to be developed further. By building open, adaptable models and training local users in several workshops, the project aims to leave a lasting impact on Africa's energy modelling capabilities.

<u>Overview of the six case studies</u>:

- <u>Egypt (local)</u>: This case study explores the feasibility of integrating a locally developed solar-powered water pump into a village electricity network. It tested combined electricity and water system optimisation in IRENA FlexTool, showing that under current cost assumptions, grid electricity remains more economical than new solar investments in most scenarios. Still, the study successfully demonstrated multi-vector modelling within FlexTool and provides a valuable proof-of-concept for rural energy-water solutions.
  Putkonen, N. (2024). Model and dataset for combined irrigation and electricity operation of a solar water pump in Egypt for IRENA FlexTool 3 (OASES project case study) (IRENA Flextool 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.13318686

- <u>Algeria (local)</u>: In Algeria's southern PIAT network in the Sahara Desert, modelling revealed that wind power may outperform solar PV, even in desert conditions, due to its more stable output profile. This finding held across several cost scenarios, suggesting wind's underestimated potential in arid regions. However, the study also highlights the technical risks posed by desert environments, such as dust and heat impacts on turbine performance.
  Niemi, A. (2025). Model and dataset for isolated PIAT grid in Algeria for IRENA FlexTool 3 (OASES project case study) (Version IRENA Flextool 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15275481

- <u>South Africa (national)</u>: The South African national simplified one-node-model tested strategies for reducing persistent electricity shortages. Results show that additional investments in renewables beyond current 2030 plans are necessary to eliminate load shedding. Even modest solar and wind additions significantly reduce coal dependency and improve system adequacy under different coal decommissioning scenarios.
  Niemi, A. (2025). Model and dataset for national electricity system of South Africa for IRENA FlexTool 3 (OASES project case study) (Version IRENA Flextool 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15222894

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

- Egypt (national): This study assessed how much additional PV could be integrated into southern Egypt's grid without triggering reliability issues. While the existing system can accommodate moderate renewable additions, it is already operating near its limits. The model supports national plans for grid reinforcement and demonstrates IRENA FlexTool's capability to simulate complex, multi-node systems at national scale.
  Putkonen, N. (2024). Model and dataset for national electricity system of Egypt 2018 for IRENA FlexTool 3 (OASES project case study) (IRENA Flextool 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.13304369

- North Africa (regional): This study modelled cross-Mediterranean power trade, focusing on Algeria, Tunisia, Morocco, and Southern Europe. Wind emerged as the dominant energy source due to its temporal alignment with demand. The study shows that significant electricity exports from the Maghreb region to Europe are possible, if in addition to new PV and wind plants interconnection infrastructure is substantially expanded. Otherwise, export potential remains minimal. The model included connections between Tunisia and Italy, Algeria and Spain and increasing the net transfer capacity of the connection between Morocco and Spain.
  Niemi, A. (2025). Model and dataset for regional electricity system of Northern Africa and Europe for IRENA FlexTool 3 (OASES project case study) (Version IRENA Flextool 3.3.1). Zenodo. https://doi.org/10.5281/zenodo.15341304

- Africa (continental): A continent-scale model was built by transforming the PyPSA-Earth model successfully to IRENA FlexTool model to study how the continent's electricity system would look like, if the increase in demand until 2030 was satisfied using only renewable investments. The study validates the feasibility of large-scale model transformation and highlights solar energy's role as the primary supply option. It also illustrates how strong transmission networks reduce the need for costly local diversification or storage. Model works as a proof of concept and provides a great opportunity to develop and explore it further.
  Tupala, A. (2025). Model and dataset for continental energy system case study in Africa for IRENA FlexTool 3 (OASES project case study) (IRENA Flextool 3.9.0). Zenodo. https://doi.org/10.5281/zenodo.14843471

Within the case studies presented, the work underscored the necessity for grid reinforcement in areas with significant solar potential, aligning infrastructure capabilities with renewable energy ambitions.

Deliverable 5.2: All these case studies, including their backgrounds, datasets and references used, model structures, assumptions and results analysis can be found in detail in the case study report which is part of the deliverable repository.

5.6 Visualization of the project results

The visualization of project results plays an important role in supporting the interpretation and improving the impact of research results on the stakeholders. Originally, an extension of a comprehensive WebGIS platform for the integration of OASES results was planned, but this could not be realized within the project timeframe. One reason for this was that many important data sets and modelling results only became available in the last two months of the project, so a stronger focus had to be placed on completing the deliverables.

Nevertheless, many results were implemented and visualized in the various project components to ensure that the most important outcome are accessible and interpretable:

- Zenodo: Serves as main platform for sharing scientific datasets, models and maps. Many of these are complemented by visual materials and documentation that allow users to effectively explore and reuse the results.

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

- GitHub repositories**:** Contain annotated example notebooks and graphical outputs that illustrate how the developed detection and modelling workflows work.
- Case studies: These are published as open access packages include diagrams and result visualizations for local, national and continental case studies.
- Fraunhofer IEE website: Selected results and illustrative figures are presented on the Fraunhofer IEE website. The websites of other partners as well as the LEAP-RE platform complement the information.
- Dissemination events: The LEAP-RE Stakeholder Forum, scientific conferences and modelling workshops included presentations with visual elements that supported both technical discus sions and broader stakeholder engagement.

