Predictions for the contribution of residential lighting to the carbon emissions of the UK to 2050

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Abstract

The publication, in 2007, of the Energy White Paper saw the UK government commit itself to reducing the country's CO_2 emissions by 60% by 2050. In November 2008, the government took this a step further when The Climate Change Act came into law, committing the UK to an 80% reduction of 1990 levels by 2050.

By 2007, lighting in the UK residential sector required around 17 TWh of electricity and resulted in the emission of 9 million tonnes of CO_2. This paper describes and projects changes to these emissions between 1990 and 2050 and explores the extent by which the commitments of the government may be met in the residential lighting sector. The forecasting is modelled on two bases: (1) projected demand for artificial lighting in terms of lumen-hours per head of population; and, (2) anticipated changes, through both policy intervention and technology change, in the luminous efficacy of the installed base of lighting technologies.

The results of this analysis show that substantial reductions can be made to lighting related energy consumption in the residential sector. The extent of these reductions is such that lighting should not only more than contribute towards its share of the government's carbon reduction commitments but also be able to meet these goals ahead of target.

Introduction

In November 2008, the UK government became the first in the world to commit itself to a legally binding framework to tackle climate change when it passed into law The Climate Change Act. Under the Act the country is committed to reducing its 1990 CO_2 emission levels by 80% by 2050.

This paper examines the potential role of policy intervention and technological change in the domestic household lighting sector in helping to meet this target.

The models described in the paper consider the installed stock of lighting in any given year and therefore reflect the lag between any implementation of policy measures and improvements in best available technologies.

Demand for Light

In this paper, demand for light in the UK domestic sector is derived from the product of population and per capita demand for light.

For the purposes of this paper, behavioural change, such as more turning off of lights when not required, is not considered. Furthermore, technological change not directly related to lamp technology – such as in increased levels of occupancy sensor based switching, or a move toward more natural day-lighting – is excluded.

The per capita demand for light is assumed to continue to follow a logistic curve based on historical changes in demand.

Population

The population of the UK remained fairly stable for the twenty years prior to 1990, growing by 0.175% per year. Over the past few years, the annual rate of growth in population has increased to around 0.5%. On this basis, the government is predicting that by 2050 the population will have risen from a current figure of 61 million to 77 million. The models used for this paper make use of UK government historical trend figures [1] together with its latest projections [2].

Lumens per Capita

The demand for artificial lighting in houses has existed for centuries. The introduction of electric lighting saw the demand begin to grow exponentially – chiefly as a result lower costs. More recently, the rate of growth in demand has begun to slow. Drawing on previous work on the demand for lighting in the UK [3], historic growth appears to fit to a logistic curve. Extension of the curve provides projections for future demand (Figure 1).

