Final report

1. Project details

Project title	Global Atlas of Siting Parameters (GASP)
File no.	EUDP 64018-0095
Name of the funding scheme	EUDP
Project managing company / institution	DTU Wind Energy
CVR number (central business register)	30 06 09 46
Project partners	EMD
Submission date	06 April 2022

2. Summary

Describe the objectives of the project, the obtained results and how they will be utilized in the future.

The short description should be in two versions:

- *English version*
- *Danish version*

Each version should be brief, no more than 2000 characters (including spaces).

English version:

The GASP (Global Atlas for Siting Parameters) project aimed at bringing down the Levelized Cost of Energy by reducing uncertainty and providing quality data for turbine siting parameters. This would ensure that the turbines' structural integrity is suitable for the environmental conditions, reducing cost by avoiding over-classification of turbines.

We obtained results as planned, including the global datasets of the 50-year wind, turbulence, recommended wind turbine classes and uncertainty classification at a spatial resolution of 250 m, at elevation of 50 m, 100 m and 150 m. The data have been made available through both technical and commercial platforms. Methodologies behind the calculations of the siting parameters are transparent and they are documented in technical reports, shared on these platforms.

The outcome of GASP can be used by wind turbine manufacturers and wind turbine and farm developers through both DTU's (WAsP Engineering) and EMD's software (windPROSPECTING.com and windPRO). The

commercial potential can be realized through the pipeline of GASP to market where GASP can help the manufacturers into a stronger position, and make wind energy more efficient for society, by determining size of potential markets for different class turbines in different geographic locations when addressing the following questions: Is there enough market for a re-design for a new place? How many sites are suitable for a particular existing turbine design? Are the production sites properly distributed?

At the same time, GASP will provide access to the developed datasets through web-based geographic information system (GIS) tools that will allow viewing, downloading and analyzing the datasets via multiple portals hosted by DTU and EMD. Part of the data and service are open, however, to enhance commercial impact, some of the data will be introduced to existing and potential users of WAsP, WEng and WindPro for more detailed, site-specific calculations of turbine design and selection.

Dansk:

GASP projektets målsætning er at sænke LCOE med et globalt kvalitets-dataset til hurtig vurdering af møllers egnethed som vil effektivisere beslutningsgange og reducere usikkerhed. Dette vil hjælpe til at sikre at bedre beslutninger træffes hurtigere samt at undgå for konservative valg af møller.

Projektet har indfriet de planlagte mål, hvilket er globale datasæt i 250m opløsning og 3 højder (50m, 100m og 150m) for: 50-års vind, turbulens, anbefalet vindmølle-klasse samt usikkerhed. Data er gjort offentligt tilgængelige igennem både kommercielle og videnskabelige platforme. De underliggende metoder er transparente og veldokumenterede i tekniske rapporter, som er tilgængelige på distributionsplatformene.

GASP's resultater er til gavn for samfundet primært igennem vindmølle-producenter og for udviklere af vindmølleparker som kan tilgå data igennem både DTU's (WAsP Engineering) og EMD's software (windprospecting.com and windPRO). Det kommercielle potentiale af GASP kan bl.a. realiseres, ved at GASP forbedrer mølle-producenternes nuværende situation - særligt ved at tillade hurtig afdækning af markedsstørrelsen for nye mølletyper og –klasser, eller ved at afdække potentialet for eksisterende møllertyper på nye markeder. Følgende vigtige spørgsmål kan besvares: er markedet tilstrækkeligt for at tilpasse et mølledesign til et nyt område? Hvor mange sites er egnede for et eksisterende mølledesign? Hvordan er de egnede sites fordelt geografisk?

GASP giver adgang til de udviklede datasæt igennem web-baserede GIS-portaler hosted af DTU og EMD med mulighed for visualisering, download og analyse af data. De udviklede data er frit-tilgængelige, men for at øge det kommercielle perspektiv integreres data også i de kommercielle portaler WASP, WEng og windPRO, hvor brugerne kan udføre detaljerede beregninger for projekter og specifikkemøller.

