Wind farm revenues in Western Europe in present and future climate

Executive summary

To limit greenhouse gas emissions from power generation, the use of renewable intermittent energy sources, such as wind and solar, has been encouraged in many European countries. Renewable energy generation, together with the electrification of carbon-intensive sectors such as transport and heating, are the pillars of energy transition. In this context, wind energy plays a particularly important role because of high wind potential in Europe, rapidly decreasing costs of technology, regulated support mechanisms and good acceptance by the public. In 2018, the European wind sector has attracted investments for €65 billion and this figure is expected to increase in the short term due to favorable economic conditions. However, this is still not enough to achieve the energy transition objectives. The investment into wind energy production is hampered by the uncertainty of future revenues of wind power producers. This uncertainty arises from the natural variability of the resource, from the climate change which is likely to impact not only future wind energy production but also electricity prices and, last but not least, from the evolution of regulatory policies. A more precise understanding of the uncertainties at stake is therefore needed for several reasons. First, it will give the private sector investors a better view of risks and opportunities associated with wind energy industry. Second, it will enable the public authorities to quantify the level of support needed for long-term sustainability of the industry and to evaluate the long-term costs of energy transition. Finally, it will allow the financial industry to develop suitable funding instruments.

Several articles in the literature use climate data to quantify wind potential and assess its uncertainty, and to evaluate the impact of climate change on the wind resource. However, these papers to not combine the data on the wind potential with the price and electricity demand component. This is all the more important because the impact of climate change on electricity demand, due in particular to the global temperature change, is expected to be stronger than the impact on the wind potential. The economics of wind energy is studied only in terms of costs but not in terms of actual revenues for the wind producers operating in the market, and consequently, the cost of public support measures needed to make wind energy profitable is rarely evaluated.

In our study, we fill this gap, by quantifying the uncertainty of the net present value of standardized wind farms in European countries and by evaluating the level and the total cost of support mechanisms needed to guarantee the profitability of the wind fleet. To this end, we build a localized model for wind power output and a country-level model for electricity demand and prices considering hourly variation of wind, load and prices, using reanalysis data, climate projections and Integrated Assessment Model

(IAM) scenarios. Our methodology is general, but for specific evaluations we focus on the examples of France, Germany and Denmark. Our study reveals that support mechanisms in these countries are needed for wind energy to be profitable under current market prices and current climate. Under future climate, using several scenarios for climate change and energy transition, we also show that the evolution of both price and wind production does not allow the wind energy industry in these countries to develop in a free-market environment and that support mechanisms will still be needed in future.

Our methodology relies on constructing a very long time series of synthetic local wind power production and national electricity prices. This is done by plugging a very long time series of climate variables into a model for wind power production and for electricity prices, calibrated on recent market and energy system data. The time series of climate variables are obtained either from historical reanalysis data (for current climate analysis) or from regional climate model projections (for future climate analysis). The synthetic local wind power production and national electricity prices are then used to simulate the revenues of standardized wind farms depending on their location, under different scenarios. This approach allows to disentangle the different sources of variability and to quantify the variations in the revenues and expenditure of wind farms at current market design and network structure, under different support schemes.

The first objective of our paper is to evaluate the net present value of standardized wind farms and quantify the associated uncertainty. In this part, we model the wind farm revenues using historical wind and temperature data spanning the 20^{th} century. Our results show that the extreme variations of net present value along the 20^{th} century are of the order of one year of revenues whatever the support mechanism used. We show that under recent climate and current market prices, profitability of wind farms is not guaranteed without support schemes. Using feed-in tariff (FiT) and feed-in premium (FiP) mechanisms with current level of support allows to guarantee profitability of wind farms in a large part of the domain.

We also show that when projecting the future value of a wind farm based on historical production records, an investor can both overestimate or underestimate the profitability due to the natural variability of wind speed and to the presence of long-term trends.

Our second objective is to quantify the support level that will be needed in future to guarantee the profitability of the wind fleet, and to evaluate the cost of such support mechanisms. To address this objective, we simulate future price scenarios using electricity demand and renewable penetration projections from integrated assessment models. These scenarios are combined with wind speed and temperature projections from the regional climate model intercomparison project (CORDEX), corresponding to several Representative Concentration Pathways (RCP). This enables us to model future local wind energy production and prices in a changing climate. Our approach allows to assess and quantify all relevant sources of uncertainty: socio-economic uncertainties corresponding to the choices made by the society (e.g the extent of climate change mitigation vs. adaptation), scientific uncertainties (corresponding to model simulations spread and associated with modelling errors), and natural/climate uncertainties (related to the natural variability of the earth system, including climate change).

Under future climate, we show that profitability of wind farms is reached in several regions of the domain only in the specific scenario of high electrification and low penetration of wind energy. Thus, to guarantee profitability of 90% of the wind farms in the future, under the assumption that future wind fleet is installed following current spatial distribution, the required premium level in France for onshore (offshore) wind farms varies from 33 €/MWh (45 €/MWh) in the best-case scenario to 66 €/MWh (78 €/MWh) in the worst-case scenario. In Germany, the premium level for onshore (offshore) wind farms varies from 68 €/MWh (76 €/MWh) in the best-case scenario to 93 €/MWh (102 €/MWh) in the worst-case scenario. In Denmark, the premium level for onshore (onshore) wind farms varies from 1.5 €/MWh (83 €/MWh) in the best-case scenario to 23 €/MWh (105 €/MWh) in the worst-case scenario. According to these results, we find that supporting the penetration of wind energy in these countries for 15 years amounts to costs for the regulator ranging from 57 to 172 billion euros in France, from 232 to 397 billion euros in Germany, and from 18 to 50 billion euros in Denmark, depending on the scenario considered and the level of penetration of wind energy.

These numbers do not consider the potential reduction of costs of wind energy; they should not be interpreted as global investment needs, but rather as costs of public support measures required to attract the necessary investments from the private sector. In comparison, the global required low carbon investments (all energy types combined) to achieve the 2°C scenario are estimated to US 320 billion per year.

However high these numbers may seem, they should be compared with potentially even higher costs of mitigating the adverse consequences of climate change accelerated by the use of fossil fuels.