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Cost and carbon reductions from industrial demand-side management: Study of potential savings at a cement plant

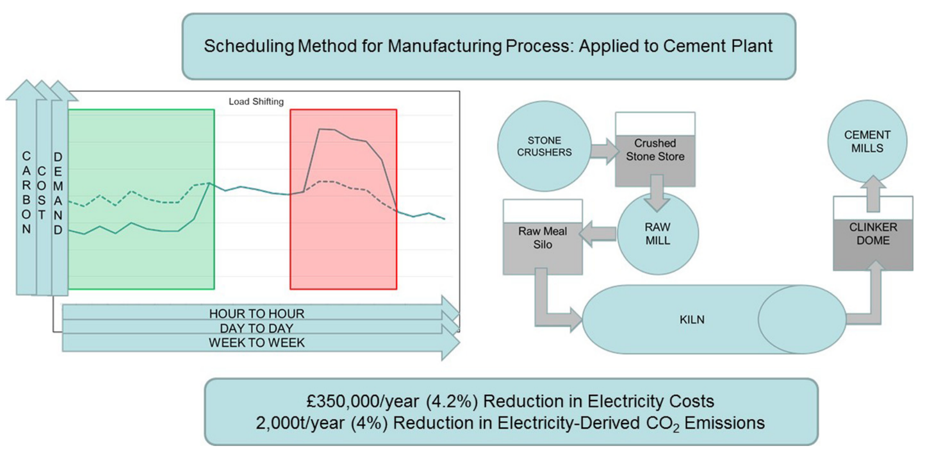
Daniel L. Summerbell[a,*], Diana Khripko[b], Claire Barlow[a], Jens Hesselbach[b]

[a] Institute for Manufacturing, University of Cambridge, 17 Charles Babbage Rd, Cambridge CB3 0FS, UK
[b] Department of Sustainable Products and Processes (upp), Universität Kassel, Kurt-Wolters-Strasse 3, Raum 2118, 34125 Kassel, Germany

HIGHLIGHTS

- Varying electricity demand from industrial consumers can reduce costs & CO_2 emissions.
- An alternative production schedule was produced for a cement plant using new method.
- This demonstrated potential to decrease electricity cost by 4.2%.
- There was also potential to reduce electricity-derived CO_2 emissions by 4%.

GRAPHICAL ABSTRACT



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ABSTRACT

Demand-side management (DSM) has the potential to reduce electricity costs and the carbon emissions associated with electricity use for industrial consumers. It also has an important role to play in integrating variable forms of generation, such as wind and solar, into the grid. This will be a key part of any grid decarbonisation strategy. This paper describes a method that can be used to develop a new production schedule for a wide range of manufacturing facilities. The new schedule minimises either electricity costs or electricity-derived CO_2 emissions. It does so by rescheduling production to low cost or low carbon periods, without loss of overall production, within the constraints of available inventory storage. A case study of a single cement plant in the UK was performed in order to determine the potential benefits of increased load-shifting DSM using this method. The alternative production scheduled showed the potential to decrease electricity costs by 4.2%. Scaled to values from a typical plant this would lead to a cost saving of £350,000, a substantial saving. A schedule optimised to minimise carbon emissions would save an estimated 2000 tonnes per year of CO_2, a 4% decrease in electricity-derived emissions. It was also observed that the actual electricity consumption of the plant was considerably higher than the minimum consumption predicted by the model. This could indicate potential for significant savings in both cost and CO_2 due to improvements in energy efficiency. The potential savings from DSM doubled when the prices passed to the plant were replaced with a price that varied in proportion to the wholesale cost of electricity. This indicates that a potential mutual benefit exists for both industrial consumers and electricity

* Corresponding author.
E-mail addresses: dls43@cam.ac.uk (D.L. Summerbell), DianaKhripko@web.de (D. Khripko), cyb1@cam.ac.uk (C. Barlow), hesselbach@upp-kassel.de (J. Hesselbach).

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generators by passing on more of the variation in price. A larger share of generation from wind and solar will also lead to increased variation in prices and grid carbon intensity in future. The value of applying the method described in this paper is therefore likely to increase further in future.

1. Introduction

One of the key challenges facing the UK government in aiming to meet its 2050 climate goals is the decarbonisation of electricity generation. As large, centrally controlled consumers of electricity, industrial facilities not only represent a significant proportion of UK electricity use, but also offer a lower-complexity route towards adjusting electricity demand to help the implementation of policy.