3. Project objectives

- *What was the objective of the project?*
- *Which energy technology has been developed and demonstrated?*

The objective of the project was to fill in the gap of the missing data and knowledge of design conditions for turbines and wind farms globally. This is motivated by the drive to take the first mover advantage, by combining DTU's and EMD's existing technologies into the new product. Before GASP, siting parameter data was only available at selected locations and typically had restrictions on its use. This means that there was often not enough or no data for energy planners to make cost and feasibility estimates, nor for manufacturers to effectively customize turbines for a particular market. Hence, there was a need for a global atlas of siting parameters and recommended wind turbine classes over the world to assist and guide planning and prioritization. This project thus contributes to the Danish technology strategy.

The project was carried out through a close collaboration between university (DTU) and industry (EMD). This enabled an efficient and effective introduction of research and development technologies into the market.

This project was developed with transparent, validated and proven methodologies, which ensures that data are re-producible.

The technology developed during GASP consists of validated and published methods for a chain of calculation of siting parameters, the most advanced computer calculation technique and facility, the platform for hosting and sharing the huge data.

The outcome of datasets have been implemented (some fully and some partially) in EMD and DTU's software. This includes: 1) GASP full data layers on data Portal, demonstrated to end users at final workshop; 2) GASP concept that is demonstrated on commercial high accuracy regional dataset by EMD and end users during the project; 3) GASP concept that is demonstrated on commercial turbine response model including load margins by EMD and end users during the project; 4) GASP data tested in DTU's software WAsP Engineering by DTU and end users during the project.

4. Project implementation

- *How did the project evolve?*
- *Describe the risks associated with conducting the project.*
- *Did the project implementation develop as foreseen and according to milestones agreed upon?*
- *Did the project experience problems not expected?*

The project took off as planned. It progressed slowly at the beginning due to members' engagement in other projects, though it caught up in the middle, slowed down again due to COVID lockdown, and speeded up afterwards. We got approved from EUDP for an extension of in total 6 months, which is very helpful for us to complete the project.

In the risk analysis of our original proposal, we listed risks for each of the 5 work packages. Three of them did happen and they are: 1) workload heavier than calculated; 2) insufficient human resources; 3) delay due to the above two. In addition, COVID also negatively affected our work. These challenges were solved by allocating new members, urging our members to prioritize the project, and open dialogues between partners aiming at more efficient coordination and optimizing workflow and work, and dialogue with EUDP regarding the adjust of project deadline.

Even though our project was challenged by various factors, its implementation developed as foreseen and we achieved all milestones agreed upon.

In addition to the unexpected COVID, the project did also experience technical challenges that were not clear to us at the beginning. To be specifically, it happened when our models are applied to areas that are challenging both scientifically and technically, e.g. extreme wind flow across coastlines, the treatment of noises when merging data at tiles. These are unseen since no one has before run similar calculations at such resolution over the globe before. However, solutions were found.

5. Project results

- *Was the original objective of the project obtained? If not, explain which obstacles that caused it and which changes that were made to project plan to mitigate the obstacles.*
- *Describe the obtained technological results. Did the project produce results not expected?*
- *Describe the obtained commercial results. Did the project produce results not expected?*
- *Target group and added value for users: Who should the solutions/technologies be sold to (target group)? Describe for each solutions/technology if several.*
- *Where and how have the project results been disseminated? Specify which conferences, journals, etc. where the project has been disseminated.*

The original objective of the project is obtained.

The project produced the technical results as expected. The obtained technical results include:

- The calculation workflow from global scale to local scale for extreme wind and turbulence
- A suit of turbulence models adjusted for GASP use.
- Improved spectral correction method for areas with strong convective atmospheric movement
- A model for uncertainty classification related to the extreme wind and turbulence
- Global atlas of 50-year wind at spatial resolution of 250 m, at 3 heights (50m, 100m and 150m)
- Global atlas of turbulence intensity at spatial resolution of 250 m, at 3 heights (50m, 100m and 150m)
- Global atlas of uncertainty class for 50-year wind and turbulence intensity
- Global atlas of Loads
- Global atlas of turbine class
- Global atlas of other atmospheric variables, including flow inclination and shear-exponent, and terrain complexity based on IEC classification

The project also obtained commercial results as planned. The obtained commercial results include:

- EMD's service 1: Applying manufacturer specific turbine response model to the GASP data
- EMD's service 2: Applying manufacturer specific turbine response model to EMD's commercial high accuracy datasets using GASP concept. Both service 1 and 2 are to be distributed to manufactures via the Portal windPROSPECTING.com for sales representatives or executives, as a sales tool and a fast decision tool.
- EMD's product: the generic turbine response models applied to EMD's commercial high accuracy datasets using the GASP concept
- DTU's service: Enhanced functions in WAsP and WEng and it will be distributed through the PyWAsP package.
- DTU's product: Intermediate datasets can be applied using more advanced microscale modelling using PyWAsP family, which is linked to the commercial potentials.

