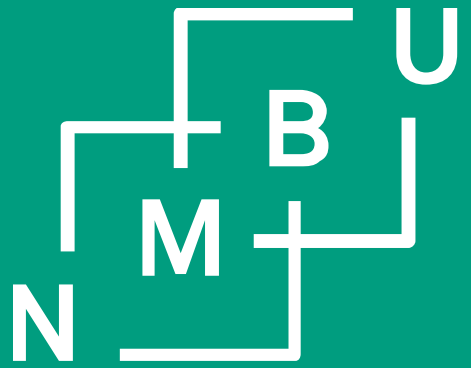


Norges miljø- og biovitenskapelige universitet

Wind Power Forecasting

Physical Modelling

05.06.2019

Alexander Dybvad

Agenda

- Background and motivation
- Goal and scope
- The wind farms
- Forecasting method
- Data foundation
- WindSim models
- Results
- Uncertainties and limitations
- Conclusion

Source: WindSim basic course

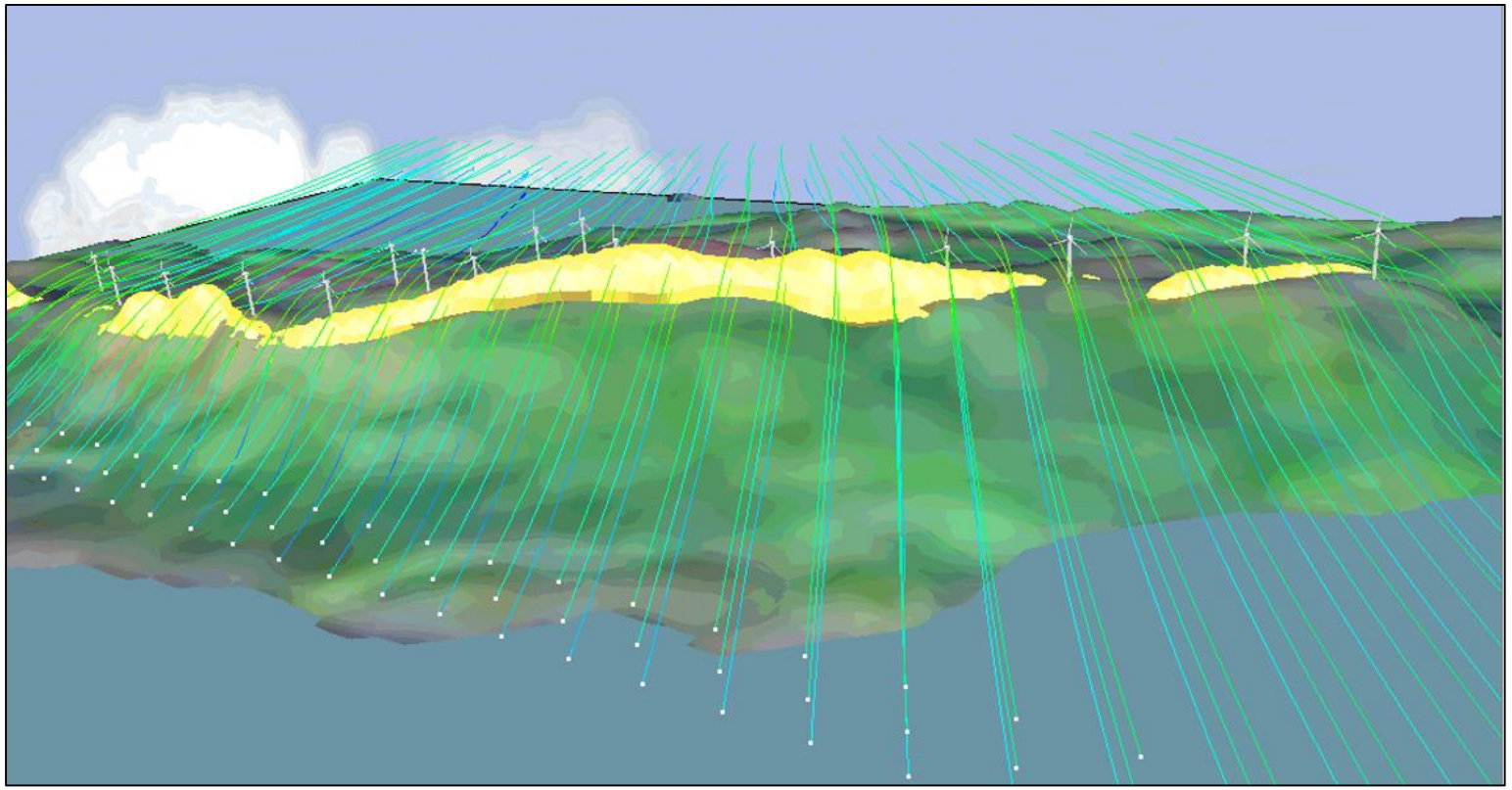
Background and Motivation

- Implementation of renewable energy (RES)
- Wind power is becoming one of the prominent RES investment areas in Norway
- Challenges with the stochastic nature of the wind

Source: Clean, Green & Renewable Energy

Goal and Scope

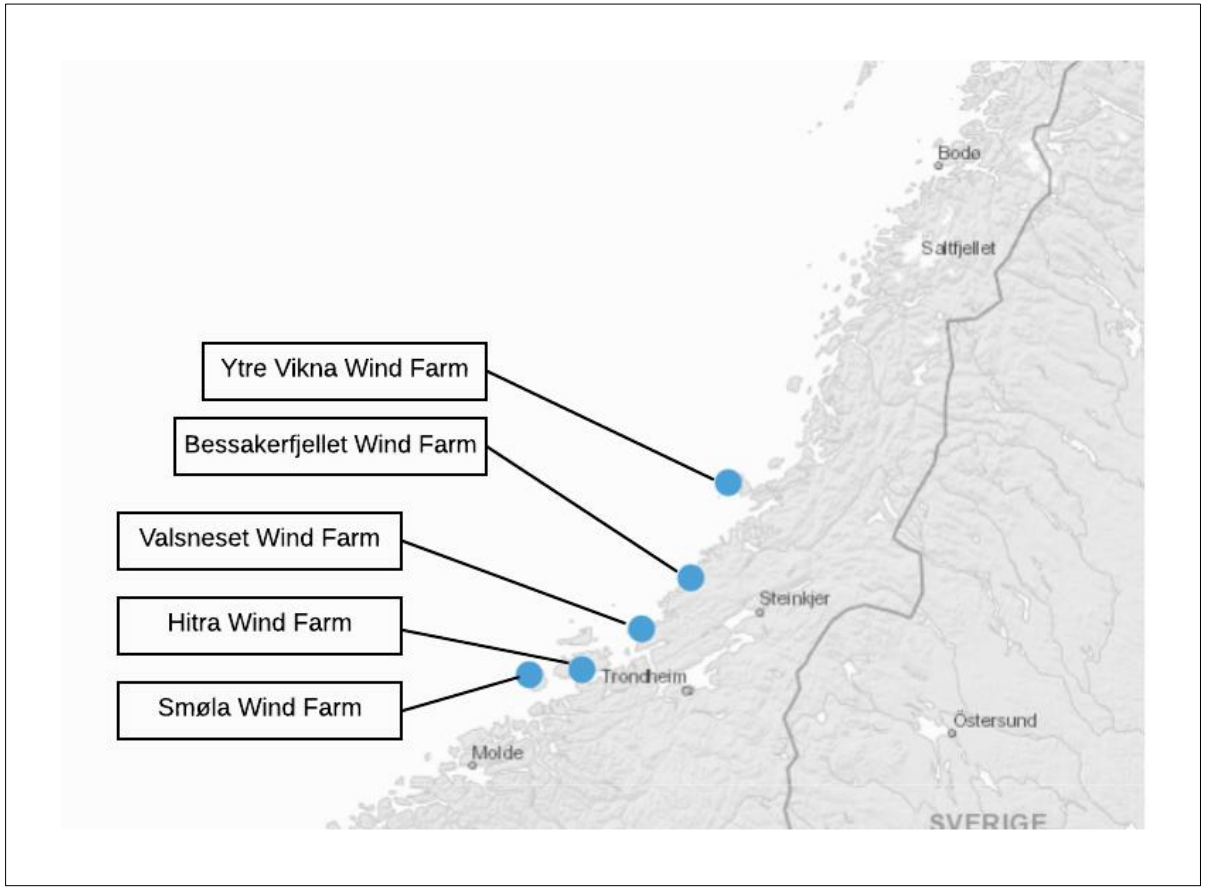
- Analyse two different forecasting strategies in combination with forecasted wind speeds.
- Benchmark the methods against actual power production.



