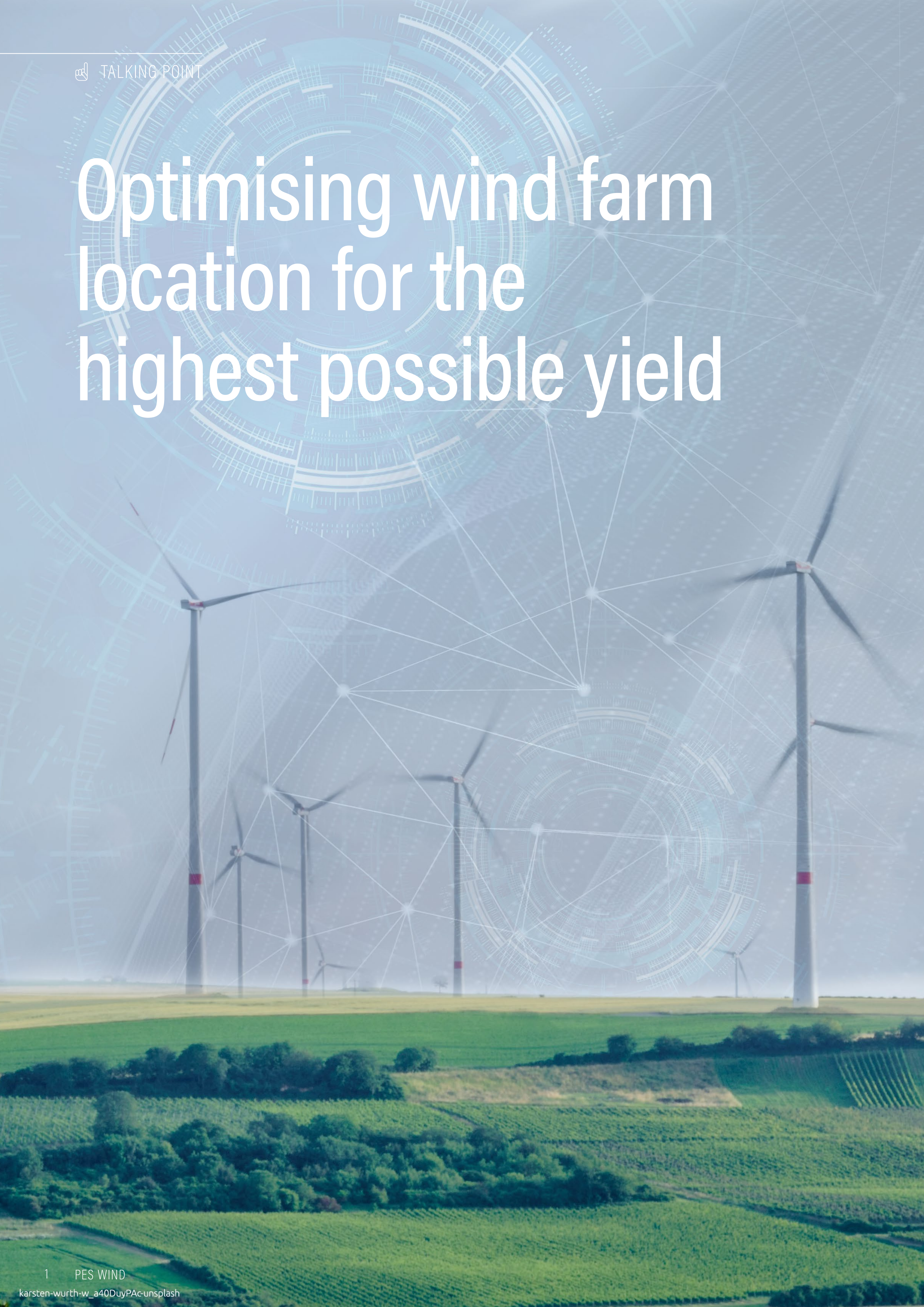
Optimising wind farm location for the highest possible yield



