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Including dynamic CO_2 intensity with demand response

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HIGHLIGHTS

- We present a formula for calculating hybrid dynamic CO_2 intensity of electricity generation mixes.
- We apply the dynamic CO_2 Intensity on hourly electricity market prices and generation units for Great Britain, Ontario and Sweden.
- We calculate the spearman correlation between hourly electricity market price and dynamic CO_2 intensity for Great Britain, Ontario and Sweden.
- We calculate carbon footprint of shifting 1 kWh load daily from on-peak hours to off-peak hours using the dynamic CO_2 intensity.
- We conclude that using dynamic CO_2 intensity for load shift, controlled by dynamic pricing mechanisms, further reduce the carbon footprint.

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ABSTRACT

Hourly demand response tariffs with the intention of reducing or shifting loads during peak demand hours are being intensively discussed among policy-makers, researchers and executives of future electricity systems. Demand response rates have still low customer acceptance, apparently because the consumption habits requires stronger incentive to change than any proposed financial incentive. An hourly CO_2 intensity signal could give customers an extra environmental motivation to shift or reduce loads during peak hours, as it would enable co-optimisation of electricity consumption costs and carbon emissions reductions. In this study, we calculated the hourly dynamic CO_2 signal and applied the calculation to hourly electricity market data in Great Britain, Ontario and Sweden. This provided a novel understanding of the relationships between hourly electricity generation mix composition, electricity price and electricity mix CO_2 intensity. Load shifts from high-price hours resulted in carbon emission reductions for electricity generation mixes where price and CO_2 intensity were positively correlated. The reduction can be further improved if the shift is optimised using both price and CO_2 intensity. The analysis also indicated that an hourly CO_2 intensity signal can help avoid carbon emissions increases for mixes with a negative correlation between electricity price and CO_2 intensity.

1. Introduction

Increased electrification in emerging markets and modernisation of power grids in mature markets are strong trends in today's society. New business models and control solutions whereby consumers take on a more active role are being discussed. Many of these discussions concern customer participation to reduce electricity consumption during peak hours. So far, demand side participation for the residential sector has been hindered by the electricity market where the major obstacles have been identified as: lack of hourly tariffs, lack of high-speed communication between retailer and household, lack of household electricity storage for shifting load, and household cost for demand response technology (Albadi and El-Saadany, 2008; Kirschen, 2003; O'Sheasy, 2003). With increased broadband access, smart meters and the introduction of hourly rates on some liberalised markets this is slowly changing. In the near future, a large proportion of electricity consumers may have demand response tariffs and will then be able to react to price variations by consumption reductions or shifts in time.

Reducing electricity consumption will have a positive environmental impact. In contrast, the environmental impact of shifting consumption using demand response tariffs can be both positive and negative. Assuming that the electricity generated during peak hours is dirtier than that generated during off-peak hours, than shifting electricity from peak hours would have a positive environmental impact. There is good reason to believe that this is the case if the marginal generation cost is considered. The EC has summarised two scenarios (high and moderate fuel price) and their impact on the costs of producing electricity with a variety of fuel sources (EC, 2008). The projected production costs for 2030 in

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the EC moderate fuel price scenario are: natural gas CCGT €80/MWh; oil CC €125/MWh; coal IGCC €70/MWh; nuclear €45/MWh; solid biomass €85/MWh; biogas €50/MWh; wind €50/MWh; hydro €30–50/MWh; and solar PV €170/MWh. Natural gas-fired, oil-fired, biogas-fired and hydro power generation can be used as spinning reserves for demand peaks. Oil and natural gas have higher production costs than biogas and hydro in the EC scenario and should thus be utilised last during peak demand. If the electricity market price for a fuel-type specific generation unit were to be linearly correlated with the generation costs of the same unit, then the market price would reflect the generation costs.

However, it is not only the generation costs that decide the market clearing price for electricity. Congestion, imbalances between demand and supply and hydro reservoir levels are just some of the other factors affecting the price of electricity on the market. Access to electricity generation fuels and technologies varies between regions and countries, thereby affecting electricity generation costs (IEA and NEA, 2010). Due to these impact factors and variations, one electricity mix with the same characteristics in terms of fuel type-specific generation units and CO_2 intensity could have a different price on different days and in different regions. For example in Sweden, hydro power is priced differently depending on the levels and inflow in the hydro reservoirs. This does not mean that the generation costs vary, but that the availability of the free fuel (water) varies.