1.1. Motivation

Cement production is a significant global consumer of energy and source of carbon dioxide emissions. Only roughly 5% of these emissions come from the electricity used in the process, the remainder being emitted by the materials used in the process (50%), the fuel burned in the kiln (40%) and the transport of both raw material and finished product (5%) [1]. The global warming potential of cement industry is its largest environmental impact, followed by the acidification potential [2]. The material derived emissions can be reduced only by reducing the clinker content of cement, or reducing the amount of binder required to deliver a given strength [3]. Previous work by the authors has found opportunity to reduce fuel derived emissions by up to 20% through operational improvement [4].

The scale of the cement industry is such that even the 5% of emissions due to electricity use is still significant. This paper will estimate the potential for reduction in these emissions due to operational changes. The cement industry consumes 0.4% of UK electricity production, and accounts for 1.5% of industrial demand [5,6]. Moreover even though electricity only comprises 13% of the energy input to the cement making process, it can account for 50% of energy costs [7]. Any opportunity to reduce costs by shifting electricity consumption to low cost times would therefore be advantageous.

The objective of this paper is to demonstrate a new method for rescheduling the production at an electricity-consuming industrial plant. The cement industry provides a good opportunity for such scheduling, due to its high electricity usage, and significant scope for load-shifting. A case study will determine the extent to which Demand Side Management (DSM) could be used to shift the time at which electricity is required by a particular cement plant, without losing production. The paper will also estimate the associated financial and environmental benefits of shifting that demand.

1.2. Literature review

In order to examine the potential benefits for the cement industry from increased DSM it is necessary to first understand the various techniques and technologies that can help manage electricity demand. Equally important is how the need for DSM has been changed over time, particularly due to increased use of renewable electricity generation.

1.2.1. Nature of demand-side management

The concept of DSM grew out of the energy crises of the 1970s. The industry began to challenge its long held model of treating customer demand as fixed, and started to look for ways to optimise demand to suit the needs of the electric utility generators [8]. The basic objectives of DSM include:

- Peak clipping: Reducing demand at peak times to reduce need for generating units only used at to supply the peak.
- Valley filling: Encouraging consumers to use more electricity at off-peak times in lieu of other energy sources.
- Load shifting: Demand making up peak demand is shifted to off-peak time. (ibid)

Different strategies to achieve DSM objectives are outlined by Palensky and Dietrich [9]. These include:

- Energy efficiency: Reducing overall demand through improved efficiency.
- Time of use pricing: Customers are financially encouraged to shift demand to off-peak by pricing signals over a certain period, fixed in advance.
- Demand response: This can include real-time pricing, where the price is varied proportionally to the wholesale cost of electricity in order to incentivise consumers to switch consumption to off peak times. It can also describe a situation where utilities pay a fee to exercise direct control over consumers' assets, having the ability to switch them off in order to rapidly decrease demand.
- Spinning reserve: Loads act as a negative reserve by reducing their power based on the condition of the grid over timescale of seconds. This is principally used to maintain frequency of supply.

1.2.2. Increasing importance of DSM

Pressure on the UK generating industry continues to increase, and the excess capacity margin steadily reducing. However, there is still potential within the existing system to mitigate these challenges. Strbac [10] noted that the utilisation of generation capacity in the UK is only 55%. DSM could shift demand from peak to off-peak. While certain generators are only suitable for peak demand, this could improve the utilisation of plants that provide intermittent power (such as renewables) or which supply baseload power. As generators only receive revenue in return for generation, this would improve the return on investment in such generation plants. Strbac estimated that the value of DSM could be between £250 and £400 per kilowatt, with the significant additional benefit of requiring no planning or construction time in contrast to new generation. In addition, industrial DSM could ease the strain on the transmission network balancing out the north to south power flow at peak time as generation in the North supplies residential demand in the south of the country by reducing demand at plants at peak times.

There can be co-benefits for consumers participating in demand-response schemes. Modelling by Amini et al. [11] found overall cost savings of the order of 10% were possible for consumers able to shift the time of their use of various domestic appliances.

1.2.3. Impact of renewable electricity generation

One factor increasing the need for demand-side management is the increased penetration of renewables into the electricity mix. In the past, electricity has been supplied by baseload power (often from nuclear or coal) and dispatchable sources (i.e. those that