The targeted group of this project and the added values for the end users can be summarized as below:

- Renewable energy industry and wind turbine manufacturers (e.g. Suzlon, Siemens, Vestas)

  The datasets and tools from this project will aid in the integration of wind energy with other renewable energy technologies, in improving the estimates of wind power to particular class of turbine, reducing the cost related to turbine operation and maintenance through improved wind farm siting that can avoid severe wind conditions, and in providing information to assist the choice of wind turbine class. Wind turbine manufacturers can use the turbine class information to guide their production of turbines, by focusing on the correct class of turbine. The generalized wind is also beneficial for industry if they eventually decide to carry out further calculations for a specific site.

- Energy planners (e.g. DONG, Vattenfall, Eon)

  The datasets and tools from this project will help energy planners to improve regional cost estimates and improve energy production estimates anywhere in the world. The GASP output provides parameters that are required for market scheme and related calculation, e.g. May (2017)[1]. To date, there is no such data available for these types of cost estimates.

- Civil engineers

  The strong wind indices, directional distributions, turbulence, wind shear and gust at modern turbine hub heights are relevant and useful for civil engineers who work with building bridges and tall buildings. A global dataset of this kind of data has never been made available.

- Academic Instituts

  The methodologies for the design parameters are based on fundamental researches and they are scientifically interesting for academic institutes who work with turbulence, atmospheric sciences, design parameters and wind energy.

The project has been disseminated at the following conferences and workshops:

- Workshops with end-users
  - Workshop 1: beginning of the project. 2019-02. Combination of physical and online
  - Workshop 2: end of the project. 2021-06-28. Online.
- Wind Energy Denmark conference
  Larsén X. G.: Invited speech: The GASP project, 2018-10-29, Vejle, Denmark
- International workshop on the specific issues of Taiwan offshore wind farm
  - Larsén X. and Ott S.: Invited speech: Modeling extreme winds – in relation to Typhoons. Taipei, 2019-08.
- European Geo. Union Conference
  - Larsén X. G., Kruger A., Floors R., Cavar D. and Hahmann A.: “Atlas of extreme wind and gust for South Africa”, 2021-04, Vienna, Austria [online]. With contributions from GASP to this study.
- Wind Energy Science Conference
  - Larsén, Davis, Hannesdóttir, Kelly, Olsen, Floors, Imberger, Svenninsen and Slot: ”Calculation of global atlases of extreme wind and turbulence”, The GASP project, Part 1. WESC mini-symposium: extreme met-ocean conditions for offshore wind turbines – floating and fixed. 2021-05, Hannover, Germany [online].
  - Svenningsen, Slot, Thøgersen, Larsén, Davis, Floors, Imberger, Kelly, Olsen and Hannesdóttir: “Calculation of a global atlas of expected wind turbine design class”, The GASP project, Part 2. The resource session. 2021-05, Hannover, Germany [online].
- WindEurope Conference

[1] May N. (2017): The impact of wind power support schemes on technology choices. Energy Economics 65, 343-354. http://dx.doi.org/10.1016/j.eneco.2017.05.017

- Larsén, Davis, Hannesdóttir, Kelly, Svenninsen, Slot, Olsen, Floors and Imberger: The Global Atlas of Siting Parameters. Resource assessment – modeling and measurements 1. WindEurope Electric City. 2021-11 (This conference was delayed due to COVID from 2020 to 2021)

