MODELLING REAL-TIME PRICING DEMAND RESPONSE IN A LONG-TERM WHOLE ENERGY SYSTEM MODEL, UK TIMES

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Overview

To meet the UK 2050 decarbonisation target, whole UK energy system should be transformed dramatically by adopting low-carbon technologies in both energy supply and demand sectors. In the UK, electricity generation alone was responsible for 31 percent of greenhouse gas emissions in 2014 (DECC, 2016a). Low-carbon power technologies, such as PV and wind turbines, should thus be deployed on a significant scale to reduce the GHG emissions from electricity generation. With the high penetration rate of variable renewable energy (VRE) in the future system, it is crucial to improving system flexibility to ensure the electricity supply stability. Demand response (DR) is one of the major measures should be taken into account to accommodate VRE and to balance energy supply and demand. An energy system model should thus incorporate the dynamics of DR to determine the optimal strategy of demand-side management.

Although many studies have been done to develop models for DR, most of those studies were only focus on power market or electricity system (Pallonetto et al., 2016; Rahmani-andebili, 2016; Neves et al., 2015). The influences of demand-side technologies were often neglected or represented by a limited number of predefined development scenarios. Therefore, only the benefits for supply-side technologies were fully explored. The complicated interaction between DR and energy demand technologies, such as electric vehicles or heat pumps, cannot be well represented in those models. This study thus aims to develop a modelling framework for DR in a whole energy system model, UK TIMES (UKTM) model, which includes all energy supply and demand sectors in the UK. As a result, not only the influences on the supply-side technologies can be evaluated, but also the impacts on demand-side technologies can be determined.

DR measures can be price-based or incentive-based. Price-based measures include Real Time Price (RTP), Critical Peak Price (CPP) and Time of Use Tariff (TOU). As for incentive-based, where the participating customers are rewarded for reducing their load when requested by an aggregator or TSO (Pallonetto et al., 2016). More automatic DR measures, such as direct load control, would require additional communication infrastructure in place; therefore, those measures will be available in the farther future. In the near- to medium-term, DR measures depending on consumers' behaviour would be carried out first to improve the system flexibility. To evaluate the benefits to the whole energy systems, consumers' responses should react to the real-time pricing signals to lower the total system costs, such as lowering peak-load demand to reduce the consumption of electricity with higher costs. Therefore, the purposes of this study are twofold.

1. Develop a modelling framework for real-time pricing DR in a long-term energy planning model.

2. Evaluate the benefits of DR in the whole energy system, including supply and demand sides.

This paper is organised as follows: The adopted energy model (UKTM model) is briefly introduced, followed by the explanation of the proposed modelling framework in the TIMES model, which is a linear programming optimisation model. The adopted elasticities for demand response are then addressed. Scenarios with and without DR in intra-day timeslots are then applied to the proposed model to investigate the impacts on the whole energy system. Finally, the benefits and influences on both supply-side and demand-side technologies are explored.

Methods

UKTM is a bottom-up, technology-rich, dynamic, linear programming optimisation model consisting numerous alternative energy supply/consumption technologies for decarbonisation in the whole UK energy system. UKTM is developed by the UCL Energy Institute as the successor to the UK MARKAL model. It is based on the model generator TIMES (The Integrated MARKAL-EFOM System), which is developed and maintained by the Energy Technology Systems Analysis Programme (ETSAP) of the International Energy Agency (IEA). Besides its academic use, UKTM is the central long-term energy system pathway model used for policy analysis at the Department for

Business, Energy & Industrial Strategy (BEIS) (DECC, 2016b) and the Committee on Climate Change (CCC) (CCC, 2015).

To model the DR, the effects of demand shedding and shifting should both be considered. Demand-shedding can be modelled in the TIMES model with the existing elastic demand mechanism. By default, the demands are fixed for each energy service requirements in each sector, such as lighting, cooking, and passenger commuting. Once demand elasticity is introduced, the model can change the energy service demands (ESDs) as a function of energy price, which is determined by the energy technology mix. The ESDs then turn into variables and are solved in an equivalent model formulation to maximise the net total surplus of system cost (Loulou et al., 2005). Consequently, while the energy price increases at a time-slice, the ESD reduces according to the given elasticity. The demand shedding effect can thus be represented.

In order to reflect the demand-shifting effect, which is missed in the original framework, new constraints are introduced to ensure the reduced ESD at a time-slice can be shifted to other time-slices on the same representative day. The summation of the left ESD and the shifted ESD for each time-slice should remain constant as their original predefined amount. With the new constraints, the new framework can deal with RTP DR in the whole energy system model.

Results

First of all, the proposed framework was implemented in the UKTM model.

Secondly, demand elasticities were applied within the range of what reported in the literature on short-run price elasticity of residential electricity demand.

Thirdly, the developed framework was applied to two scenarios, one with DR and the other without DR, to reveal the influences of DR. The differences of hourly ESDs, activities of residential technologies, fuel consumption in the residential sector, sectoral electricity consumption, electricity supply by fuel type, primary fuel consumption, total system costs, and GHG emissions are presented.

Conclusions

According to the results, residential energy service demands in peak-load time-slices are shifted to reduce electricity consumption and to balance electricity supply and demand. More heat pumps are deployed to improve system flexibility and to further decarbonise residential heating. On the supply side, wind and storage technologies are more active while less electricity is generated by nuclear power. As a result, in 2050, GHG emissions can be further reduced by 1.8 million metric tones of CO2eq (about 1% less) and total system costs is about 835 million GBP less (about 0.18% cheaper). However, the influences are relatively small. Further sensitivity studies are essential to verify the robustness of the conclusion.

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