Hourly electricity market price or time of the day is therefore not necessarily a good indicator of the hourly emissions of the electricity generation mix. We therefore constructed a better indicator, the dynamic hourly CO_2 intensity signal, which uses statistics on hourly electricity generation mix data as input. Actual hourly generation data, not capacity data, are used to calculate the generation mix carbon intensity. The signal is used to study historical relationships between hourly electricity market price and CO_2 intensity. To our knowledge this has not been done previously, owing perhaps to the fact that actual electricity generation (not capacity) and price data with an hourly resolution are seldom published in a format that does not require considerable editing or aggregation over a very long period. We found three data sets with hourly resolution, for the Great Britain, Ontario and Swedish electricity markets, respectively. These data sets were used to establish the dynamic CO_2 signal and to test the hypothesis of a correlation between hourly electricity price and CO_2 intensity. The data sets were also used to test the cost and carbon footprint impact of shifting 1 kWh daily from an on-peak hour to an off-peak hour.

In subsequent sections of this paper we discuss the electricity market, demand response for the residential sector, electricity information disclosure and potential customer responses to electricity disclosure. We then describe the justification and the method for calculating dynamic CO_2 intensity and present the resulting dynamic CO_2 intensity and load shift values for the electricity markets in Sweden, Great Britain and Ontario. We end by discussing the results of the dynamic CO_2 intensity application.

2. Demand response

2.1. Electricity pricing

In the electricity market, the customer has a contract with a distribution company, which makes sure that the customer has a functional grid connection point. In the early days of electricity system development, there was no market separation between electricity supply and distribution and the same company managed the grid connection and the electricity supply. Today many countries, especially in Europe, have opened up their electricity markets. The result is a separation of distribution and supply, which allows customers free choice of supplier.

In the last couple of years, electricity suppliers and researchers have tested new ways of billing customers for electricity on a time basis. Each hour of electricity supply is given a special price characteristic in relation to the hours of peak consumption. Suppliers talk about on-peak and off-peak hourly prices or tariffs. Although electricity supply still remains a service, each hour of supply can be seen as a product which the customers are expected to buy more or less of, depending on price. Customers are expected to change their demand patterns in response to hourly prices per kWh. A response could be to e.g. do laundry or cook later on in the evening.

Demand response is defined as the change in electricity usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time (Albadi and El-Saadany, 2008; Borenstein et al., 2002). The changes can be implemented as time-of-use (TOU) tariffs dividing the hours of the day into periods, with for example on- and off-peak tariffs. Another option is critical-peak-prices (CPP) which increases the electricity price significantly when the grid is in danger of not coping with the peak demand. A third option is real-time-prices (RTP), which are directly proportional to the hourly electricity market prices. Demand response is seen as a cost-effective alternative to investments in electricity storage and network improvements (Sioshansi, 1991). Furthermore, demand response has been investigated as a tool for mitigating market power, stabilising wholesale market prices, managing system reliability and maintaining system resource adequacy (Herter et al., 2007). Developments in demand response vary substantially between countries, reflecting national conditions and triggered by different sets of policies, programmes and implementation schemes (Torriti et al., 2010).

Demand response programmes struggle with the incentive models for the customers. Reported participation levels from trials around the world demonstrate that residential demand response has to be worked for, even when some form of variable pricing has become the default option (Darby and McKenna, 2012). However, demand response tariffs could benefit from being complemented with an environmental disclosure in the form of a dynamic CO_2 intensity signal.

2.2. Electricity disclosure

A mix of modern technology and new government policy is about to transform disclosure (Thaler and Tucker, 2013). Disclosure can be taken to mean opening up, exposing, viewing or making known information (Merriam-Webster, 2013). The goal of good disclosure should be to ensure that consumers know what they are getting and can compare products. The US approach to better disclosure is called “Smart Disclosure” (McGowan, 2012) and the UK approach is called “midata” (BIS, 2012). Disclosure can concern any kind of data, e.g. location data but also electricity attributes data.

Electricity disclosure according to the European Union (EU) means that electricity suppliers should specify in or with their bills and in promotional materials made available to end customers:

(a) the contribution of each energy source to the overall fuel mix of the supplier over the preceding year; and (b) at least the reference to existing reference sources, such as web-pages, where information on the environmental impact, in terms of at least emissions of CO_2 and the radioactive waste resulting from the electricity produced by the overall fuel mix of the supplier over the preceding year is publicly available (EC, 2009).