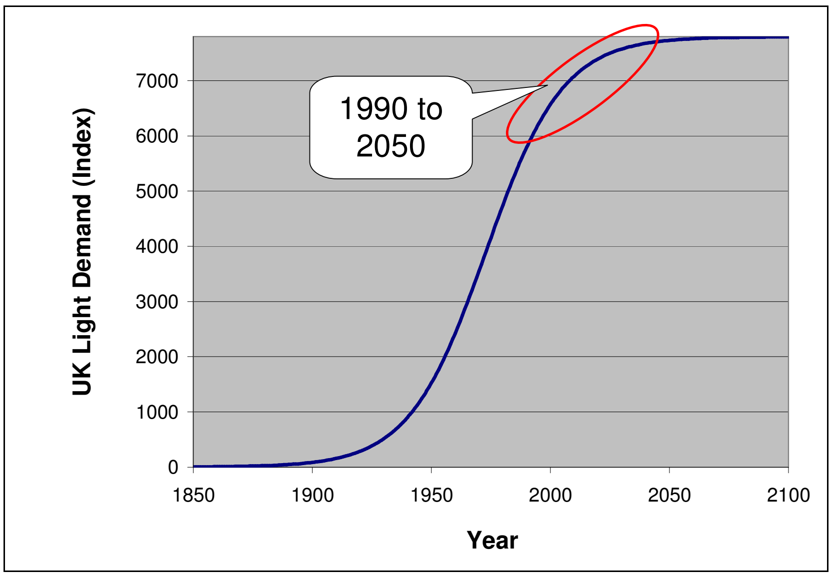

Figure 1: Demand for Artificial Lighting in the UK

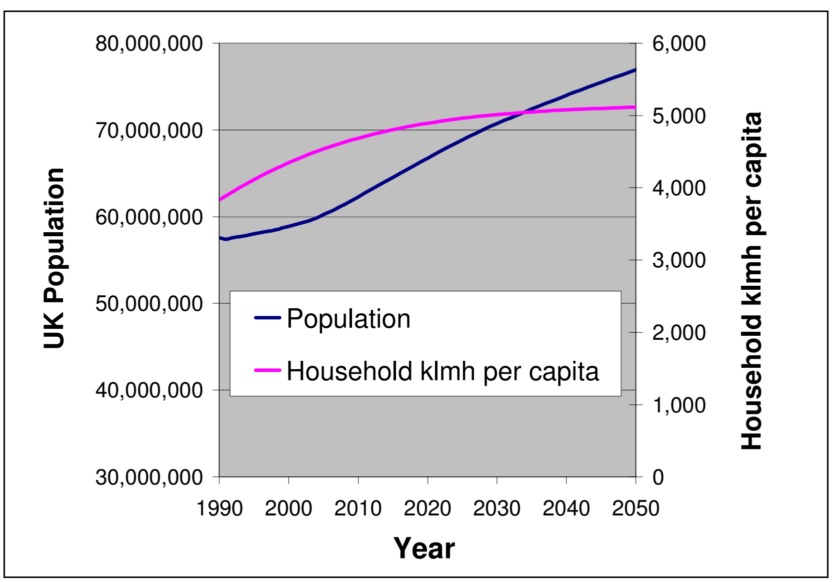

Figure 2: Growth in Population and in per Capita Lighting Demand

Overall Lumen Demand

The proportion of overall UK artificial light going into the domestic sector is estimated on the basis that in the late 1990's each UK household was estimated to consume approximately 10 million lumen-hours per year – equating to 4,300 million lumen-hours per capita [4]. On this basis, approximately 20% of UK demand is taken to be for household lighting – the remainder being for industry, commercial buildings, and street lighting.

Figure 2 compares growth in population with growth in per capita demand, and Figure 3 shows the product of the two to provide a picture of expected overall lumen-hour artificial lighting demand for the UK domestic sector.

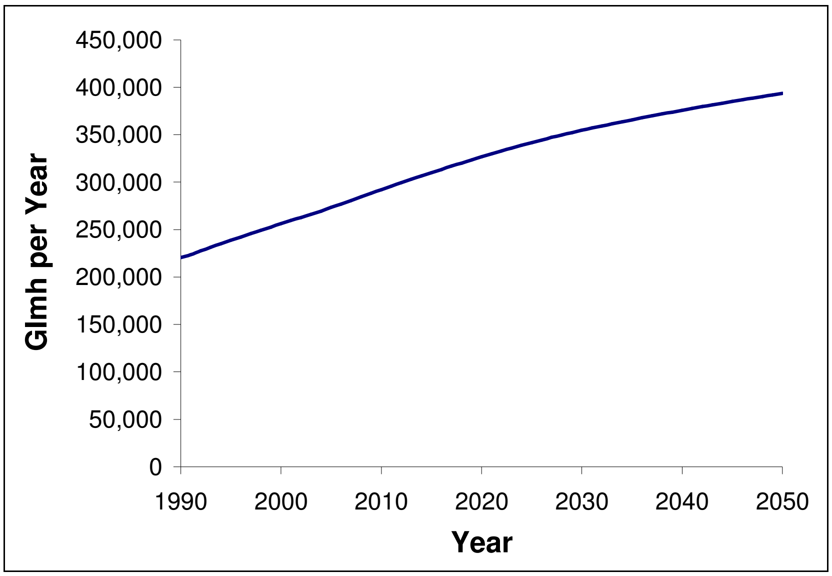

Figure 3: Demand for Artificial Lighting in the UK Domestic Sector (1990 to 2050)