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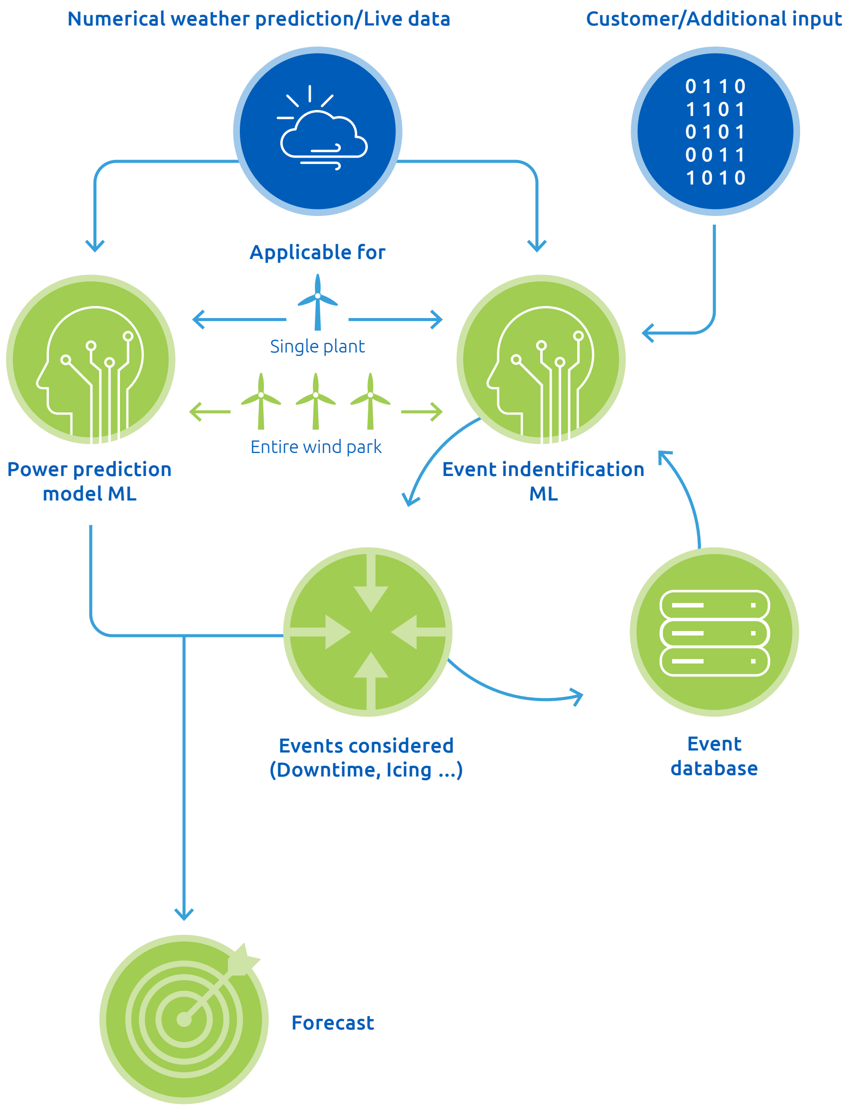
Although wind parks can't produce power without wind, too much isn't favourable either, as beyond a certain wind speed, turbines risk being damaged. In fact, strong winds can even force production to come to a complete halt or cause wind plants to fall over. To assess the profitability and safety of a wind park in advance, a thorough evaluation of the wind conditions at the site is necessary and this can be initiated by estimating the potential yield.

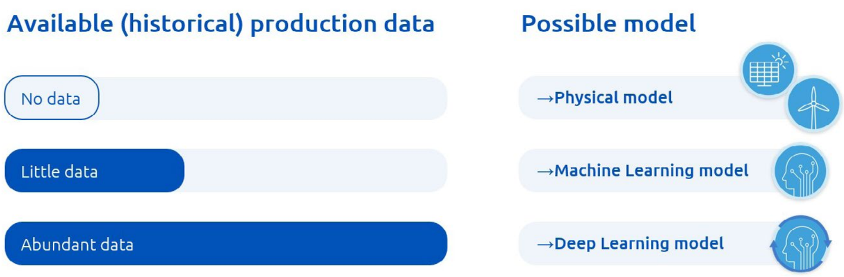
A yield estimate creates the opportunity to classify an area as profitable or unsuitable for wind energy production from the outset. This classification is done in a differentiated manner and is subject to a process that shows in detail the quality of the area. A yield estimate doesn't follow any set rules, so can be drawn up very quickly compared to a wind report. Despite this, the results include all the essential parameters required for production of the subsequent wind report. Yield estimation is therefore a very good tool as a first step in determining whether an area is generally suitable as a wind farm.

The wind report follows explicit rules. In Germany, Technical Guideline 6 (TR6) is used as the basis for testing the area and due to its complexity, it may only be issued by accredited wind experts. This ensures that the different areas are always assessed using the same parameters, with comparable results. The wind reports then form the basis for financing and are mandatory in external cases, so have far-reaching consequences.

In order for such an expert opinion to be created, various disciplines work together to obtain a differentiated result. For example, various calculations are carried out which take into account the shutdown of the wind turbines to protect local residents or to protect nature, because of course turbines have an impact on their environment and their negative influence should be kept to a minimum.

