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Quantifying the co-impacts of energy sector decarbonisation on outdoor air pollution in the United Kingdom

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ABSTRACT

The energy sector is a major contributor to greenhouse gas (GHG) emissions and other types of air pollution that negatively impact human health and the environment. Policy targets to achieve decarbonisation goals for national energy systems will therefore impact levels of air pollution. Advantages can be gained from considering these co-impacts when analysing technology transition scenarios in order to avoid tension between climate change and air quality policies. We incorporated non-GHG air pollution into a bottom-up, technoeconomic energy systems model that is at the core of UK decarbonisation policy development. We then used this model to assess the co-impacts of decarbonisation on other types of air pollution and evaluated the extent to which transition pathways would be altered if these other pollutants were considered. In a scenario where the UK meets its existing decarbonisation targets to 2050, including the costs of non-GHG air pollution led to a 40% and 45% decrease in PM_{10} and $PM_{2.5}$ pollution (respectively) between 2010 and 2050 due to changes in technology choice in residential heating. Conversely, limited change in the pollution profile for transportation were observed, suggesting that other policy strategies will be necessary to reduce pollution from transport.

1. Introduction

There exists widespread agreement in the scientific community that outdoor air pollution can be detrimental to the environment and human health, both through its contribution to global climate change and local air quality challenges (Watts et al., 2015; World Health Organization, 2013). While outdoor air pollution levels have improved considerably in the UK since the famous "pea soupers" (smog) seen in the first half of the 20th century, an estimated 40,000 people still prematurely die each year due to exposure to outdoor air pollution and cost the UK economy £20 billion (Royal College of Physicians, 2016). In London, up to 9416 people die prematurely due to anthropogenic $PM_{2.5}$ and NO_2 pollution exposure alone, with an estimated annual monetised cost of £1.4–3.7 billion (Walton et al., 2015).

Under the Environment Act 1995, the UK Government and devolved administrations in England, Scotland, Wales and Northern Ireland are responsible for producing a national air quality strategy. This strategy was last reviewed and published in 2007 and set out a plan for meeting the UK's air quality objectives via action at national, regional and local levels for a number of pollutants including nitrogen dioxide, particulate matter, and sulphur dioxide. Under Part IV of this Act, along with Order 2002, local authorities in the UK are required to measure their local air quality and establish air quality management areas for locations requiring improvement (UK DEFRA, 2013).

The UK is also subject to a number of directives at the European (EU) level, including the National Emissions Ceilings Directive (2001/81/EC) and the EU Air Quality Directive (2008/50/EC) and its legally binding limits on outdoor air pollution levels. The former requires that Member states develop and maintain national programmes to meet emissions ceilings and required reporting of emissions inventories for sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOCs), and ammonia (NH_3). The latter includes limits for particulate matter (both PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2). Further action is needed; the UK Supreme Court ruled in 2015 that the government must take action to reduce air pollution levels to meet EU Air Quality Directive limits for outdoor air pollution, which it currently violates.

In parallel, the UK has set a long-term national GHG reduction target of 80% by 2050 compared to 1990 levels, with a series of interim carbon budgets that will require significant changes in the energy system. Most recently, the UK Government set out the 5th carbon budget (2028 – 2032) in late July 2016 based on guidance published by the Committee on Climate Change in 2015 (Committee on Climate Change, 2015; Department for BEIS, 2016; Department of Energy and

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Climate Change, 2016).

There is significant value to be gained from insights on the trade-offs and synergies between proposed air quality and climate interventions (Lott and Daly, 2015; Pye et al., 2008; Pye and Palmer, 2008). Much of the outdoor air pollution in the United Kingdom arises from the use of fossil fuels. Furthermore, multiple air pollutants are often produced by the same energy system technologies (e.g. fossil fuel power plants, gasoline and diesel vehicles). Studies have shown how the inclusion of these multiple externalities greatly change the relatively competitiveness of different fuels (Shindell et al., 2012).

However, such externalities are not included in the costs of energy technologies today. Furthermore, no peer-reviewed papers have been published on a methodology that endogenizes these air pollution co-impacts and corresponding damage costs into a national whole energy systems optimisation model. Given that these optimisation models are central to energy sector policy assessment – including the 2016 impact assessment for the fifth carbon budget level published by the UK Department of Energy and Climate Change - the addition of other air pollutants provides valuable additional insights on the co-impacts of climate and air quality interventions (Department of Energy and Climate Change, 2016).

Within the published literature, many studies exist that internalised local air quality externalities into an energy system optimisation process (Bhattacharyya and Timilsina, 2010; ETSAP, 2014a; Klaassen and Riahi, 2007; Kudelko, 2006; Loulou et al., 2005; Nguyen, 2008; Pye et al., 2008; Pye and Palmer, 2008; Rafaj and Kypreos, 2007; Zvingilaite, 2011, 2013; Zvingilaite and Klinge Jacobsen, 2015). But these studies only considered a portion of the energy system (e.g. the electricity generation or regional heating systems). Furthermore, a number of studies have focused on the co-benefits of climate change policies using integrated assessment models (Amann et al., 2009; Bollen et al., 2009; Department of Energy and Climate Change, 2009; Intergovernmental Panel on Climate Change, 2007; Nemet et al., 2010; Östblom and Samakovlis, 2004; Stern and Taylor, 2006; Zvingilaite, 2011). But, only two of these models included an estimate of the economic value of air quality co-benefits (Department of Energy and Climate Change, 2009; Stern and Taylor, 2006).