Efficiency of Light

The efficiency of artificial lighting may be described in terms of luminous efficacy and expressed in Lumens per Watt (lm/W). Filament-based light sources have low efficacies (typically 8 to 15 lm/W), whereas discharge-based light sources have higher efficacies (typically 30 to 100 lm/W). Historically, UK household lighting has mainly been provided by filament-based light sources and this is reflected by a low overall efficacy. Based on stock models [5], it is estimated that between 1990 and 2005, the average installed efficacy of household lighting rose only very slightly, from around 14.3 to 15.6 lm/W. More recently, the efficacy has been increasing more rapidly through greater uptake of compact fluorescent lamps: by 2008, the figure was closer to 17.4 lm/W. This trend is set to accelerate.

Policy Incentives

In May 2007, the government published its White Paper on Energy describing measures that would be taken to tackle climate change and ensure the future security of energy in the UK. In September of the same year, there was an announcement that the country's major lighting suppliers were, in 2008, to begin a voluntary phase-out of most tungsten-filament lamps. The timetable for change is shown in Table 1.

Type of Lamp	Phase-out Year
150W GLS	2008
100W and 75W GLS	2009
60W GLS	2010
40W and 25W GLS as well as 60W candle and golfball bulbs	2011

Table 1: Voluntary Phase-out of Tungsten Filament Lamps in UK

The phase-out does not mean the lamps described will be prohibited from sale but does mean that consumers find will such lamps more difficult to source. Compact fluorescent lamps will be offered (often at highly discounted rates – through measures such as CERT) as alternatives. Further into the future it is expected that regulation will be introduced via the EU EcoDesign Directive and that this will remove almost all tungsten-filament lamps from the market by 2012. This will leave households with two main choices of lighting source: compact fluorescent and halogen. Most halogen lamps are, at present, little more efficient than tungsten-filament bulbs and the Directive is expected to target these too, such that only the most efficient remain available for sale after 2012 – these will be Xenon-filled, or infra-red coated.

Technological Change

While in the immediate future the domestic lighting market looks set to be dominated by compact fluorescent and more efficient halogen lighting, it is widely expected that solid-state electronic lighting (through LED or OLED technologies) will become the standard in the long-term. The use of solid-state technology as a white light source is still very much in its infancy. This is expected to change as costs come down, and light quality and efficiency improve. The US DoE is undertaking a programme to deliver commercially available "white light" LEDs with efficacies of 200 lm/W by 2025 [6]. For the purposes of this model, it is assumed that solid-state lighting makes a serious entry into the market in 2014 and grows to dominate it by 2040. It is assumed that by this point all lighting will be solid-state with a luminous efficacy of 200 lm/W.