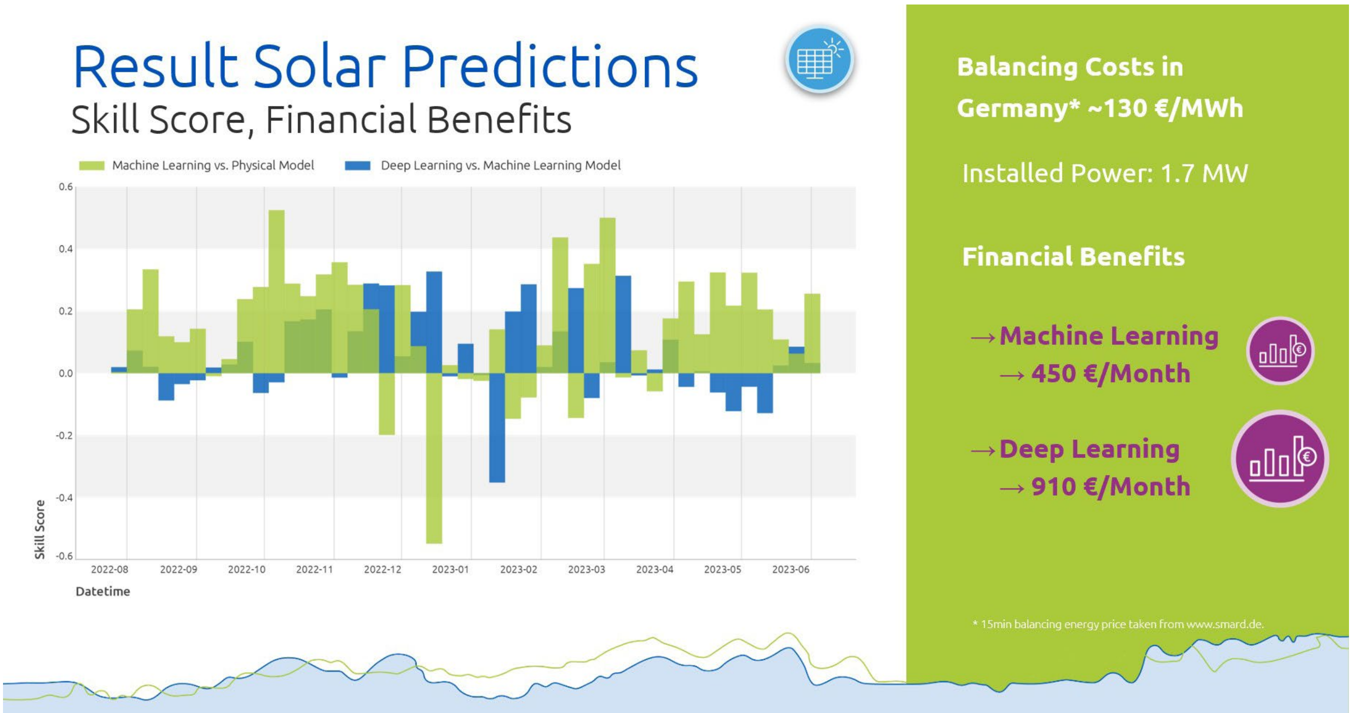
The wind report can also calculate exactly where individual wind turbines should be located and their proximity to each other. Viewed from above, it can give the impression that the turbines of a wind farm are randomly placed within the landscape, but this is far from the case, as the location of each individual turbine is precisely defined.





Optimal locations can be identified in advance using wind measurement campaigns and existing wind turbine data.

In Europe, there is usually a main wind direction from which the energy can be used effectively. Within a wind farm, the individual wind turbines are often arranged in rows and not every turbine can be positioned optimally to allow electricity to be produced to maximum effect. The turbine's rotor takes energy from the wind and converts it into electrical energy, so the systems further back receive less high-energy



wind for power generation. This is important, as it affects the electrical energy yield.

Whether the property is situated on a flat area or a hilly location, or even mountainous landscape also has an enormous influence on the energy yield. This is not always a positive influence, as the density of the air also changes in higher layers, which has a negative impact on the amount of energy available for electricity generation.

The roughness of an area, i.e. which objects are around the respective system and at what height, are also very important. It makes a difference whether there is a flat field around the facility, or tall buildings, or a forest. Onshore and offshore also have big differences, because offshore wind turbines can flow across the sea without major obstacles. All of these factors are taken into account in the wind report.

