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Hourly-based greenhouse gas emissions of electricity – cases demonstrating possibilities for households and companies to decrease their emissions

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ABSTRACT

Greenhouse gas emissions from electricity production are a crucial part of the environmental impact assessments of any kind of product, service or consumption. Usually, average annual emissions are used, but lately there has been increased interest in the daily-based and hourly-based emission coefficients for electricity. In such markets, where the technology mix in the production process includes technologies with different emission factors, there is potential for large variation in hourly based emission factors and consequently this offers potential for decreasing the emissions by real-time based demand management. However, in real life the timing of electricity use in households and companies has restrictions. In this paper, we show illustrative household and company cases with realistic shifts in the timing of electricity use. We determine hourly based emission factors and give examples of how emissions may be decreased in households and companies by changing usage patterns, and consequently the timing of electricity use, with the total amount of electricity consumed remaining unchanged. The examples show decreases of emissions in the range 3–8% due to optimised timing, indicating that there is important potential for managing hourly based demand loads and the resulting emissions even with realistic assumptions of the timing of consumption.

1. Introduction

Electricity production is, at a country level based, on a combination of different technologies. The mix of production technologies can vary significantly hour by hour, depending on the demand and supply conditions. Due to this, the marginal cost of producing electricity can change significantly according to the time of the day. This has not been, however, reflected in retail electricity prices, which have not typically been dynamic on an hourly basis. Economists have long seen this unbundling of marginal costs from current prices as potentially problematic. Until recently, technological constraints have prevented the use of efficient price setting logic. The development and installation of intelligent automated metering technologies and devices, however, changes this picture. The first real-time pricing contracts have already been signed in many countries, and this development can be expected to gain ground in the near future. According to several recent analyses (Kopsakangas-Savolainen and Svento, 2012a, 2012b; Holland and Mansur, 2008), real-time price based contracts give an incentive for more efficient production structures, but their impact on greenhouse gas (GHG) emissions is not always straightforward. Real-time pricing was developed in order to reduce demand through price signals, consequently reducing demand mainly at peak load hours, allowing for efficiency in load management. However, this does not mean that total demand reduces. Depending on other market conditions demand may be only shifted from peak demand hours to less high demand hours. This gives the correct signal from a long-term cost efficient production structure point of view, but the effect of this kind of demand shift on emissions is not straightforward (Holland and Mansur, 2008). The impact on emissions depends on the underlying production

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technologies and the primary fuels they use. If e.g. peak load production[1] is based on gas turbines and mid-merit production[2] is based on coal fired condensing power production, then the demand shift from peak load hours to mid-merit hours increases emissions. Consequently, in order to more efficiently manage demand in an emission-reducing way, there is also need for more than just a price based mechanism. Automatic measurement and control technology and smart grids enable a new type of demand-oriented electricity contracts, including those which utilise emission-based demand elasticity. From an energy system point of view, real-time emission based demand management and real-time price based demand management should not been seen as alternative to each other but rather as a complementary methods.

The various emissions, including GHG emissions, from electricity production are a crucial part of the environmental impact assessments of any kind of product, service or consumption. Usually, average annual emissions are used, but lately there has been increased interest in the electricity market in daily-based and hourly-based emission coefficients for electricity. The variation in hourly based emission factors depends especially on the technology combination used in the production process. If the technology combination in the production process includes technologies with widely different emission factors, as is the case for GHG emissions in Nordic power markets, and in Finland as a part of it, there is potential for large variation in hourly based emission factors, and consequently this offers potential for decreasing GHG emissions with efficient real-time-based demand management.