Source: WindSim basic course

The Selected Wind Farms

- Ytre Vikna (2012) nominal power: 38.80 MW
- Bessakerfjellet (2008) nominal power: 56.446MW
- Valsneset (2006) nominal power: 11.71 MW
- Hitra (2004) nominal power: 54.41 MW
- Smøla (2002) nominal power: 148.45 MW



Data Foundation

Norwegian Metrological Institute and Yr.no

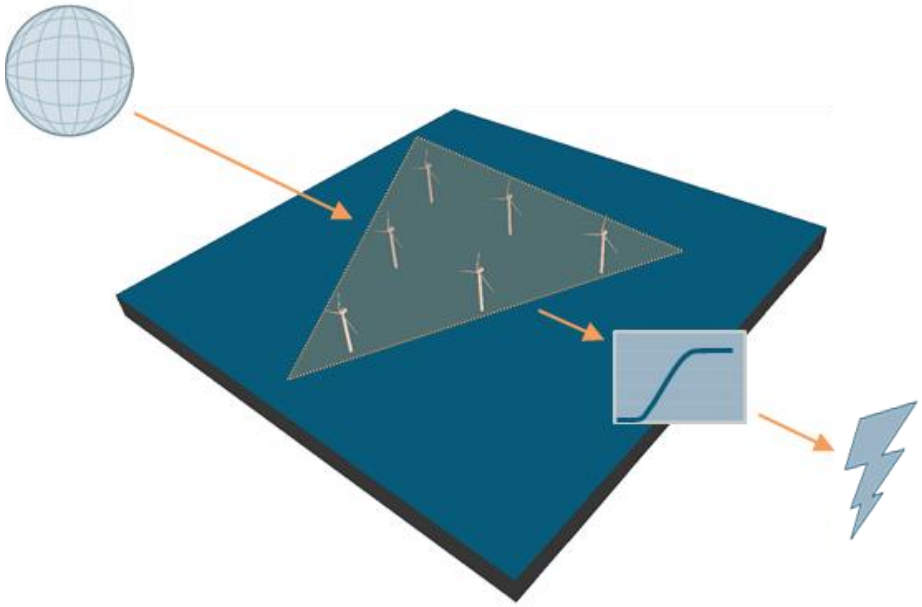
- Timeseries with forecasted wind speeds for 2017
- Wind speed forecast with one hour time steps

Norwegian water and energy directorate (NVE)

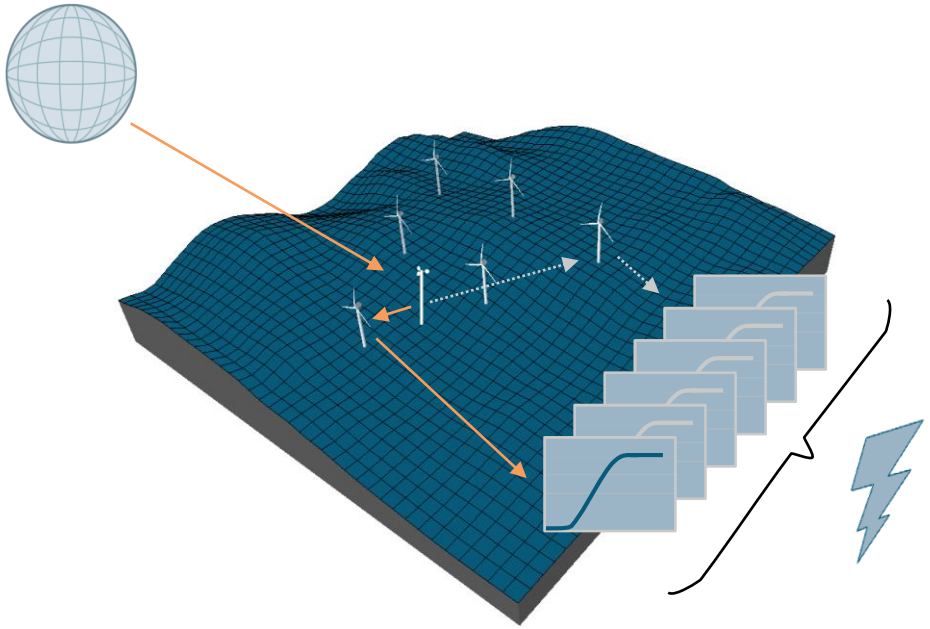
- Hourly records of power delivered to the grid
- Provided by the Norwegian grid operator Statnett