Furthermore, entire parks can be planned virtually on a computer and fed with realistic data on wind conditions and the essential local conditions. With the help of this exact planning, factors can be determined about the yield of the systems in a certain period of time. This makes it possible to use a physical model to calculate certain yields for the area, taking into account the specifications of the systems.

With these tools and exact calculations, the risk can be accurately assessed and calculated commercially, with profit and loss for the plant operator clearly broken down. There are several reasons to invest in renewable energy and from a business point of view, and while preserving and protecting nature is an important focus, there is a commercial interest in profit too. The construction of a wind or solar park is associated with enormous costs. Therefore, the wind report, following the strict guidelines for all externally financed wind farms in Germany, provides the bank with a reliable decision-making basis.

For economic reasons, it is important to keep an eye on the costs of these projects and further costs can be optimised as the process progresses. A key factor is the marketing of the electricity produced by the plants after they have been built. The main reason for setting up such plants is to produce energy that can then be fed into the grid and consumed. The direct marketers or the system operators must state how much energy they will feed into the grid. Thus, the total amount within the power grid can be monitored and the grid as a whole can be balanced. Balancing the power grid is a very complex and, above all, essential task. It must not be overloaded at any time, as too much current could damage parts of the electricity for consumers. However, it must not carry too little electricity either, or it could collapse.

The European network extends from Portugal via Poland and Ukraine to Turkey. It is fed with alternating current, which has a frequency of approximately 50.0 Hz. With the exception of short-term local power fluctuations, this grid frequency is the same throughout the entire interconnected grid. At any given moment, the power plants must generate exactly as much electricity as is consumed.

An exact yield forecast is crucial in any case. Depending on the yield forecast and the actual feed-in, costs or income can arise on the part of direct marketers, plant operators or energy traders in general. So-called compensation payments must be made if either more or less electricity is produced than previously stated. Therefore reliable yield forecasts are needed. There are various options and models for this, which include the different factors of the weather and all other external conditions in the calculation.

Potsdam company 4cast takes an innovative approach, creating various data models to calculate the yield of the systems. The development team at 4cast describes the procedure as follows. 'One approach is to shift the perspective to analysing weather conditions to unlock the potential for forecasting energy production for the day ahead. This leverages a state-of-the-art machine learning pipeline that includes various data inputs, including numerical weather forecast data, with a variety of weather models to choose from. In addition, there is various live data, such as that of the systems themselves or live weather data from satellites and weather observations themselves. Through careful pre-processing, this data is transformed into a powerful tool for predicting the future, covering time periods from just 15 minutes to a week.

'Data plays a crucial role in machine models and forms the basis for accurate forecasts. When analysing historical production data, the amount of data makes it possible to explore numerous variants and optimise the models accordingly. Sufficient data allows us to make informed decisions about the most suitable model for the purposes. When data availability is limited, the physical model using the laws of physics is used to simulate the behaviour of renewable energy sources. On the other hand, the abundance of data allows the machine learning model to produce excellent results, extracting patterns and relationships for accurate predictions.

> **In summary, the deep learning model provides excellent wind yield predictions, and therefore unprecedented accuracy and cost-effectiveness.**

However, care must be taken when modelling as the quality of the data has a significant impact on the performance of the model.

To evaluate the forecasting models, we use various metrics such as absolute and relative errors to assess accuracy and interpretability. Before we decide on a model, we compare a large number of models with each other. We distinguish between three main categories: physical, machine learning and deep learning models. The mapping is mainly based on data quality and data quantity.

In general, we can say that we achieve the most accurate predictions with fine tuned deep learning models, followed by various machine learning models. Only if the data availability is not sufficient do we apply a physical model, which in absolute terms also delivers reliable results.

We have illustrated the differences between the three models using an example. The skill score is a common metric used to compare competing models and to assess which model performs better over an aggregated period of time. A positive skill score shows that the model to be tested performs better, while a negative skill score speaks for the reference model.

For a better interpretation of the results, we have calculated the savings in balancing costs on the German electricity market. We compared the real production data with the respective forecasts over a fixed period of time and calculated the compensation costs based on the real 15-minute values. In the case of solar, we took a park with 1.7 MW of installed capacity as an example. Here, €450 is saved per month if a machine learning model is used instead of a physical model. The savings are even higher when using a sophisticated deep learning model based on neural networks. €910 can be saved monthly here.

With wind, the savings are even more significant. Here, we have considered a farm with 10 MW installed capacity. Machine learning saves around €9,000 per month, while a deep learning model would save around €14,000.'

In summary, the deep learning model provides excellent wind yield predictions, and therefore unprecedented accuracy and cost-effectiveness. Although it requires extensive data, it rewards us with valuable insights and even more accurate forecasts.

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