A TEMPORALLY AND SPATIALLY EXPLICIT FRAMEWORK FOR ANALYSING LONG-TERM DECARBONISATION STRATEGIES- CASE STUDY FOR WIND ENERGY IN THE UK

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(1) Overview

Transitioning to a low carbon energy future needs long-term planning and technically feasible solutions. The economic modelling of electricity markets is not possible without accounting for technical constraints (Huppmann and Kunz, 2011). Investment decisions regarding renewable energy generation, transmission and storage are interconnected. A large-scale deployment of renewable energy generation can be facilitated by combining long-term planning for these infrastructure investments with seasonal, daily and short-term dynamics of supply and demand (Haller et al., 2012). Intermittent renewable energy sources (RES) vary with time and in space. Energy system models integrate the several components of the system from resource extraction, conversion into energy carriers till end-use consumption in the various economic sectors. However, they have a simplified time and geographical resolution (Simoes et al., 2013). Recently, there have been first approaches for more detailed temporal modelling in order to account for fluctuating renewable energy sources: (Kannan and Turton, 2013) and (Ludig et al., 2011). Others developed hybrid modelling approaches soft-linking energy system models with temporally detailed power system models: (Pina et al., 2013), (Deane et al., 2012) and (Welsch et al., 2012). In all those studies the focus is on the improvement of the time resolution in energy system models but they disregard the spatial variability. However, intermittent renewable energy sources and demand vary with time and in space due to the small spatial resolution over which these vary. Further, without considering the location of transmission lines and generation capacities, effects on the transmission grid and the need for its extension can not be evaluated. If introducing geographically differentiated availabilities the energy system model will consider a supply cost curve. Consequently, only regions with high enough availabilities will be considered for the solution. If using geographically aggregated renewable resource data in a dispatch model, the choice of flexible instruments will be under- or overestimated. Averaging wind availability and demand does not capture events of e.g. low wind availability and high demand when the usage of backup plants or stored electricity is necessary. Further, a disaggregated approach allows modelling at different aggregates.

There is a lack of research methodologies being able to answer the following questions: What are the cost effective, technically feasible long term decarbonisation strategies leading to a low carbon power system? What is the role of flexible elements in the energy system to support a large scale integration of renewable energy sources? Most studies do not include the systemic view necessary (Haller et al., 2012) combining long-term planning with an adequate representation of the spatial and temporal characteristics of RES to provide sufficient insight to answer these questions. We address the lack of previously developed methodologies by proposing a hybrid-modelling approach that addresses both temporal and spatial characteristics of renewable energy sources by combining an energy system model with a power dispatch model. This framework allows examining the technical feasibility and market implications of the results from a long term planning model.

We apply the model to the United Kingdom which is in the process of integrating high shares of intermittent renewable energy sources into its energy system and is therefore a good case study. The target share of energy from renewable sources in gross final energy consumption amounts to 15% in 2020 from 1.3% in 2005 (European Commission, 2009). In the National Renewable Action plan the UK government estimates wind offshore to represent 37%, wind onshore 29%, ocean energy (tide and wave) 3% and solar PV 2% of gross renewable electricity consumption in 2020 (Department of Energy & Climate Change, 2010). According to the (Department of Energy & Climate Change, 2010) the UK has the best wind, wave and tidal resources in Europe. Wind and tidal energy sources are geographically diverse over varying terrain, meaning that analysis of spatial variability is interesting. As wind energy will represent the largest share of variable RES we will in this modelling exercise solely concentrate on this resource.

(2) Methodology

We soft- link two models in order to analyse long term-investment decisions in generation, transmission and storage capacities and the effects of short-term fluctuation of renewable supply: The national energy system model UKTM (UK TIMES model) and a dispatch model both developed at the UCL Energy Institute. This approach allows us to determine the technical feasibility of the UKTM solution from 2010 until 2050, thus determining lower bounds of flexible generation. Further, the dispatch model gives additional insights into the electricity market. UKTM is a linear optimization bottom-up technology-rich model based on the TIMES model generator. It minimizes total energy system costs required to satisfy the exogenously set energy service demands subject to a number of additional constraints (Loulou and Labriet, 2008). UKTM contains 16 time slices: 4 seasons and 4 intraday (day, evening, late evening, night). The model comprises a time period from 2010 (the base year) to 2050 with one model period covering 5 years (represented by one representative year). More information on UKTM can be found in (Daly et al., 2014) and on the TIMES model generator in (Loulou and Labriet, 2008) and (Loulou, 2008). Similar to other dispatch models (Brancucci Martínez-Anido et al., 2013; Weigt et al., 2010), our dispatch model maximizes welfare or in other words minimizes annual variable electricity production costs. Costs are defined for each electricity generation source as the sum of the variable operation and maintenance costs and fuel costs. In addition, we also include CO_2 emissions. Input data are the power plants resulting from UKTM and variable electricity production costs per plant. For the dispatch model we combine them with technical information such as start costs and ramping rates. Other data are hourly demand time series and hourly resource time series (wind output, solar irradiation, run- of river flows and inflows to storage).In the scope of this analysis, we use highly spatially and temporally resolved time series for potential sites of wind power installations. We obtained wind speed data from the NCEP - CFSR climate reanalysis (National Centre for Climate Prediction Climate Forecast System Reanalysis) (Saha et al., 2010). We interpolate the meteorological data to a 0.5^o x 0.5^o decimal grid. Wind speed is provided at 10 m above the Earth's surface by NCEP – CFSR. This was adapted to turbine hub height using the power law, and a Hellman exponent of 1/7 onshore and 1/9 offshore, following a review of relevant literature. We locate the existing plants, plants under construction and for which construction is confirmed using the DECC planning database on renewable generation (Department of Energy & Climate Change, 2014). Based on the location we allocate the wind power plants to the wind power time series. This gives us the yearly wind power output for each turbine. We implement in UKTM regional wind power potentials differentiated by availability per time slice taking into account the currently installed wind power plants. Running UKTM gives us as result built power plants, built wind turbines per region and total electricity demand which we use as input into the dispatch model. We again allocate them to the wind time series to get the hourly electricity production per wind turbine and run the power dispatch model with the built power plants resulting from UKTM. We use the dispatch model to study the technical appropriateness of the solution given by UKTM from 2010 until 2050. We run a sensitivity analysis changing the wind resource year.

(3) Results

Results allow us to determine the technical feasibility of the UKTM solution. We can evaluate if the model installs enough flexible elements (e.g. storage, gas turbines) to manage the intermittency of wind energy output. Furthermore, the use of the power system model will give us additional information on the electricity market such as market prices. Preliminary results indicate that the spatial disaggregation of wind energy resources leads to a higher share of wind energy in the energy system. The energy systems model does not implement sufficient backup capacity such as gas turbines or energy storage which suggests to implement upper bounds (e.g. maximum wind capacity without backup capacity) and lower limits (e.g. storage) and run the models in an iterative process.

(4) Conclusions

We present a methodology which allows to better represent the power sector in energy system models. This will become increasingly important when evaluating energy systems with high share of fluctuating renewable energy sources. The modelling approach combines the benefits of two models: an energy system model to analyse decarbonisation pathways and a power dispatch model which can evaluate the technical feasibility of those pathways and the impact of intermittent renewable energy sources on the power market.
Further research will include the linking of a regional version of UKTM and the modelling of the electricity grid and interconnectors to neighbouring countries in the dispatch model to allow for a more realistic analysis.

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