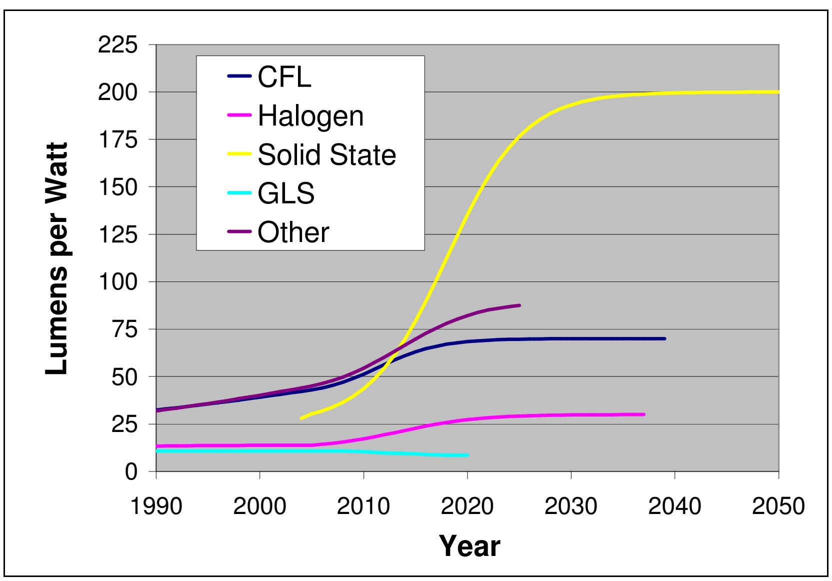

Figure 4: Assumed Changes in Efficacies of Installed Lighting Technologies

Figure 4 shows the changes in luminous efficacy of the five categories of lighting considered in this paper:

- Compact Fluorescent (CFL) is expected to improve over time as manufacturers seek to make them more attractive to the consumer. Efficacies have been de-rated to reflect research on warm-up times, lamp lumen maintenance, and manufacturer over-ratings [7]

- Halogen is expected to improve significantly in response to expected regulation
- Economically competitive, quality “white light” (CRI: 90+, CT ~3000K) Solid State is expected to reach 150 lm/W shortly after 2020 and peak at 200 lm/W
- GLS tungsten-filament lamps will fall in efficacy before leaving the market owing to the fact that the more efficacious higher power lamps are to be the first to go
- Other lamps include discharge lighting such as fluorescent strips and metal halide. Efficacies of installed stock are expected to increase to around 80 lm/W

The overall change in luminous efficacy over time resulting from policy intervention and technology change is shown in figure 5. The change, over time, in the proportion of light contributed by each of the five sources is shown in Figures 6 and 7.

