End of project popular science description

Introduction

Wind power is currently the largest renewable energy source worldwide for power generation, partly because of its vast and successful deployment during the last three decades. Wind farms in Mexico produced 3.44% of the world's wind energy in 2017 (3% of the country's electricity came from wind). Mexico doubled the installed capacity of wind energy from 2017 to 2019, primarily because of government policies that incentivized renewable energies. However, between 2020 and 2021, the wind energy boost decelerated because the Mexican government introduced new policies that favour the usage of fossil-fuel-based technologies. Nevertheless, Mexico is a country with some of the highest wind potential. In particular, the wind power density over the Tehuantepec Isthmus, extended areas of Baja California, mountainous regions in the states of Sonora and Chihuahua, and the north of the Tamaulipas state can easily be above 1000 W/m^2, i.e., they are among the best of the world in terms of wind resources. The success of wind energy implementation depends on the accuracy of wind resource predictions. High accuracy and low uncertainty on these predictions provide the means to establish a secure basis for a clean and effective energy supply from wind power. Therefore, MEWA aimed to investigate methodologies for microscale-mesoscale model coupling to estimate and characterize wind resources. Such coupling is necessary because the mesoscale model cannot resolve local landscape features, which can modify the wind locally. In contrast, the microscale model cannot predict the large-scale wind climatology driving the atmospheric flow. Current coupling methods have limitations when applied at sites with complex topographies and climatographies. **MEWA** also aimed to investigate the impact of climate change and variations in surface characteristics, land cover, and topography on wind resources. Therefore, Mexico was an ideal scenario because it experiences rapid changes in land cover and surface characteristics as well as topography variability. Lastly, **MEWA** aimed to strengthen the relations between research centers in Denmark and Mexico, and their research capacity.

MEWA's approach consisted of three phases. First, we collected atmospheric flow observations, models and simulations over Mexico, which we could use to test/validate models and implement methods for characterizing wind resources. Some of these models were used and improved (either by improving their inputs or methods) during the subsequent phases of **MEWA**. Second, we developed and tested coupling techniques and numerical experiments using various models for wind prediction. These techniques included the dynamical coupling of large atmospheric flow scales down to turbulence scales. Third, we evaluated the models and coupling techniques using measurements from datasets available in Mexico, Denmark, and Northern Europe, with particular emphasis on measurements from the Wind Atlas of Mexico (WAM) project. WAM was a Mexican-Danish cooperation project for climate change mitigation, with high-quality mast observations available at ten locations across Mexico.

Results

MEWA established two publicly available data inventory reports. The first is an inventory of datasets of atmospheric flow simulations and observations conducted over Mexico, including a server set up for interested stakeholders to access both simulated and observed data. The second is an inventory of models used for wind resource assessment. These inventories are the basis for evaluating methods and models throughout **MEWA**. The main output of **MEWA** is the analysis of results from evaluations of the models and methods that were used and developed in **MEWA**. These analyses have been published in the form of international peer-reviewed journal publications. A total of 11 of these are already published or accepted for publication, 4 are under review, and 4 are under preparation. Results were also presented as 23 abstracts submitted to international conferences, 2 national conferences and lectures, and 1 book chapter. 4 conference sessions were organized under the **MEWA** umbrella, three in Mexico and one in the USA. Generally, **MEWA** focused on regional or local wind/turbulence climatologies. Regional case studies included Mexico or its subregions, Denmark, Northern Europe or the North Sea. Local studies focused on mast measurements located in Mexico and Denmark. Some detailed analyses focus on either understanding methods and tools used for wind resource assessment, e.g., on the usage of wind speed time series for wind characterization or satellite products for roughness length estimations, sensitivity analyses on atmospheric model configuration, studying phenomena such as hydraulic jumps and mountain waves, wind turbine wakes, or machine learning approaches for improving wind predictions. Other studies focused on the possible changes in wind resources in Mexico and North Europe based on predictions from climate models under possible future scenarios, as well as the challenges and opportunities for Mexico concerning wind energy and the energy transition.

Conclusions

MEWA provides methods and tools that can be used for the detailed current and future planning of wind power, which are particularly useful for Mexico and countries with complex climatologies and topographies. **MEWA** also provides validated strategies and best practices to perform wind resource characterization and wind turbine siting targeting wind energy planers, wind farm owners, operators, investors, wind turbine manufacturers and policymakers.

MEWA strengthened, and in some cases established, the collaboration of Danish institutions/agencies, particularly DTU, with Mexican and American institutions. **MEWA** facilitated the creation of new partnerships, e.g., both with the Tecnológico de Monterrey, with which DTU has also now an institutional agreement since 2022 and with CICESE; most of the dissemination of the project has been in cooperation with the latter. MEWA strengthened our partnership with INEEL and we are now preparing an application to get Mexican funding to establish a “new” **MEWA** focused on offshore winds. MEWA strengthened the long record of research collaboration that DTU has had with NCAR (USA). A new partnership was established with the Lawrence Livermore National Laboratory (USA) as they are developing methods for atmospheric modelling in complex terrain and turbine implementations in atmospheric models. Unfortunately, during **MEWA**, a new government came to power in Mexico, which in 2020 introduced regulatory changes and laws hampering investments in the renewable energy sector. Consequently, SENER, the Ministry of Energy of Mexico, experienced personnel and strategy changes that have strongly diminished the interaction between the partners in **MEWA** and the Mexican authorities and agencies, which are the central stakeholders in the project.

Recommendations

As it has also occurred in Europe, we have explored within **MEWA** the challenges and opportunities that wind energy, and more broadly the energy transition offers to Mexico. **MEWA** was focused on a relatively small but significant aspect of wind energy research: the coupling of atmospheric models dealing with large but coarse with small but fine scales, as well as the future changes in wind resources due to climate change. Both subjects are currently key research areas in wind energy worldwide, and our knowledge and tools for the study of winds are far from being robust (and in many cases accurate) due to the complexity of the turbulent atmosphere. Therefore, as it also applies to Europe, developing other methods to better predict winds over Mexico is mandatory. However, this can only be achieved when research institutions, wind turbine developers and manufacturers, wind consultants, and governmental agencies agree on a strategy to foster wind power harvesting. As mentioned before, this strategy is currently nearly non-existent in Mexico. As **MEWA** concentrated on studying the atmosphere over land, it becomes natural to recommend that similar studies are required in both coastal and offshore areas, as these generally have the most significant potential for wind power harvesting. Presently, there are no offshore wind farms in Mexico. However, current offshore wind developments worldwide suggest that the tools we use to predict winds and turbulence onshore do not necessarily perform well offshore or close to the coasts. Further, high-quality measurements of winds and turbulence in Mexico are rare over land; offshore, there are almost non-existent. High-quality, long and extensive measurement campaigns are as important as using complex atmospheric models to understand the behaviour of winds in the atmosphere.