Wind power and emissions in Norway vs. Germany
- a simulated case study -

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One project, suitable for master/bachelor.
Project period: June-September after agreement with supervisor.

In this internship, we will study how Norway and Germany can collaborate to reduce the overall CO2-emissions from energy production using renewable energy, hydro reservoirs as batteries and cable connections between the two energy systems. We will study this using simulation to incorporate uncertainties in demand and production. The goal is to see whether it is better to send all the wind power in Norway to Germany, or to reduce our own CO2-emissions from oil production using the wind power, or to import the wind power from Germany to cover up for our CO2-emissions.

Norway is, roughly speaking, producing more electricity than needed from hydro power. Still we are increasing the supply side by opening new wind mill plants at different locations across the country. This is to meet an expected increase in energy demand in the future as well as to reduce the emissions from the oil production by "electrifying" the platforms.

Germany, on the other hand, has a mixed power production from coal, gas, nuclear and a large share of renewable production. The renewable power is generated from PV, wind and biomass. Germany experiences often negative prices of electricity, which is due to over-supply of renewables (i.e., too much wind compared to demand). The coal and gas-fired power producers choose to run their production with loss in times with a lot of wind power in-feed, as it is more costly to shut down their plants rather than taking some losses over short time spans. With lack of sufficient battery capacity, the over-production from wind is in fact a waste of power. In Norway, we have batteries available, in disguise, as hydro reservoirs.

Norway and Germany is connected via a cable where one can transport electricity both ways. Hence, with over-supply in Germany, some of their production can be "shipped" to Norway "charging the hydro reservoir batteries". On the other hand, when over-supply in Norway, Norwegian wind and hydro power can be "shipped" to Germany whenever the renewable production there is not meeting demand, and hence in effect reducing the demand for power generated from coal and gas. Of course, the cable capacity is limiting the possibility for electricity exchange.

Demand for power is uncertain. For example, in Norway the electricity demand is much driven by temperature, as a large proportion power is used for heating in the winter. Wind and solar power production is highly intermittent, as one obviously does not have constant wind nor a clear blue sky at all times. The intermittency is also uncertain.

In the internship project, we will model the demand for power by a time series (on a weekly or monthly time), and the wind power production as a time series as well. We will have four time series for demand and wind, two for Norway and two for Germany. The time series will model the uncertainties, and be dependent on each other. The dependency may be rather small, as wind and demand overall in Norway is possibly not strongly connected to wind and demand in Germany. For simplicity, we let wind be the representative for all renewables in Germany. The CO2-emissions from the Norwegian oil production is assumed constant, coming from gas-fired production units on the platforms, which means that there is a constant additional demand for power in Norway due to electrification of the platforms.

In Germany, we will assume that the fossil-fuelled power production is equal to

$$P_f := max(D - P_r, 0)$$

Where *D* is the demand and P_r is the renewable production. For simplicity, we smash nuclear also into this part. The resulting CO2-emissions from the fossil production can be directly computed from the amount of electricity produced by fossil fuels.

On the other hand, in Germany, we send power to Norway whenever $P_r > D$. We can only transport an amount not exceeding the capacity of the connecting cable. This amount is then fed into the Norwegian power system in the next time step, which then reduces the need for using hydro power. For Norway, we assume that we have hydro power production given as an additional time series, positively correlated with the demand, reflecting the hydro balance, as well as wind power. We suppose that we can always cover the demand, but as we have indicated, we use German wind from previous time step instead of hydro power. Also, we use wind power from Norway before hydro power (as this is now subsidised and gets implicitly a priority into the grid). If the total production is bigger than demand in Norway, we send power back to Germany. The power from Norway is *only* sent to Germany if the German renewable power production is less than its demand (substituting fossils in Germany in that case). If Germany is fully covered, then the Norwegian surplus is wasted.

Question 1: How much is the CO2-emissions in Germany reduced in one year in such an energy system? We are after a full description of the probability distribution of the aggregated emissions, and we suppose that Norwegian wind power (as well as necessary hydro power) goes to cover up for the electrification of the platforms so that Norway is zero emitting.

Question 2: Suppose that we do not electrify the platforms in Norway, but let the platforms emit CO2. If we use the added wind power in Norway with an exchange with Germany, how will the total (Norwegian+German) CO2-emission probability distribution look like? Can we draw any conclusions?

Question 3: Assume we do not have any wind production in Norway, but only hydro. Based on the exact same models as before, how will the CO2-emission probability distribution look like if we use hydro in Norway to also cover the electrification of platforms. In some sense, German wind is in this case used for electrifying the platforms.

Question 4: If we reduce the oil production by a certain amount of oil, we will also reduce the CO2-emissions from production. But, equally important from an environmental point of view, is that we reduce emission also from the use of oil (for example, reduce emissions from cars or plastic production). So, if we reduce the production so that the total reduced CO2-emissions from both production and use of oil is equal to the CO2-emissions reduced by a complete electrification of the production, how is then the CO2-emission distribution of Germany? In this question, we do not introduce any wind power in Norway, or we use all the added wind power to cover own demand and in exchange with Germany.

The outcome of this project is an assessment of how uncertainty may play a role in evaluation of whether one should electrify the platforms in Norway or integrate better with Germany to reduce their CO2-emissions.

The time series models will mimic stylised features of demand and production, building on autoregressive models. We choose parameters so that we mimic the market patterns in Norway and Germany, which requires some investigations of official documents of aggregated power production, demand, share of renewables, emission rates etc.. The success of this project rests on some knowledge of Monte Carlo simulations and statistics by the internship candidate. The results are to be documented in a scientific essay, along with user-friendly software in an appropriate program environment.