Use of the CASCADE agent-based model to examine the UK energy system with climate reanalysis data

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07 August 2014

1. ABSTRACT

UK electrical demand is met by various sources of generation, with an increasing integration of renewable energy in recent years. By modelling the UK electricity network from 2005-2012 for a two region scenario (Scotland and Northern Ireland, and England and Wales) using climatic reanalysis data, patterns in the UK energy mix have been examined in detail. It is found that past electrical demand could have been met by a large variation of different generation types, achieved by altering the capacity factors of power plants. This includes a 33% reduction in the use of natural gas in 2009.

2. INTRODUCTION

The results in this report are derived from the agent based model, CASCADE (Complex Adaptive Systems, Cognitive Agents and Distributed Energy). The framework of the model was initially set up to investigate the smart grid concept (Rylatt et al., 2013), but its structure has been adapted to model the UK electrical grid with climate data. The structure of this model is shown in Figure 2.1.

The first level of Figure 2.1 shows the inputs into the model. Further details of these inputs follow in the next section. The second level of Figure 2.1 is the context. In CASCADE the context is the “area” where agents are built and interact with each other. Here, the data is read into the context, the context creates the prosumers, the aggregators select the appropriate prosumers, and the aggregators themselves are added to the context. The third level in Figure 2.1 contains the prosumers: a producer and/or a consumer of energy. These consist of individual generating stations, and a demand prosumer for each region. Finally, the forth level contains the aggregators: one for Scotland and Northern Ireland and one for England and Wales. These aggregators select the prosumers that are in their region and sum their supply/demand.

Figure 2.1: Structure of the CASCADE model for a 2 region scenario
3. METHOD

Three datasets are required for CASCADE to run (3.1). This collected data was demand data (3.1.1), generation data (3.1.2) and climate reanalysis data (3.1.3). The fixed time step of 30 minutes meant half hourly demand data and climate data was needed. The CASCADE code that existed was adapted to suit the purpose of this project (3.2). The coding of this project involved creating a context (3.2.1), prosumers (3.2.2) and aggregators (3.2.3). The coding was implemented in the java language.

3.1 Data Collection

3.1.1 Demand data
The demand data was extracted from the national grid website (National Grid, 2013). This data is publicly available at 30min time steps for the entire period we are interested in, therefore the data was simply extracted from the website and read directly into the model.

3.1.2 Generation data
The generation data collected was separated into wind and non-wind because wind generation has a weather dependence, therefore it made sense to keep them apart in the model. The non-wind data needed to include generation plants in the UK that were open for any amount of time from 2005-2012. This data was obtained from the Digest of United Kingdom Energy Statistics (DECC, 2013) containing: date opened, date closed and max capacity, for each generating station. The location data was found from various sources and verified via existing maps of UK power stations.

Wind generation data was obtained from the UK Wind Energy Database (RenewableUK, 2013). This contained each wind generation project in the UK operational as of July 2013 with type, date opened, date closed, location, number of turbines and max capacity of each turbine, for each wind project.

3.1.3 Reanalysis data
The climate data was extracted from NASA’s MERRA reanalysis (Rienecker et al., 2011). The reanalysis data used for the England and Wales region represented a location of -1°E 51.5°N (roughly London) while the data used for the Scotland and Northern Ireland region represented a location of -3.2°E 56.0°N (roughly Edinburgh). The original data was at an hourly time step from 2005-2012, but because of the fixed time step of the model, we required half hourly data. To adapt the original data linear interpolation was used to create a half hourly data point between each of the hourly data points.

3.2 Coding

3.2.1 Context
At the centre of the CASCADE code is a suitable context. This reads in the data files, creates the prosumers and aggregators to be used in the model and builds the context with these agents added.

3.2.2 Prosumers
The context calls to create prosumers in the model. It is in the prosumer code where the attributes of individual prosumers are set. Each of the non-wind generators are created as a prosumer and assigned a location (lat/long), maximum capacity and a date operational/closed.

Each of the wind generators are created as a prosumer and assigned a location (lat/long), max capacity of each turbine, number of turbines, current generation based on weather data and date operational. In addition, each wind prosumer also falls into a capacity bin which defines its hub height, efficiency, cut in/cut out wind speed and blade length.

The final type of prosumer is the demand prosumer. The total UK demand is divided according to the population of each region, and the demand prosumer simply contains a location and demand.

3.2.3 Aggregators
The model contains two aggregators, one for each region. The purpose of these aggregators is to balance all the demand and supply that falls into its region, with a particular interest on the wind generation, as this shows variability due to the climate data. To do this each prosumer is added to a network in the context, and then a list is created of all prosumers contained in that network within the aggregator. The aggregator then extracts the prosumers that fall into its location and balances their
demand and supply. It does this by first finding the region demand, and then adding supply (most cost effective supply first) until it meets the demand. At this stage, a capacity factor is applied to account for the fact that power stations don’t operate at their full capacity all of the time.