Publications

- Data on Portal: https://science.globalwindatlas.info/
- Floors R. and Nielsen M. 2019: Estimating air density using observations and reanalysis outputs for wind energy purposes. Energies. 12(11), 2038, https://doi.org/10.3390/en12112038
- Larsén, X. G., Davis, N., Hannesdóttir, Á., Kelly, M., Olsen, B., Floors, R., Nielsen, M. & Imberger, M. (2021): Calculation of global atlas of siting parameters. DTU Wind Energy E-0208. Technical report.
- Larsén X. G., Imberger M., Davis N., Kelly M. and Hannesdóttir A.: "GASP uncertainty classification". DTU Wind Energy E-report-0221.
- Larsén, Xiaoli Guo; Davis, Neil; Hannesdóttir, Ásta; Kelly, Mark C.; Svenningsen, Lasse; Meklenborg Miltersen Slot, René; et al. (2021): Global Atlas of Siting Parameters V1. Technical University of Denmark. Dataset. https://doi.org/10.11583/DTU.14753349
- Larsén X. G., Davis N., Hannesdóttir A., Kelly M., Svenningsen L., Slot R., Imberger M., Olsen B, and Floors R.: "The Global Atlas for Siting Parameters (GASP) project: extreme wind, turbulence and turbine classes", to be submitted to Wind Energy, 2021.
  McKenna R., Pfenninger S., Heinrichs H., Schmidt, Staffell, Gruber, A. Hahmann, Jansen, Klingler, Landwehr, X.Larsén, J. Lilliestam, B. Pickering, M. Robinius, T. Tröndle, O. Turkovska, S. Wehrle, J. Weinand, J. Wohland 2021: Reviewing methods and assumptions for high-resolution large scale onshore wind energy potential assessment. eprint arXiv:2103.09781 Economics.

6. Utilisation of project results

- *Describe how the obtained technological results will be utilised in the future and by whom.*

The technical results, as listed in section 5, will be utilized in the future by the end users such as renewable energy industry when estimating wind power to particular class of turbine and integrating wind energy with other renewable energy. It will also be used by and wind turbine manufacturers (such as Suzlon, Siemens, Vestas), where they can use the turbine class to guide their production of turbines by focusing on the correct class of turbines. Energy planners can use the technical results to improve regional cost estimates.

- *Describe how the obtained commercial results will be utilised in the future and by whom the results will be commercialised.*

The commercial results were listed in section 5. Service 1 and 2 from EMD are distributed to manufacturers via EMD's portal windPROSPECTING.com for sales to new and existing costumer, with a high price per sale, but with a low volume. Similarly, product from EMD is distributed via the Portal of both windPROSPECTING.com and windPRO for sales to new and existing costumer, with a low price per sale but with a high volume. DTU's service with the GASP data and function to enhance relevant functions in WAsP and WEng, and will thus be introduced to the costumer. Although the methodologies developed in this project are transparent and published, if actual application needs to be adjusted to the costumer's special requirement, the cost will be issued.

The availability of the data and tools from GASP is seen as commercially attractive for many countries in the world that have the need for wind energy, but do not have the information to fully exploit the resource. The integration of GASP to the existing DTU Wind Energy platform for wind resource atlas (the global wind atlas) will further increase the outreach and global use of the product. This DTU platform is for dissemination of wind conditions. So far it contains data and tools to analyze wind resources, in a collaborative project with World Bank as partner. We see it as a natural extension of the existing wind resource atlas to serve siting parameters and the website as a powerful information channel because website analytics show an average of 150 users per day on 250 sessions over 189 countries worldwide.

- *Did the project so far lead to increased turnover, exports, employment and additional private investments? Do the project partners expect that the project results in increased turnover, exports, employment and additional private investments?*

It is planned to incorporate GASP into EMD and DTU's commercial software at the end as well as after the project and in two years after the project end, to the market. So even though the project partners expect results in increased turnover, exports, employment and additional private investments, our workflow, as planned, has not reached that stage. For EMD the GASP project has not yet led to increased turnover, however, an increase is expected in the future, the global GASP data is seen as a funnel into more detailed commercial solutions in a Freemium business model which funnels users of the free data into multiple different commercial products.

- *Describe the competitive situation in the market you expect to enter.*
  - *Are there competing solutions on the market? Specify who the main competitors are and describe their solutions.*

At this moment, we do not see direct competitor offering an open global dataset of this kind with transparency of methodology. There are a few potential competitors regarding commercial software development, e.g. Vortex and AWE Truepower, though they have not included design parameters and turbine class in their software. Not like the data we have here which are pre-run and ready to be used, their approach is on-demand for a particular site.