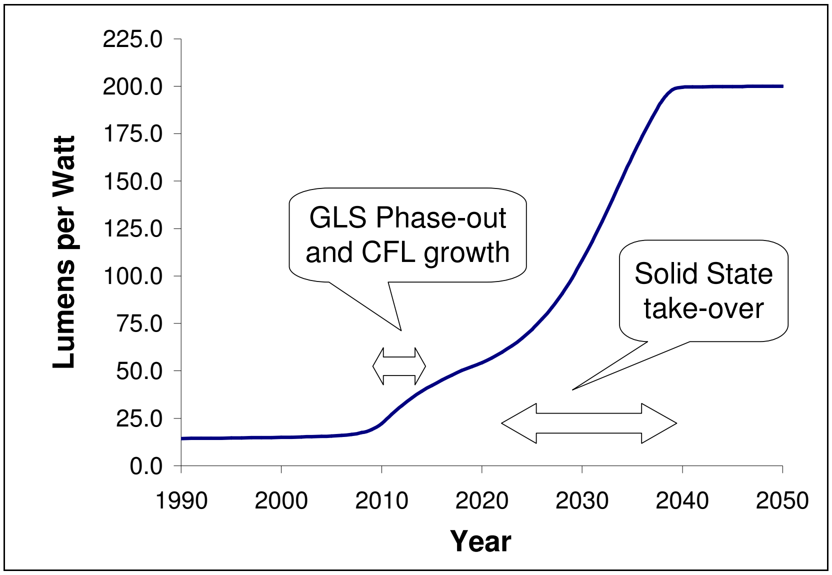

Figure 5: Overall Change in Installed Luminous Efficacy of Domestic Lighting

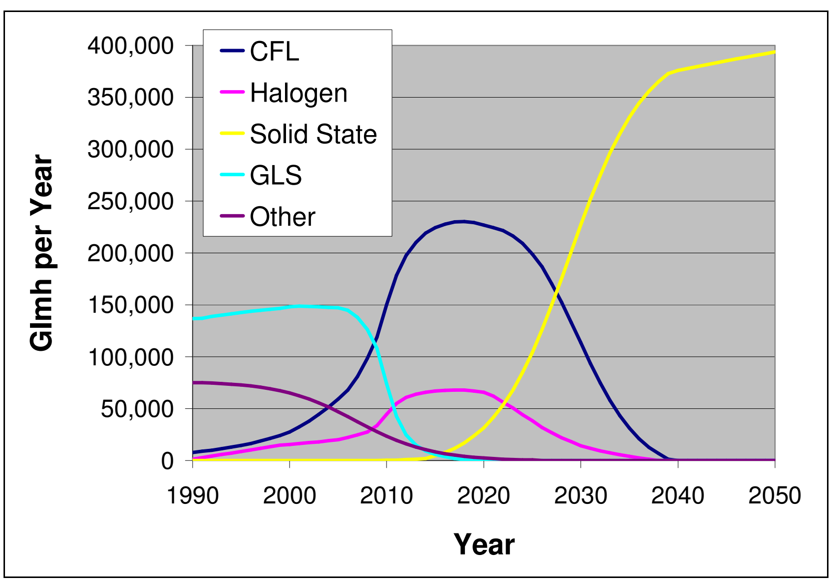

Figure 6: Household Lighting Contribution by Type of Light Source

The future stock levels are modelled on the substitution of tungsten filament lighting by CFL, halogen, and solid state, and continued trends in the downward demand for other types of lighting.

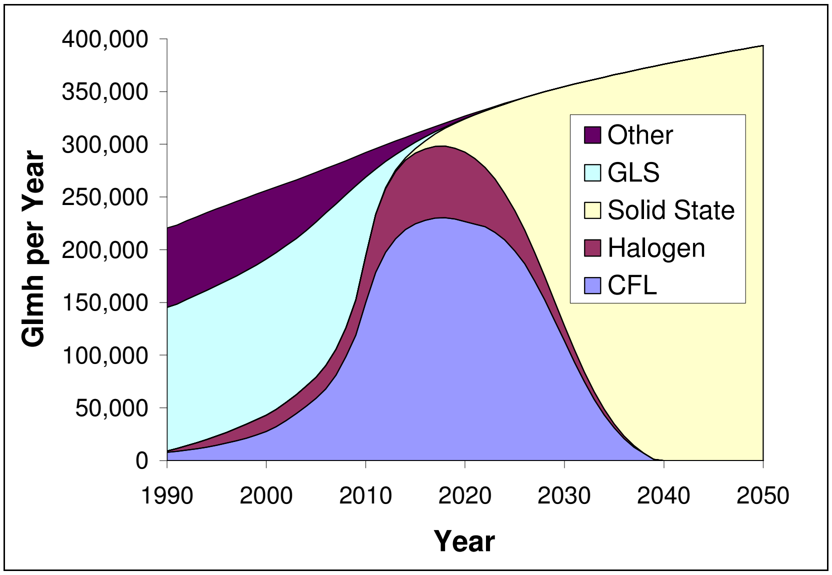

Figure 7: Make up of Household Lighting Demand by Type of Light Source

Penetration of Solid State lighting is modelled on a Bass Diffusion assuming market entry in 2014 with final total saturation of lighting demand, and based on Coefficients of Innovation (P) of 0.005 and Innovation (Q) of 0.25. The numbers used for the coefficients are low compared with other products but typical of lighting technologies [8]. A comparison of assumptions for changes in efficacy and indexed cost per lamp lumen is provided in Figure 8. The price of solid state lighting is expected to be lower, on an installed lumen basis, than GLS by the early 2020s: at the same time, the efficacies are expected to be at least fifteen times higher. Owing to the similarities in technology, together with industry-growth related economies of scale, the cost/efficacy development of Solid State lighting is widely expected to follow a pattern not dissimilar to that of Moore's Law with computer chips [9]: the product of efficacy and cost is assumed to halve every three years (with Moore and computer chips, the product of number of transistors per chip and cost has been observed to halve every *two* years).