Housing uses a great amount of energy (IEA, 2008), in which space heating has an important role. The provision of real-time information has been associated with a decline (up to 17%) in electricity consumption (Gans et al., 2013). On the other hand, residential electricity demand has been found to be price-inelastic, indicating that lowering electricity-consumption-related GHG emissions requires more than an increase in electricity retail price (Lima et al., 2011). Demand side management, and specifically impacts of households' load control, together with different type of smart technologies in homes, such as home energy management systems (HEMS) and advanced metering infrastructure, have been studied and discussed previously (see e.g. Gans et al., 2013; Malik and Bouzquenda, 2013; Rastegar et al., 2012; Fróes and Portillo, 2012). Real-time information about electricity consumption enables direct and dynamic load control, and can thus help and support conscious, as well as sustainable consumption. In the future, demand for systems providing such real-time information about the consumption, and moreover the related emissions and costs, will increase. Some smart system tools and services for load control are already available for consumers (see e.g. BaseN, 2013; Giordano et al., 2011).

Avoiding emission intensive production by shifting the timing of some electricity consumption, *e.g. by means of smart grid technologies,* has been seen as an important means for decreasing the GHG emissions from the production-consumption system (Giordano et al., 2011). Koksal et al. (2015) presents side-by-side analysis of energy, cost, and environment effects of hourly electricity consumption of the main electricity end-uses in a sample of homes in the Canadian province of Ontario and show how this information may be used by homeowners for reducing their electricity consumption and by system operators for reducing peak loads. In analysing the potential decrease at a national level, only general assumptions can be made about the shifting of electricity use. In real life there are restrictions on the timing of electricity use in households and companies, as the running of various appliances cannot be organised at any time of day: daily routines determine the times when washing machines and dishwashers are loaded with dirty clothes and dishes, and company workers need lightning during their shifts. In this paper we determine hourly based GHG emission factors and give illustrative cases showing how GHG emissions may be decreased in households and companies by making realistic changes to the use patterns and consequently the timing of electricity use, with the total amount of electricity consumed remaining unchanged. In these cases, electricity production in Finland, as well as electricity consumption in some Finnish households and companies are used.

The rest of the paper is structured as follows: In Section 2 we give background information on the Finnish electricity markets as a part of a larger Nordic power market. Section 3 presents the methodology behind the emission factor calculation. In Section 4 we give the results of emission factor calculation and analyse cases illustrating the decrease in GHG emissions due to realistic shifts in the timing of electricity consumption. Section 5 discusses the findings and concludes the study.

2. Background on Finnish electricity markets

Finland is part of the Nordic power market. The Nordic power market was the first international power market and it consists of four Nordic countries (Sweden, Finland, Norway and Denmark), Estonia and Lithuania. These countries run a common power exchange, the Nord Pool, where market participants can buy and sell electricity. The common power market was mainly motivated by efficiency reasons. The combination of production technologies in the Nordic Power market is quite large, and it has been argued that it would improve the efficiency of production if market participants could trade between countries. The main part of the production in Finland and Denmark is based on thermal generation, whereas Norway is a very hydro-intensive country where 99% of total electricity production is based on hydro-power (see e.g. Statkraft, 2015). In Sweden, electricity production is mainly based on hydro and nuclear power (83% of total production in 2013, see e.g. Swedish Energy Agency, 2015).

In the Nordic power market the wholesale trade of electricity is organised through the Nord Pool power exchange, which is owned by national transmission system operators. The power exchange operates by market participants, who consist mainly of large energy producing companies or energy consuming companies,[3] making their quantity-price bids one day in advance to the hourly market. The resulting market clearing price for each hour is called the system price. The system price is the main driver behind the retail prices. The retail price for a specific customer (residential or commercial/industrial) is based on their individual retail price contract. There are a large variety of retail price contracts, from which the customer can freely choose the one he/she prefers. Retail price contracts include e.g. flat price contracts, time-of use contracts and spot price contracts. Even though Nord Pool is a voluntary market, more than 70% of the total consumption of electricity was traded through it in 2011. The remaining 30% went either to own consumption or was traded based on bilateral contracts. The aggregate demand for electricity in the Nordic countries has been quite stable from year to year and the increase has been mainly due

[1] In this study it is assumed that peak technology includes oil fired condensing power plants as well as gas turbines.

[2] By mid-merit production we mean a production which is in the middle of the merit order dispatch schedule.

[3] For further information regarding on market participants of the Nord Pool day-ahead markets see www.nordpoolspot.com/TAS/membership.

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