- *Describe entry or sales barriers and how these are expected to be overcome.*

GASP is a free dataset, and the main value-proposition is its consistency, fast and easy availability anywhere in the world. However, whereas this on the one hand is adequate for initial coarser site investigations and decisions – it is on the other hand insufficient in the sub-sequent steps of project-development which require increasing accuracy and degree of detail. Hence, GASP will be an initial attraction and preliminary solution to the end-users needs – but will inevitably create a need for further accuracy and detailed which will be met by the commercial services from EMD.

- *How does the project results contribute to realise energy policy objectives?*

The project results will enhance the **security of energy supplies**. The outcome from this project GASP will support energy planners and manufacturers to better design the farm and better choose the correct turbine classes, which will help avoiding damage and downtime caused by the choice of wrong turbines. This will contribute to a more secure operation of wind turbines and farms for their life time (10 years+), and accordingly safer supply of wind energy. Most recent analysis by IEA Wind TCP and Ea Energy Analyses[2] shows the importance of technology design considerations when evaluating the value of wind power generation.

The project outcome will also help countries to be **independent of fossil fuels**. GASP will make possible a global profiling of site conditions and suitable turbine and thus accelerate energy planning, thereby promoting wind energy and supporting a more sustainable integration of renewable energy, increasing cost efficiency, not only on national scale but also on international scale, thus promoting Denmark, as well as other countries to be independent of fossil energy. For Denmark there are still missing pieces in the national mapping of wind development, especially for onshore, where a high resolution load parameter map is still missing and it is seen

[2] Riva, Hethey and Vitina (2017): Impacts of wind turbine technology on the system value of wind in Europe. Report IEA Wind TCP Task 26. https://community.ieawind.org/blogs/cezanne-murphy-levesque/2017/11/27/what-is-the-impact-of-different-wind-turbine-techn.

to be an important basis for an efficient national decision model for selecting the most feasible areas. This is important for Denmark to identify and optimize the use of the limited areas for onshore wind development, which is still the most competitive renewable energy source in Denmark, in order to reach the green energy target.

The project outcome impacts positively the **climate and environment**. GASP will promote green energy globally towards an even stronger player in the energy market, consequently reducing CO2 emissions, which is beneficial to both climate and environment. The expected annual global installation of new farms is approximately 50 GW, which will reduce CO2 emissions by 1 billion tons over the lifetime of 25 years of the wind farms. Being able to increase the effect by just 1% will yield a saving of 10 million tons over the wind farms' life time, equivalent to 1.6 million Danes current annual CO2 emissions.

The GASP project outcome will increase **cost efficiency**. It is directly for the technology design. An analysis by IEA Wind TCP and Ea Energy Analyses[25] shows the relevance and importance of considering technology design for wind power developers and turbine manufacturers, as well for policy makers designing renewable energy support schemes.

- *If Ph.D.'s have been part of the project, it must be described how the results from the project are used in teaching and other dissemination activities.*

There is no PhD education involved in this project.

7. Project conclusion and perspective

- *State the conclusions made in the project.*

The conclusions made in the project can be summarized as follows:

  - Cooperation between university and industry is an effective and efficient way to introduce research results to market
  - The support from EUDP is essential for the cooperation on such projects
  - It is important to deliver research to create knowledge and open (free) data, which can be used to initiate and/promote wind energy development in wind-less-developed countries and regions
  - It is possible, in addition to provide free data to the society, to create possibilities to advance our own commercial development
  - The calculation over the entire globe reveals further challenges in our existing methodologies in physics as well as numerical domains.
  - Further validation and improvements on research are needed

- *What are the next steps for the developed technology?*

The next steps for the developed technology are:

  - To complete the implement of the project output (services and products) to software
  - To push the products to the market

- *Put into perspective how the project results may influence future development*

For the future development, for general users, they can start with our data, tools and method to advance their own development.

For us ourselves as partners in this project, we will continue the collaboration, and continue exploring the solutions to new challenges.

8. Appendices

- *Add link to relevant documents, publications, home pages etc.*

The appendices include:

- Deliverables from the project in GASP_Deliverables.zip (8 deliverable reports, 4 milestone reports and 3 commercial milestone reports)

- Publications in GASP_Publication.zip

- Data portals as given in the following
    - https://science.globalwindatlas.info/#/ [Display of atlases for variables as listed in D4.2]
    - https://data.dtu.dk/articles/dataset/Global_Atlas_of_Siting_Parameters_V1/14753349 [actual datasets]
    - windprospecting.com [one needs to register a free prospecting account at the site]