4. INITIAL RESULTS

At this early stage only simplified tests are carried out by CASCADE. The generation in England and Wales, by type, that meets demand in summer and winter is analysed to identify temporal trends (4.1). Net demand in each region is plotted to observe if demand ever exceeds supply at a set capacity factor (4.2). The actual generation mix and the generation mix produced by the CASCADE are compared to look at how demand could have been met, compared to how it was met (4.3).

4.1 Temporal trends

*Figure 4.1* represents a typical summer and winter week in the England and Wales region. First note that the capacity factors (defined as average operational capacity/max capacity) are set for hydro, coal and gas as 0.28, 0.64 and 0.7 during the summer and 0.28, 0.8 0.8 during the winter, respectively. Since the capacity factors are seasonally fixed in the model, the values used are higher than annual average capacity factors (DUKES, 2013) to account for peak demand times.

Both *Figure 4.1 a)* and *b)* show strong weekly and daily trends. In the both seasons weekend peak demand is 13-14% lower than the weekday peak demand. This trend highlights the higher non-domestic demand on weekdays. The diurnal cycle consists of minimum demand during the overnight hours, and max demand during the morning and evening. The evening peak during the winter appears to be much more pronounced, likely due to the requirement for domestic heating at this time of year.

Monitoring at the generation by type shows that nuclear and coal act as the “base load generators” providing the energy that is constantly needed, and the more expensive gas power stations meet the peak demand when required. In summer coal generation is not saturated at lower demand, but in winter, coal generation remains saturated throughout the week. This is a direct result of how the model has been set up, and varying the capacity factors with time would allow greater variation in the base load generators. It is also clear to see that the renewable generation plays an important part in meeting the peak generation in both summer and winter.

*Figure 4.1*: Friday-Friday demand/supply in summer and winter by generation type.
4.2 Net Demand
The model was run for the entire period 2005-2012, with the capacity factors at their winter values. The only time that demand exceeded supply in either region was at the end of 2007 in England and Wales. Figure 4.2 shows the net demand during the week this occurred. The demand outweighed supply on two consecutive 30min periods, once by 102MW and the other by 347MW. Looking at the same periods for the Scotland and Northern Ireland region, we can see that there is approximately 1000MW excess supply at both times, so the shortfall in England and Wales could have been supported.

Figure 4.2: Net demand for each region from 2005-2012

4.3 Generation mix
Comparing the actual generation mix for 2009 shown in Figure 4.3 a) and the generation mix produced by the CASCADE model in Figure 4.3 b) it is seen that the UK had the resources to meet demand with a significantly different mix of generation than it was. The capacity factors were set at the winter values and gas and oil are combined in the model. The model met 33% less of the demand with gas/oil and 36% more of the demand with coal and nuclear. This again is a direct result of how the model is set up. Since the model allows nuclear and coal to meet the base demand, and gas to meet peak demand only when needed, a shift from gas to nuclear and coal is expected.

Renewable generation was well represented in the model with only 1% difference from the actual generation. This confirms the reanalysis data is accurate as the renewable generation depends highly on the wind speed input. This naturally determines the capacity factor of the renewable energy, rather than having a fixed value hard coded into the model.

Figure 4.3: 2009 UK electrical generation by type
5. CONCLUSION

This report has summarised the set up and current status of the CASCADE model to examine the UK electrical grid using demand, supply and reanalysis data.

The findings show that when looking at generation by fuel type, past UK demand could have been met with a large mixture of different generation types, achieved by altering the capacity factors of power plants. By setting nuclear and coal as base-load generators, the fluctuating demand (due to daily and weekly trends) could then be met by varying other generation, mainly natural gas. When testing to see if supply meets demand in each region it was found that the demand exceeded supply on two occasions from 2005-2012 in England and Wales. On both occasions, the shortfall in England and Wales could have been supported by transmission from the Scotland and Northern Ireland region. Finally it is shown that the energy mix proposed by the model differs to figures published by the BBC, showing that the UK had the resources to use 33% less natural gas than it has done in the past. However, this resulted in a 21% increase in the use of coal.

Although many useful results have been derived from this project, it is clear that it still contains large simplifications of a real world scenario. Currently there is no transmission link between the two regions in the model, but this is something that could be added in further development. This would create an interaction between the two aggregators allowing agent based behaviour to emerge. The concept of trading could be extended to reduce costing by including a market aspect to the model. For example, if one region was producing energy with an expensive fuel, while another region had potential to produce that energy with a cheaper fuel, then a transmission link could allow the energy to be generated at a lower cost in the other region and transferred over. In the existing version of CASCADE, a market aspect of the model already exists. This is something that should be implemented in the future and would greatly enhance the value of the model output. The power plants in the model currently switch on at their maximum capacity, but realistically power plants take time to build up to this capacity. Adding a ramping rate functionality would give a better representation of supply that is available at any given time. This would work side-by-side with the market with, choosing whether to use any power plant based on its ramping rate. Using London and Edinburgh as representations of the two regions across the UK is a large approximation. By separating the UK into smaller grid boxes, the errors in the climate data become smaller, and transmission between areas in the UK can be accounted for.

Once these improvements have been applied, the model could continue to run into the future using predicted demand, supply and a simulated future climate where the output could be beneficial to future development of the UK electrical grid.

6. REFERENCES

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