For the UK, research has been conducted to examine particular strategies for simultaneously reducing carbon and non-GHG emissions such as increased levels of active travel, household energy efficiency, and clean car penetration (Jarrett et al., 2012; Jensen et al., 2013; Watts et al., 2015; Wilkinson and Tonne, 2011; Woodcock et al., 2009). But, again, these studies did not holistically look at the whole energy system or at the full range of air pollution co-benefits considered in this research.

Outside of the peer-reviewed literature, two consulting reports (Pye et al., 2008; Pye and Palmer, 2008) integrate non-GHG air pollution into a whole energy systems model, quantifying changes in air quality pollutant emissions under different UK policy scenarios. In this work, they included three pollutants (SO_2, NO_2, and PM_{10}) into the UK MARKAL energy systems model and found that "air quality emissions could be significantly reduced in future years as a result of technology improvements, improved efficiency and less use of polluting fuels under a reference case… [and] benefits due to [air quality] emission reductions are estimated at between £0.9–1.0 billion in 2050" (Pye et al., 2008). At the time, the authors noted that the model "could be further developed to assess both climate and air quality targets simultaneously. This could be done by including emission ceilings, for example, for air quality pollutants, which the model would factor in as part of the optimisation process" (Pye et al., 2008).

In this paper, we further enhance the analysis in Pye and Palmer (2008) by considering 3 additional pollutants ($PM_{2.5}$, NMVOCs and NH_3), and develop a more rigorous representation of emission factors in the model based on the latest inventory information. The approach and methods used are described in this manuscript, including a discussion of the extent to which non-GHG air pollutants can be mapped to an energy systems model, in this case UKTM-UCL. Results from six (6) scenarios are then presented with a corresponding discussion. We conclude with the key insights gained from this work.

2. Approach

This section provides a brief overview of UKTM-UCL and explains how an air pollution emissions and damage cost database for particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NO_x), sulphur oxides (SO_x), ammonia (NH_3), and non-methane volatile organic compounds (NMVOCs) was added to the model in order to endogenize air pollution co-impacts. This section concludes with a description of the set of six (6) scenarios that we used to explore the impacts of incorporating non-greenhouse gas air pollution on UK decarbonisation strategies.

2.1. UKTM-UCL

The MARKAL (Market Allocation) and subsequent TIMES (The Integrated MARKAL-EFOM System) model generators are perhaps the most well-known dynamic technology-economic models and have been used to simulate many national and international energy systems (ETSAP, 2014a, 2014b; Loulou et al., 2005). These models combine "two different, but complementary, systematic approaches to modelling energy: a technical engineering approach and an economic approach" (ETSAP, 2014a). They are bottom-up, perfect-foresight, linear optimisation models that identify the lowest-cost pathway for meeting all energy demands in an economy across all energy sectors, subject to constraints such as emissions targets. They are maintained by the International Energy Agency's Energy Technology Systems Analysis Programme (Loulou et al., 2005).

The UK TIMES Model (UKTM-UCL)[1] is a technology-oriented model that represents the entire UK energy system as a single region, spanning from imports and domestic production of fuel resources, through fuel processing and supply, explicit representation of infrastructures, conversion to secondary energy carriers (including electricity, heat and hydrogen), end-use technologies and energy service demands. A generic TIMES model structure is displayed graphically in Fig. 1.

UKTM-UCL was developed to replace the UK MARKAL model, which has contributed underpinning insights to policy processes over the last decade, including the Climate Change Act 2008 (Dodds et al., 2014). UKTM has been co-developed with the UK Department of Energy and Climate Change (DECC), who use it to provide evidence to support their long-term climate policy.

2.2. Air quality pollutant emissions database

We incorporated an air pollutant emissions database into UKTM-UCL for six (6) air quality pollutants: particulate matter that is either less than 10 or less than 2.5 micrometres in diameter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NO_x as NO_2), sulphur dioxide (SO_x as SO_2), ammonia (NH_3), and non-methane volatile organic compounds (NMVOCs). This update allows air pollution emissions accounting by year out to 2050. A full list of the emission factors included in this database by sector and technology are found in Appendix A: Supplementary material.

Emission factors (EFs) for the current energy system were compiled from the UK National Atmospheric Emissions Inventory (NAEI)[2] using

[1] https://www.ucl.ac.uk/energy-models/models/uktm-ucl (accessed April 2016).

[2] Emission factors (EFs) were mapped from the National Atmospheric Emissions Inventory (NAEI), published online at http://naei.defra.gov.uk (accessed November 2015), which provides the official annual air quality pollutant emission estimates for the United Kingdom. The inventory is structured around reporting under the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (CLRTAP) and emission estimates are presented in Nomenclature for