Forecasting Methods

Strategy I – Wind to Power

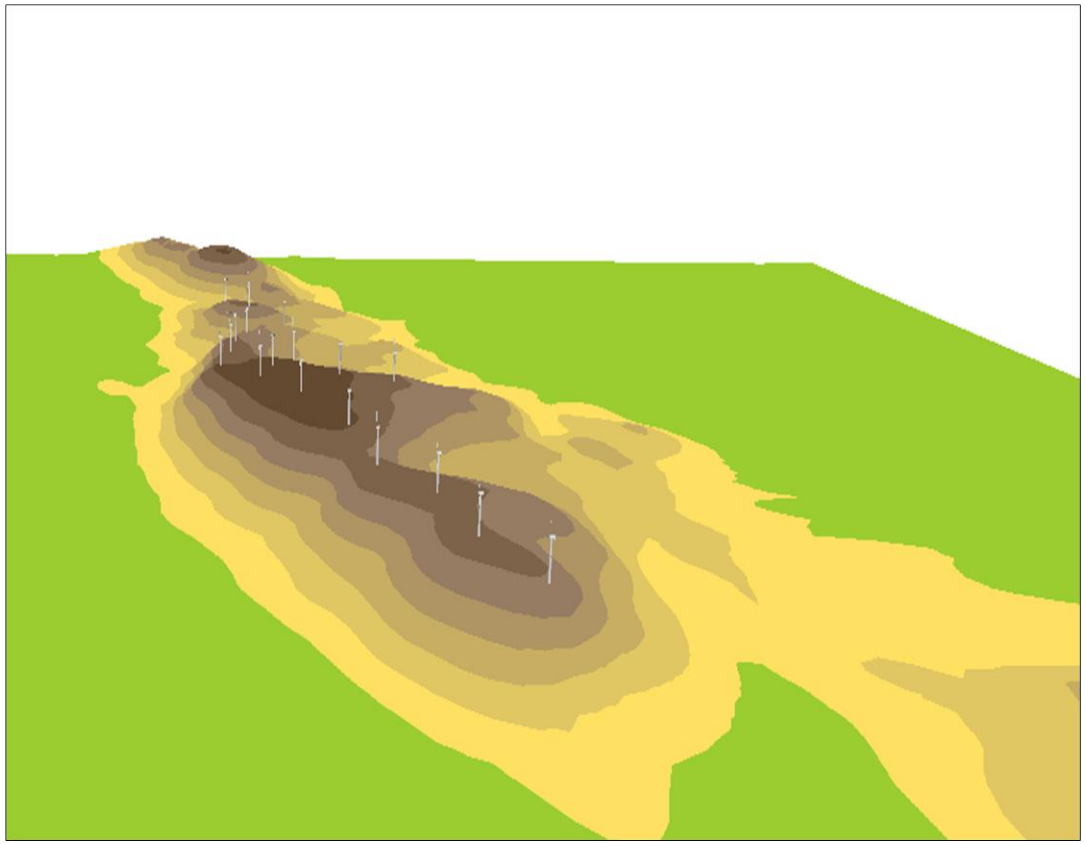


Strategy II – Wind + CFD to Power



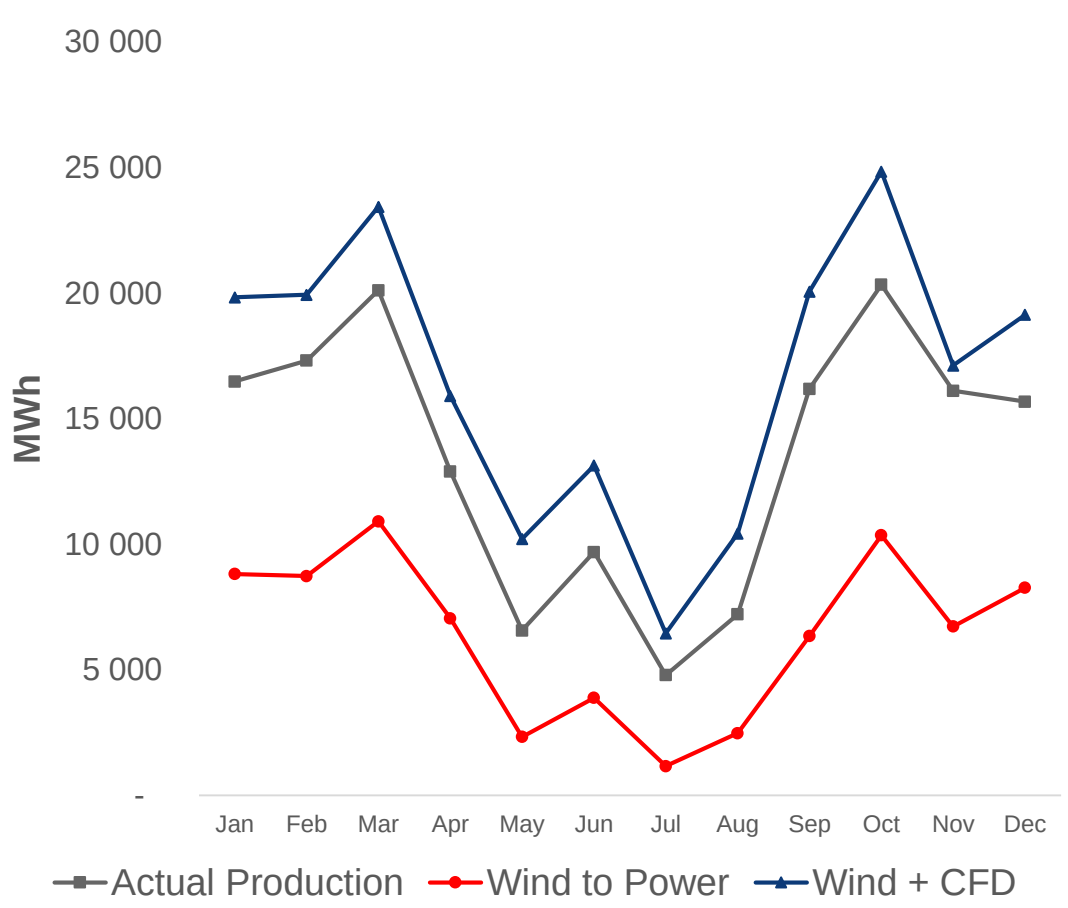
WindSim Models

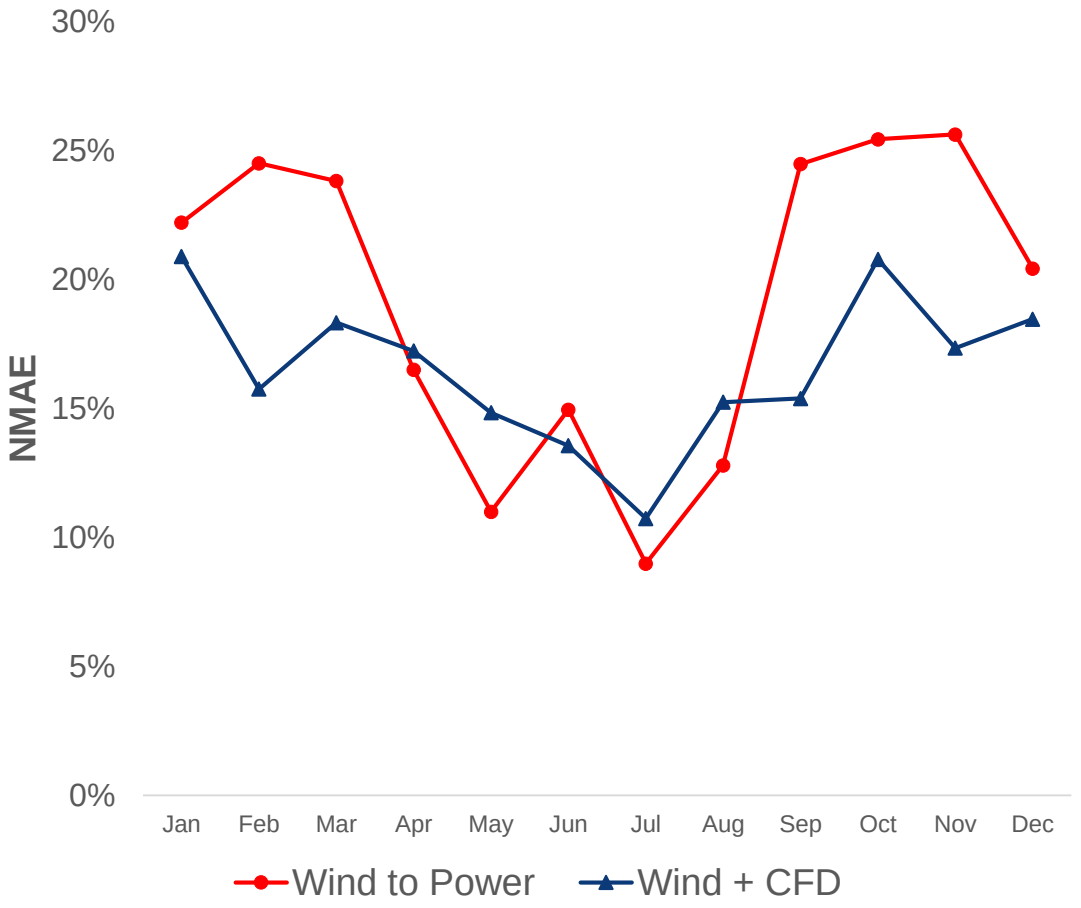
- ASTER GDEM v2 Worldwide Elevation (100m)
- CORINE Land Cover Europe 2006 (100m)
- 500 000 cell limit for the numerical model
- 500 iterations
- Standard turbulence modelling and air-pressure was set to standard 1.225kg/m^3
- Object placements imported from NVE geographical atlas