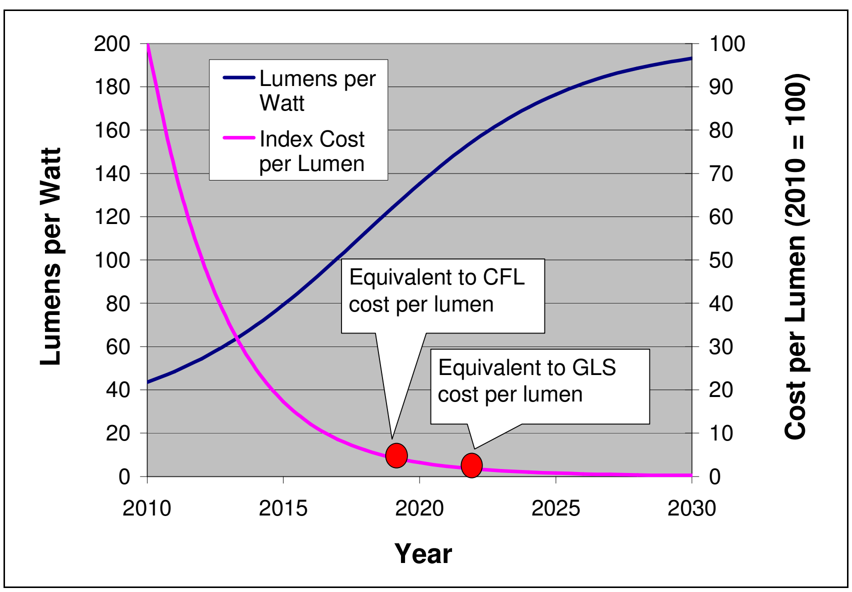

Figure 8: Solid State "white light" Efficacies and Indexed Costs over Time

Energy Savings

Division of the light output of each source (in Glmh per year) by the luminous efficacy (in lm/W) of each source provides figures for their energy demand (in GWh per year). The changing energy demand resulting from the changing use and changing efficacies of the five light sources is shown in Figures 9 and 10.