Overall, while integration into a unified WebGIS platform has not been implemented, the project ensured that visual content is available across multiple platforms and use cases. This decentralized but targeted visualization strategy supported the continued engagement and use of OASES results with data and methodologies appearing in the African-European energy community and beyond.

5.7 Long-term partnership

The OASES project has laid the foundation for a strong and lasting collaboration among its African and European partners. Throughout the project duration, excellent collegial relations developed, supported by regular exchange, joint capacity-building activities, and in-person meetings. The partner institutions plan to conduct additional mutual visits, further deepening trust and cross-institutional understanding.

The OASES partnership already extended beyond the scope of the project: the consortium has jointly applied for follow-up projects, including within the context of the LEAP-SE initiative and other AU-EU funding programmes. These proposals build upon the open science principles, shared tools, and transcontinental research focus.

In addition, the consortium has produced several collaborative scientific publications, including peer-reviewed journal articles and conference papers. Some have already been published (e.g. in *Remote Sensing*), while others are currently under review (e.g. for *ISPRS IJGI* and *IGARSS 2025*). These joint outputs reflect the high level of scientific integration achieved during the project and underline the partners' commitment to continuing their joint research efforts.

The use of open-source tools, shared datasets, and transparent workflows has fostered a collaborative culture that will outlive the formal project duration. With strong interpersonal relationships and a technically interoperable framework in place, the OASES consortium is well-positioned to contribute to future regional and international initiatives in the field of renewable energy and in particular energy system modelling.

This project has received funding from the European Union's Horizon 2020
Research and Innovation Program under Grant Agreement 963530.

Conclusion

The OASES project has delivered a robust, open-access modelling framework for renewable energy systems, grounded in strong scientific cooperation and practical capacity building. By combining technical innovation, stakeholder engagement, and a commitment to open science, the consortium has built both tools and trust across continents.

Beyond its technical achievements, OASES fostered a resilient network of institutions and individuals dedicated to shaping a common, sustainable energy future in Africa and Europe. With shared methodologies, strategic goals, and ongoing collaborations already underway, the project has laid a solid foundation for continued joint action and long-term impact.

Bibliography

Botha, N., Coleman, T., Wessels, G., Kleebauer, M., & Karamanski, S. (2025). Power generation time series for solar energy generation: Modelling with Atlite in South Africa. *Solar, 5*(1), 8. https://doi.org/10.3390/solar5010008

Bending, R., & Eden, R. J. (1984). *UK Energy: Structure, Prospects, and Policies*. Cambridge, UK: Cambridge University Press.

Grobler, J.-H., Malatji, D., Karamanski, S., & Wessels, G. (2025). *OASES WP3: Literature & Data Report*. Zenodo. https://doi.org/10.5281/zenodo.15372696

Huberman, N., & Pearlmutter, D. (2008). A life-cycle energy analysis of building materials in the Negev desert. *Energy and Buildings, 40*(5), 837–848. https://doi.org/10.1016/j.enbuild.2007.06.002

Kleebauer, M. (2025). *A wind turbines dataset for South Africa* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15221465

Kleebauer, M. (2025). *PIAT Solar Photovoltaic Systems, Algeria* [Data set]. Zenodo. https://doi.org/10.5281/zenodo.15294535

Kleebauer, M.; Braun, A.; Horst D.; Pape, C. (2025). Enhancing Wind Turbine Location Accuracy: A Deep Learning-Based Object Regression Approach for Validating Wind Turbine Geo-Coordinates. IGARSS 2024, Athens, Greece. https://doi.org/10.1109/IGARSS53475.2024.10641018

Kleebauer, M.; Karamanski, S.; Callies, D.; Braun, M. (2025). A Wind Turbines Dataset for South Africa: OpenStreetMap Data, Deep Learning Based Geo-Coordinate Correction and Capacity Analysis. ISPRS Int. J. Geo-Inf. 2025, 14, 232. https://doi.org/10.3390/ijgi14060232

Kleebauer, M., Marz, C., Reudenbach, C. & Braun, M. (2023). Multi-resolution segmentation of solar photovoltaic systems using deep learning. *Remote Sensing, 15*(5687). https://doi.org/10.3390/rs15245687

Kleebauer, M., Marz, C., & Reudenbach, C. (2023). *Multi-Resolution Segmentation of Solar Photovoltaic Systems Using Deep Learning – DeepLabV3 ResNet101 Model* [Model]. Zenodo. https://doi.org/10.5281/zenodo.10036926

Kleebauer, M., Niemi, A., Putkonen, N., Kiviluoma, J., Boodhraj, K., van Reenen, T., Lindenmeyer, M., Dobschinski, J., & Braun, M. (2024). *OASES: Open-Source and Data Strategy Report*. Zenodo. https://doi.org/10.5281/zenodo.13365309

Wessels, G., Botha, N., Karamanski, S., Malatji, D., & Coleman, T. (2025). *OASES WP 3.2 RES Potential Analysis*. Zenodo. https://doi.org/10.5281/zenodo.15372732

This project has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.