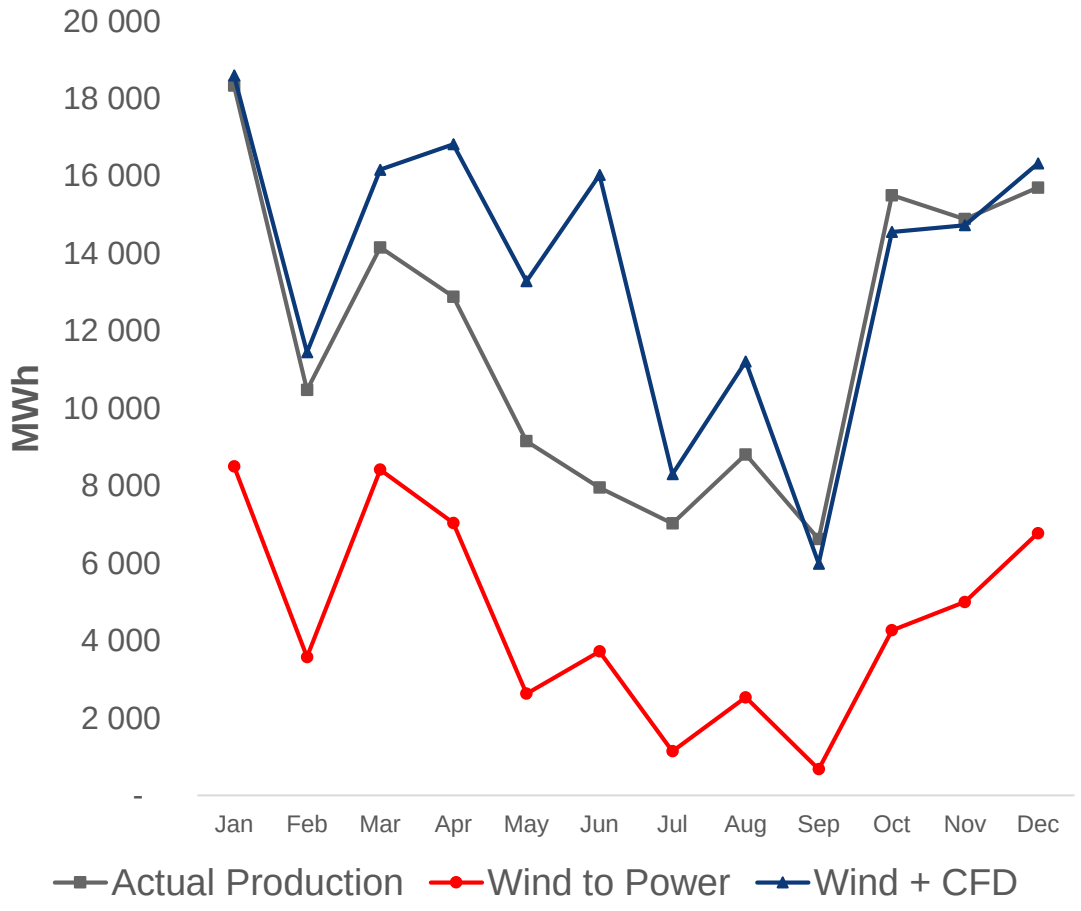
Source: WindSim basic course

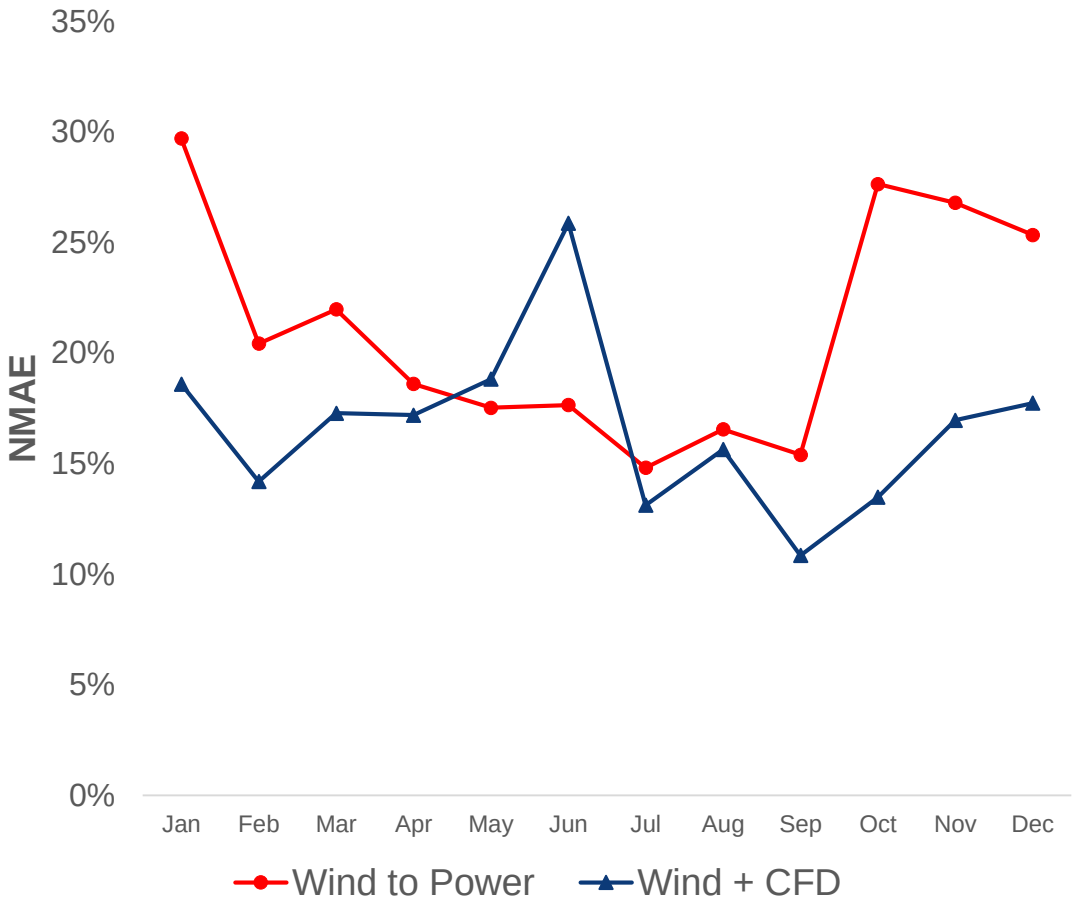
Bessaker Wind Farm



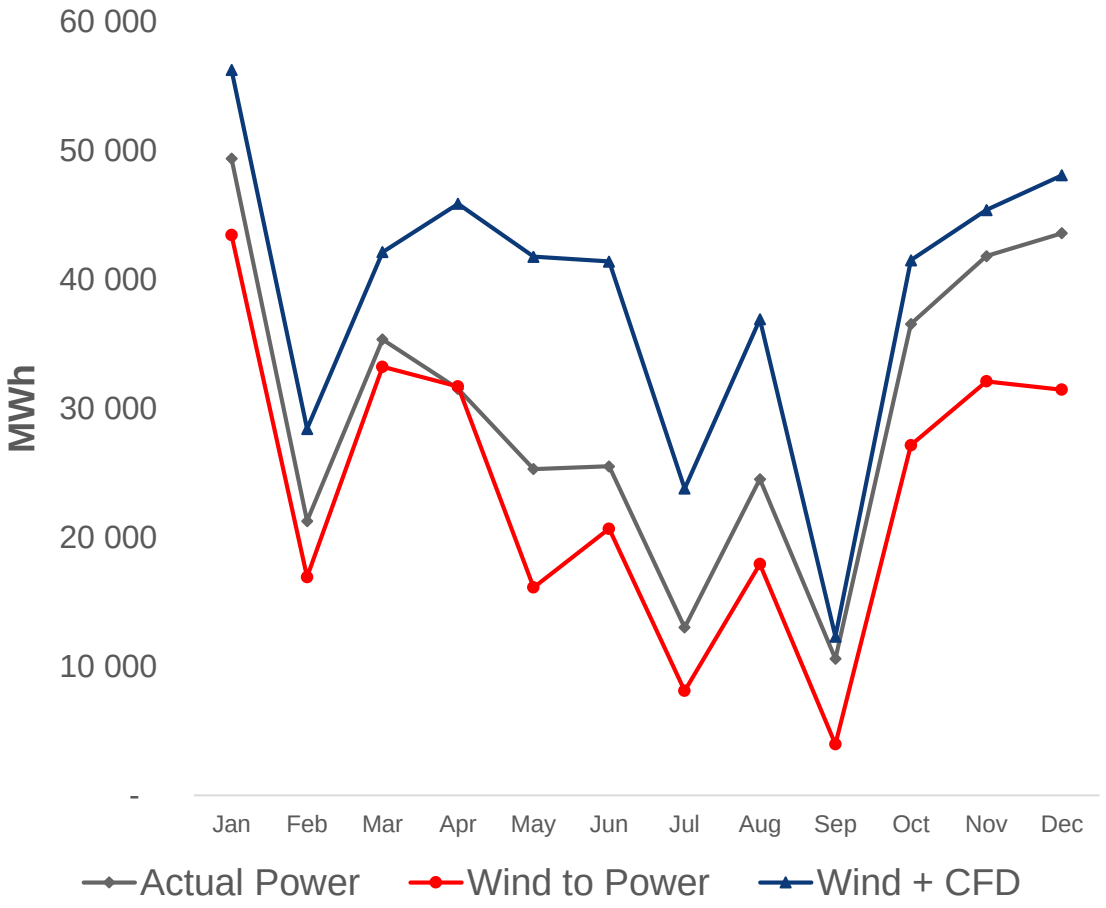


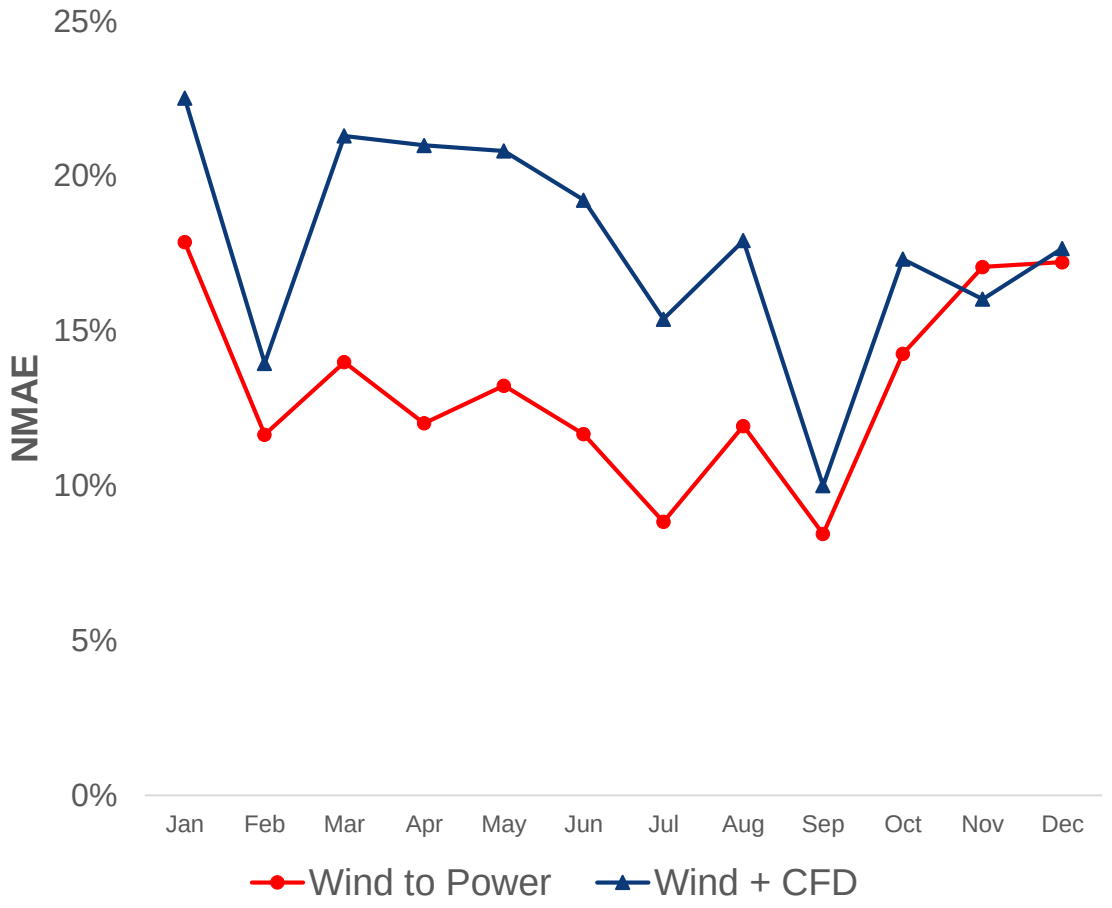
Hitra Wind Farm



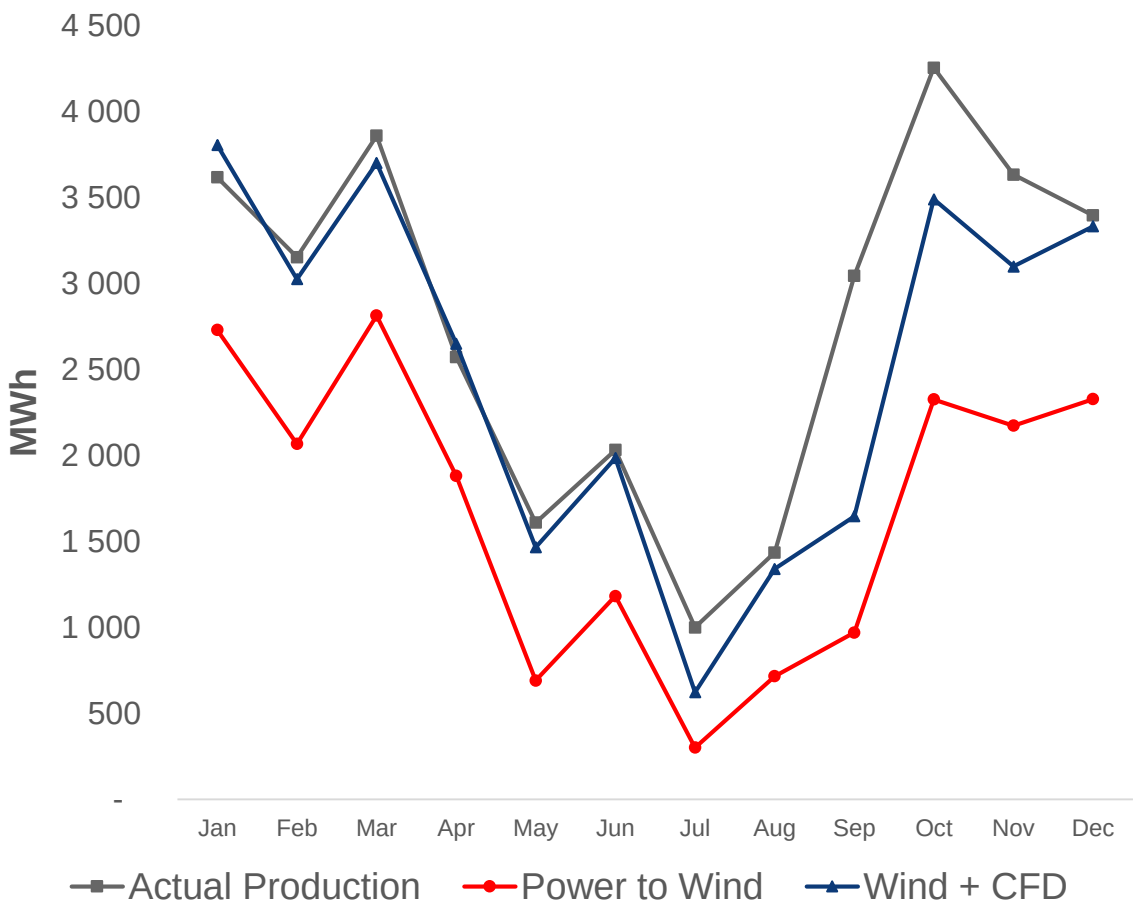


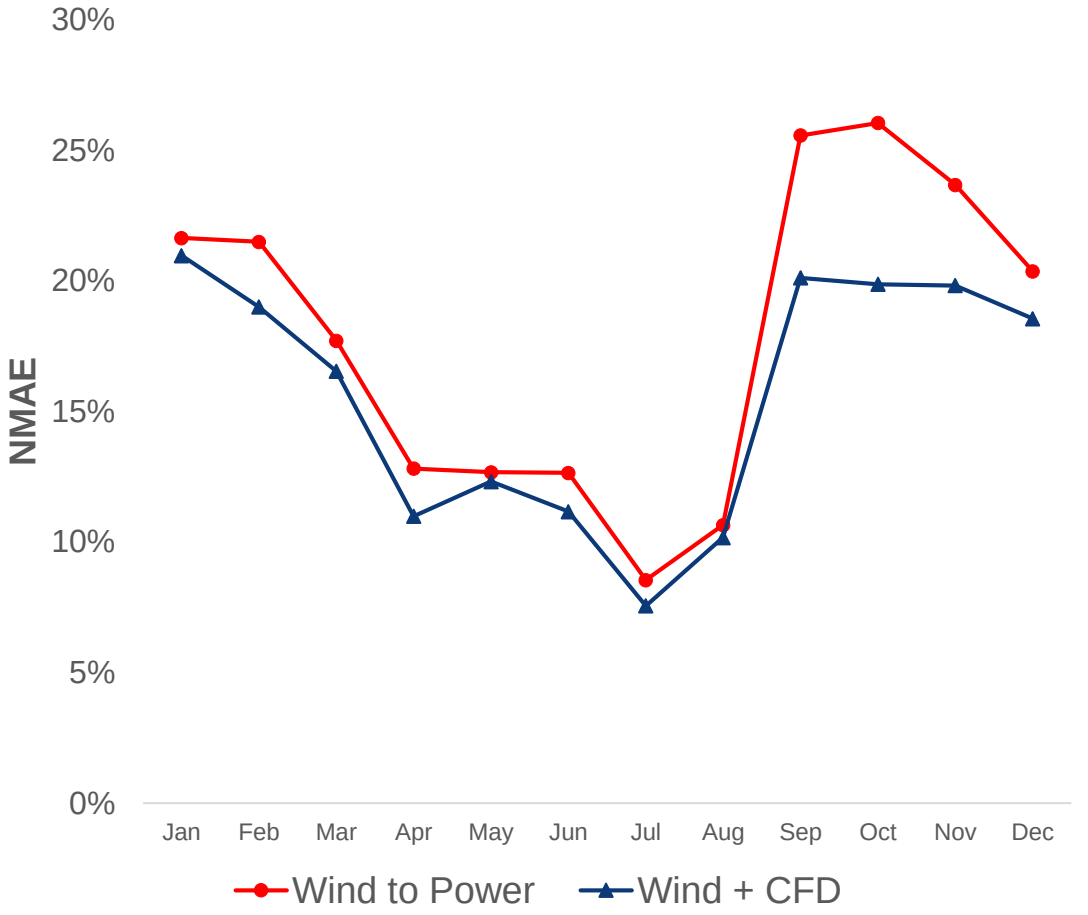
Smøla Wind Farm