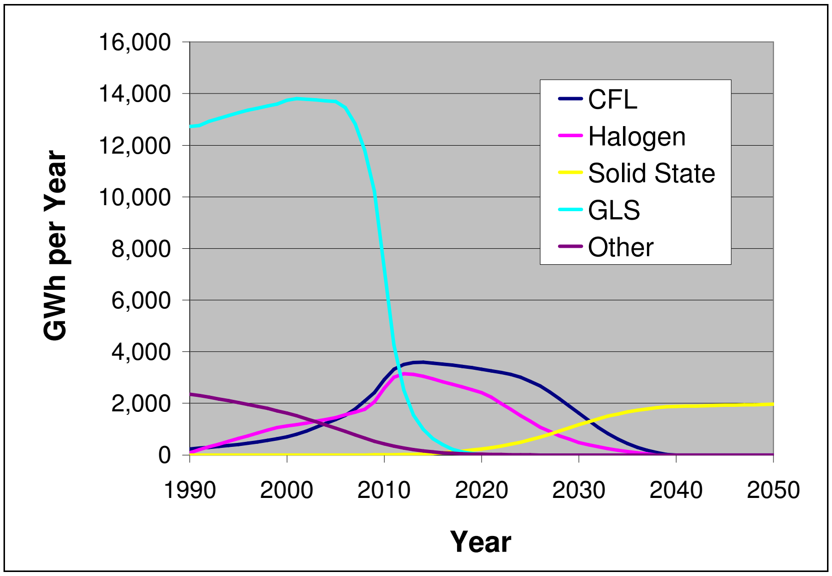

Figure 9: UK Household Energy Demand by Individual Light Sources

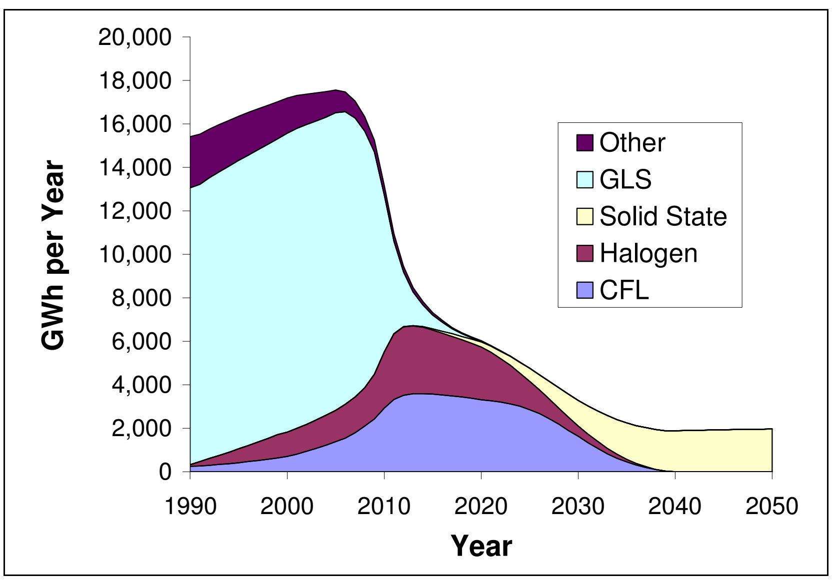

Figure 10: UK Household Energy Demand by all Light Sources

Discussion

The results show that there is the potential for an 80% reduction in 1990 baseline energy required for domestic lighting in the UK by 2031 and that this reduction could increase further to 87% by 2050. These reductions are based on the assumption that solid-state lighting becomes the sole lighting technology in use by 2040 and that by that time it has reached a luminous efficacy of 200 lm/W. Such a scenario would require a revolution in lighting, with the substitution over a 25 year period of all existing traditional filament and arc based lighting technologies by electroluminescent solid-state technology. Such a revolution is not without precedent: electrification of houses led to the rapid demise of candles, paraffin, and gas-lighting.

This paper assumes the *substitution* of existing indoor lighting with solid-state technologies and consideration is not given to *supplementation*. At present, the great majority of solid-state lighting is used in niche fixtures – it is still a niche industry – and so may be considered a supplement. However, there are limits to the amount of light a household will require and these, hopefully, are reflected in the analysis of historical and future demand for lighting. Furthermore, it is possible that the very flexibility of solid state lighting fixtures is such that their lumen outputs come to be better utilised than those of conventional lighting fixtures – the bare lamps of which are often shaded, leading to reduced lamp-lumen to illuminance ratios.

The implications for meeting the 80% CO_2 reduction target are linked to the energy savings that would be achieved by the scenario here described – but not directly. The extent by which an 80% plus reduction in electrical energy demand affects domestic lighting related CO_2 emissions will depend on at least two external factors:

- Carbon intensity of electricity – at present this is over 0.5 $kgCO_2$ per kWh, in the future this is hoped to change downwards with less carbon intensive forms of generation
- Carbon intensity of heating and cooling – this is important, since indoor lighting contributes towards the heating of buildings. Any reduction in the heat energy dissipated through lighting will affect the heating and/or cooling requirements for buildings

Further work could help establish the additional savings that could be achieved through behavioural change and technology changes such as better use of daylight in buildings.

References

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[2] Government Actuary's Department. From the Population Projections Database, using 2006 base year. http://www.gad.gov.uk/Demography_Data/Population/2006/uk/wuk06cc.xls

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[4] Boardman B. Palmer J. *Domestic Efficient Lighting (DELight)*, Environmental Change Unit. University of Oxford (UK), 1998. ISBN 1-874370-20-6.

[5] Variety of sources, most importantly, *DEFRA Market Transformation Programme*, see: http://whatif.mtprog.com/Level3/SelectScenario.aspx

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[9] Schubert et al., *Solid-State Light Sources Getting Smart*. Science. May 2005.