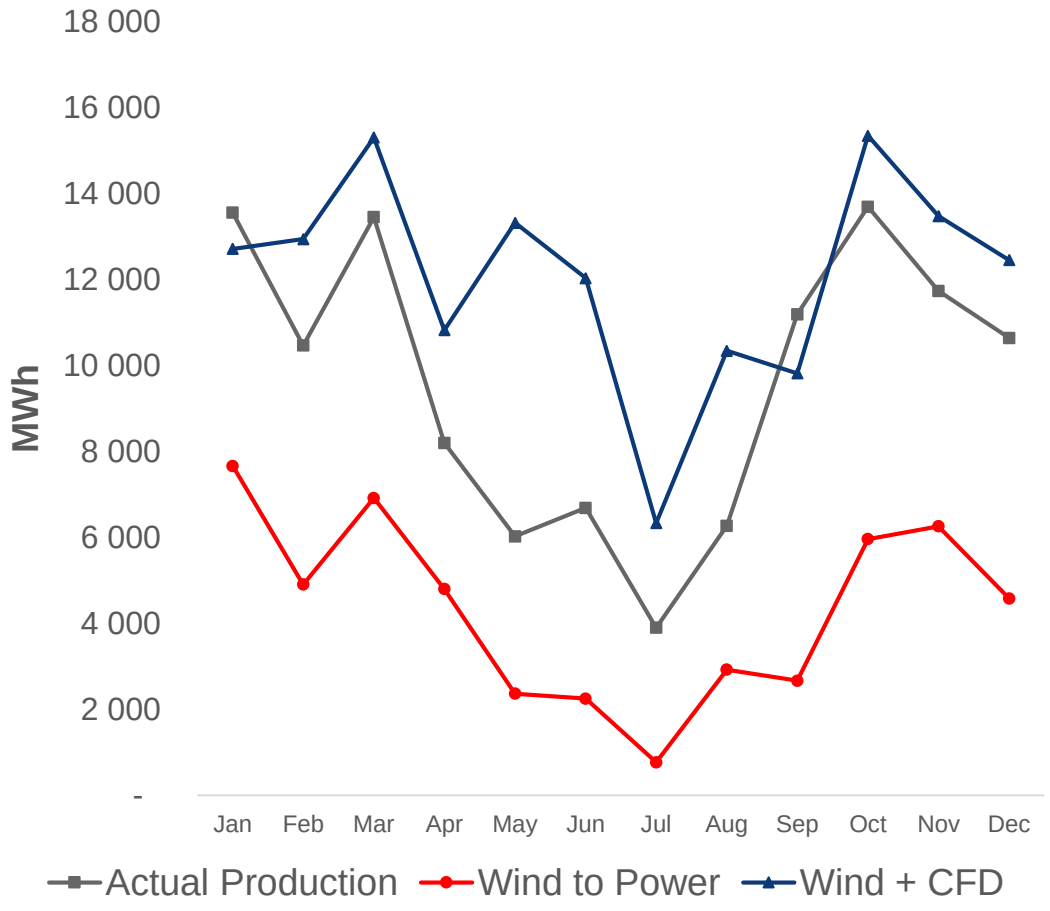


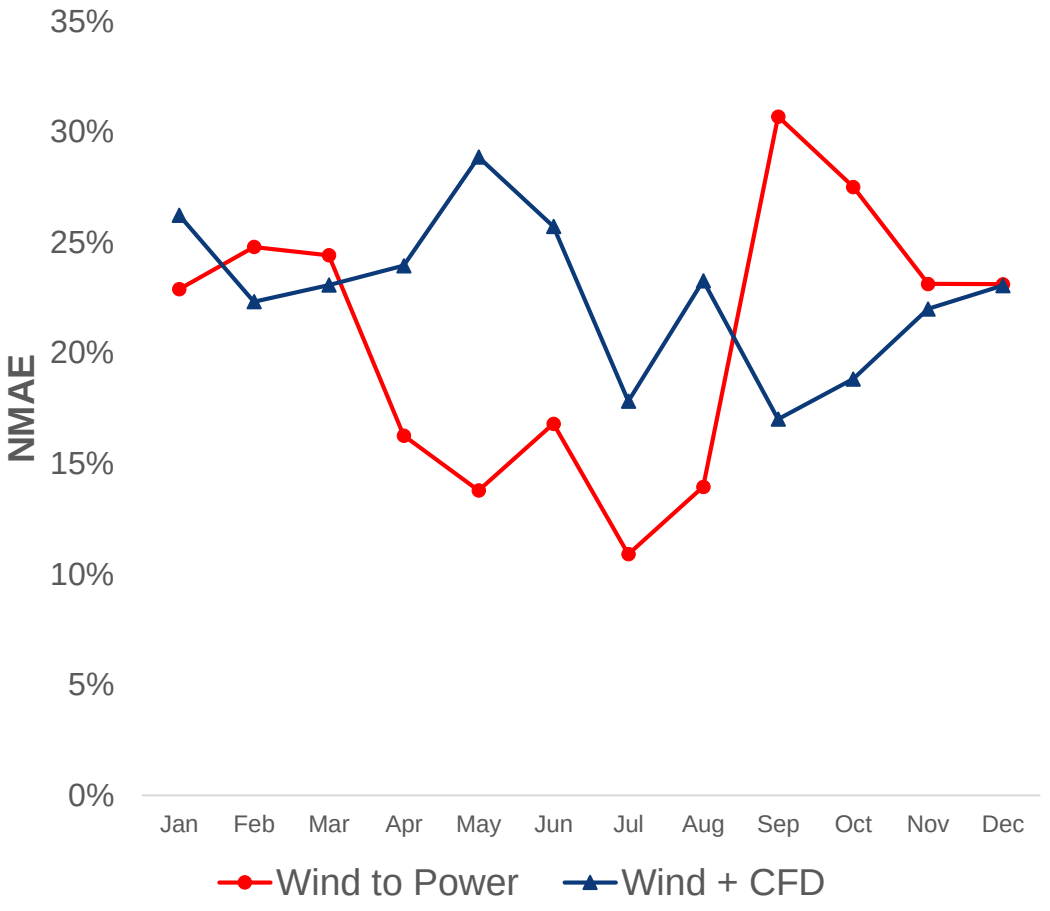
Valsneset Wind Farm





Ytre Vikna Wind Farm





Result Summary

Wind Farm	Nominal Power (MW)	Wind to Power (NMAE*)	Wind + CFD to Power (NMAE*)
Bessakerfjellet	56.446	19.19%	**16.56%**
Hitra	54.410	21.06%	**16.64%**
Smøla	148.450	**13.21%**	17.80%
Valsneset	11.710	17.80%	**15.58%**
Ytre Vikna	38.800	**20.69%**	22.71%

*NMAE – Normalized Mean Absolut Error

Uncertainties and Limitations

- WindSim user experience and time frame
- Computational capacities
- Data foundation
  - Time resolution
  - Wind speed measurements
- Post-processing analysis and adjustment of the models

Valsneset wind farm. Source: Valsneset wind turbine

Conclusion

- The forecasting method with CFD provided the highest accuracy in three out of the five cases analysed.
- With further improvement and post-processing of the forecasting models, the accuracy is expected to improve.
- The findings indicates that the use of CFD and WindSim is beneficial in wind power forecasting.

References

- Aarnes, J. F. & Aubert, K. E. (2018). *Interpolation - mathematics* Online Encylopedia Store norske leksikon Available at: https://snl.no/interpolasjon_-_matematikk (accessed: 04.05).
- Anderson, J. D. & Wendt, J. (1995). *Computational Fluid Dynamics an Introduction* vol. 206: Springer.
- Barbosa de Alencar, D., de Mattos Affonso, C., Limão de Oliveira, R., Moya Rodríguez, J., Leite, J. & Reston Filho, J. (2017). Different models for forecasting wind power generation: Case study. *Energies*, 10 (12): 1976.
- Blazek, J. (2015). *Computational Fluid Dynamics: Principles and Applications*: Elsevier Science.
- Castellani, F., Astolfi, D., Mana, M., Burlando, M., Meißner, C. & Piccioni, E. (2016). *Wind power forecasting techniques in complex terrain: ANN vs. ANN-CFD hybrid approach*. Journal of Physics: Conference Series: IOP Publishing.
- Corbo, F., Mana, M. & Meißner, D. C. (2015). Benefits of using CFD for wind power forecasting in complex terrain *EWEA*.
- DNV-GL. (2018). *Energy Transition Outlook 2018 - A global and regional forecast of the energy transition to 2050*. www.dnvgl.com.
- Foley, A. M., Leahy, P. G., Marvuglia, A. & McKeogh, E. J. (2012). Current methods and advances in forecasting of wind power generation. *Renewable Energy*, 37 (1): 1-8.
- Giebel, G., Badger, J., Perez, I. M., Louka, P., Kallos, G., Palomares, A., Lac, C. & Descombes, G. (2006). *Short-term forecasting using advanced physical modelling-the results of the anemos project*. Proceedings of the European Wind Energy Conference.
- Gravdahl, A. & Meißner, C. (2015). *Best Practices - WindSim*. WindSim Basic Course. Unpublished manuscript.
- Gravdahl, A. (2019). *WindSim Basic Course - Demo Project Hundhammerfjellet*. Gravdahl, A. (ed.): WindSim AS.
- Greaves, B., Collins, J., Parkes, J. & Tindal, A. (2009). Temporal forecast uncertainty for ramp events. *Wind Engineering*, 33 (4): 309-319.

References

- Hau, E. & Renouard, H. v. (2013). *Wind Turbines*. 3 ed. ed.: Germany: Springer Verlag.
- Hervik, S. (2017). *Numerisk metode* Store Norske Leksikon www.snl.no.
- Hiester, T. & Pennell, W. (1981). *Meteorological aspects of siting large wind turbines*: Battelle Pacific Northwest Labs., Richland, WA (USA).
- Hoel, A. (2004). *A wind Bonus for Siemens*. POWER ENGINEERING INTERNATIONAL: POWER ENGINEERING INTERNATIONAL. Available at: https://www.powerengineeringint.com/articles/print/volume-12/issue-11/regulars/news-analysis/a-wind-bonus-for-siemens.html (accessed: 28.04).
- Jensen Støver, I. (2019). *Om Yr* web page In Jensen Støver, I. (ed.). www.yr.no: NRK Available at: https://hjelp.yr.no/hc/no/articles/206550539-Fakta-om-Yr (accessed: 12.03).
- Kariniotakis, G., Pinson, P., Siebert, N., Giebel, G. & Barthelmie, R. (2004). *The state of the art in short-term prediction of wind power-from an offshore perspective*. Proceedings of.
- Landberg, L. & Watson, S. J. (1994). Short-term prediction of local wind conditions. *Boundary-Layer Meteorology*, 70 (1-2): 171-195.
- Lei, M., Shiyan, L., Chuanwen, J., Hongling, L. & Yan, Z. (2009). A review on the forecasting of wind speed and generated power. *Renewable and Sustainable Energy Reviews*, 13 (4): 915-920.
- Li, L., Liu, Y.-q., Yang, Y.-p., Shuang, H. & Wang, Y.-m. (2013). A physical approach of the short-term wind power prediction based on CFD pre-calculated flow fields. *Journal of Hydrodynamics, Ser. B*, 25 (1): 56-61.
- Lont, A. (2018). *Annual report 2018* Statnett Annual Report 2018. https://www.statnett.no/en/about-statnett/investor-relations/annual-and-semi-annual-reports/.
- Manwell, J. F., McGowan, J. G. & Rogers, A. L. (2010). *Wind Energy Explained: Theory, Design and Application*: Wiley.
- Milligan, M., Schwartz, M. & Wan, Y.-h. (2003). *Statistical wind power forecasting models: Results for US wind farms*: National Renewable Energy Lab.(NREL), Golden, CO (United States).
- NVE Atlas. (2019). *NVE atlas* NVE.no: The Norwegian Water Resources and Energy Directorate. Available at: https://atlas.nve.no/Html5Viewer/index.html?viewer=nveatlas# (accessed: 02.05).

References

- Rosvold, K. & Hofstad, K. (2013). *Betz` Lov* Store Norske Leksikon. www.snl.no Store Norske Leksikon
- Sohoni, V., Gupta, S. & Nema, R. (2016). A critical review on wind turbine power curve modelling techniques and their applications in wind based energy systems. *Journal of Energy*, 2016.
- Soman, S. S., Zareipour, H., Malik, O. & Mandal, P. (2010). *A review of wind power and wind speed forecasting methods with different time horizons*. North American Power Symposium 2010: IEEE.
- Søviknes, T. (2018). *Wind power in Norway post 2020*. Energy, M. o. P. a. Norwegian Govurnment: Berthelsen, Ole.
- US Department of Energy. (2018). *The Inside of a Wind Turbine* US Department of Energy US Department of Energy. Available at: https://www.energy.gov/eere/wind/inside-wind-turbine (accessed: 22.03.).
- Versteeg, H. K. & Malalasekera, W. (2007). *An Introduction to Computational Fluid Dynamics: The Finite Volume Method*: Pearson Education Limited.
- Wang, X., Guo, P. & Huang, X. (2011). A review of wind power forecasting models. *Energy procedia*, 12: 770-778.
- Wegley, H. L., Ramsdell, J. V., Orgill, M. M. & Drake, R. L. (1980). *Siting handbook for small wind energy conversion systems*: Battelle Pacific Northwest Labs., Richland, WA (USA).
- Weir, D. E. (2013). NVE Vindkraft—Produksjon i 2012. *Norges Vassdrags-og Energidirektorat: Oslo, Norway*.
- Willmott, C. J. & Matsuura, K. (2005). Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate research*, 30 (1): 79-82.
- Wu, Y.-K. & Hong, J.-S. (2007). *A literature review of wind forecasting technology in the world*. 2007 IEEE Lausanne Power Tech: IEEE.
- Zhao, X., Wang, S. & Li, T. (2011). Review of evaluation criteria and main methods of wind power forecasting. *Energy Procedia*, 12: 761-769.

Thank You