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Aerosol loading in an urban environment from a biofuel based CHP plant: assessment and mitigation

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Abstract

This study presents outcomes from a preliminary dispersion modeling exercise for the extent of aerosol loading owing to enhanced biomass combustion in the future energy mix. Secondary aerosol generation potential from photochemical interactions between the precursor emissions from a typical biomass based combined heat and power (CHP) plant and the associated local emissions from harvest and transportation of the biofuels has been estimated for a peri-urban site in the UK.
Keywords: biofuel; miscanthus; secondary aerosols; photochemical; CHP; decentralised generation.

1. Introduction

The role of combined heat and power (CHP) plants in securing next generation energy supplies has been recognized by several governments worldwide, mainly towards sustainable climate change mitigation from this sector. Ligno-cellulose crops (called so owing to their characterization with high lignin and cellulose contents) such as perennial rhizomatous grasses, short rotation coppiced wood, etc. have been identified as solid biofuel sources contributing to this technology with low green house gas emissions and hence considered as “cleaner fuel”. As a consequence, there has been large-scale land use shift towards bioenergy production in many areas around the world. For example, in England the Energy Crops Scheme promotes the amount of energy crops that can be grown in appropriate locations and through this initiative approximately 7500 ha of bioenergy crops have been established between 2001 and 2007 alone (Natural England, 2010).

A recent study has performed GIS-based suitability assessment of appropriate locations in England for growing Miscanthus (Lovett et al., 2009). Their study considers available information on relevant factors such as yield potential, hydrology and social acceptability in determining appropriateness and as such should be treated as the most recent advancement till date in applying spatial modelling techniques for identifying the land areas where biomss crops are most likely to be planted, alongside possible future expansion potentials, under different scenarios. However, it is still early days to appraise its real benefits in terms of overall sustainability. Potential air quality issues in an urban environment, arising from such distributed electricity generation plants located at per-urban sites in close vicinity to bioenergy crop plantations, is not considered extensively in the current state of affairs while proposing new developments. This is owing to limited capabilities in the current operational models to make realistic predictions of secondary pollutant formation, rooted primarily in the inadequacy of the emission inventory applied to model such scenarios. Precise estimation of greenhouse gas and ammonia emissions from harvest sites at any time of the year would depend on farm management practices, soil type, fertilizer use, type of crop, size and location of the farm, etc. This makes quantification of the sources and successful targeted measures and policies for their mitigation very difficult (Fowler et al., 2009). On the other hand, there has been growing amount of research focused on mitigating the precursor emissions from the stack of a CHP plant, mainly through pre-processing of the fuel to attain higher combustion efficiency – for example, biomass gasification prior to combustion (Tiwary et al., 2010).

This paper presents preliminary results from a dispersion modeling exercise to assess the extent of secondary aerosol loadings in an urban environment from enhanced biomass combustion in the future energy mix. It utilizes a life cycle approach to generate the emission inventory from constituent activities on a city-scale which is then used to quantify the secondary inorganic aerosol formation potential from photochemical interactions between the emissions from the stack of a CHP plant and the local harvest site for two case scenarios.

2. Methodology

The main scope of this study is to assess the potential secondary aerosol loadings from photochemical interactions between precursor emissions from a CHP plant and the emissions from the neighboring harvest sites. This is aimed to establish the level of air quality issues, if any, from such future developments and the possible mitigation measures to provide sustainable solution to urban energy provision from distributed generation using renewable sources. A hypothetical situation has been assumed for a city-scale domain in the UK midlands (**Figure 1**). It comprises of a 50 MW-electricity CHP plant operating on locally sources biomass (miscanthus) from 3 nearby locations - one relatively small site (2 km^2) close to the biomass facility located on the eastern fringes of the city and two relatively larger plots located on the southern (14 km^2) and on the western (24 km^2) fringes of the city. The study covers two scenario cases, both utilizing current technologies, in order to assess the aerosol generation potential:

Case 1 (Base scenario) – It assumes direct firing of energy crop (*miscanthus*) in a CHP plant.

Case 2 (Mitigation scenario) – It represents biomass gasification prior to combustion using integrated gasification/ combined cycle technology.

The study was carried out in two steps – one, preparation of the emissions inventory to populate the sources of precursor gases on a life cycle basis; two, application of dispersion model to estimate the photochemical inorganic secondary aerosol generation potentials .

The emission database for the CHP system has been generated on the life cycle basis, including all the constituent activities such as biomass harvest, local transport and combustion in the CHP plant (**Figure 2**). This is developed using literature data from a recently reported study on this topic (Tiwary et al., 2010) and inventoried information (Öko-Institut, 2006) from a European project. More details on the assumptions herein can be therefore found in these two documents.

Secondary aerosol generation potentials for the two case scenarios were estimated using the FRAME (Fine Resolution Atmospheric Multi-pollutant Exchange) photochemistry modeling framework. FRAME is a Lagrangian atmospheric transport model used to assess the long-term annual mean deposition of reduced and oxidized nitrogen and sulphur over the UK landscape. It has been widely applied as a robust multi-chemical species tool. It comprises a dry and an aqueous phase chemistry scheme for sulphur and oxidized nitrogen to estimate NH_4^+, NO_3^- and SO_4^{--} aerosol formation. This is the main pathway for aerosol formation studied in this paper and the FRAME emission inventory had been adequately modified to capture the chemistry involved.

The output domain for the FRAME model typically covers the entire British Isles at a grid resolution of 5km (Dore et al., 2007). In this study the national emission inventory was modified to account for the sources within the case study boundary to reflect the inclusion of a CHP plant as well as three nearby harvest sites for perennial biofuel crops. In the next step the FRAME model was re-run in order to assess the photochemical transformations and dispersion of the additional aerosol loading for the base case and the mitigation case using local meteorology for 2007.

3. Results

Utilization of locally sourced biofuel seems to accentuate secondary aerosol production in the base case (**Figure 3a**). This is mainly owing to photochemical neutralization of the acidic emissions from the CHP plant with ammonia released from neighbouring harvest sites, resulting in additional aerosol loadings of up to 1 μg m^{-3} in certain parts of the city.

Biofuel gasification prior to combustion seems to mitigate the aerosolisation potential by reducing the release of precursor acidic emissions from the stack of the CHP plant. However, on considering all the life cycle stages at the systems level, this study demonstrates that the overall implication for this mitigation is seemingly traded off by increased emissions from harvest and transport stages incurred while meeting additional biomass feedstock demands in this case (**Figure 3b**). Therefore, transportation of biofuels holds significant potential to optimize the aerosol loadings, borh from the direct emissions as well as the interactions of the nitrogen oxides with the VOC emitted from vegetation. However, the latter has not been covered in this study owing to the lack of modeling capabilities to capture the intricate VOC/NOx chemistry.

4. Conclusions

Our results suggest that photochemical interactions between the precursor emissions from the stack of the CHP plant and the harvest emissions from the nearby growing sites can lead to an increase in the aerosol loading on a regional scale. However, it appears that additional interactions of the road transport emissions, involved in the delivery of the fuel to the combustion plan, can play a significant role in mitigating the aerosolisation. This needs careful assessment prior to large scale implementation of distributed electricity production units, especially in cities with established air quality management areas.

5. References

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6. Figures

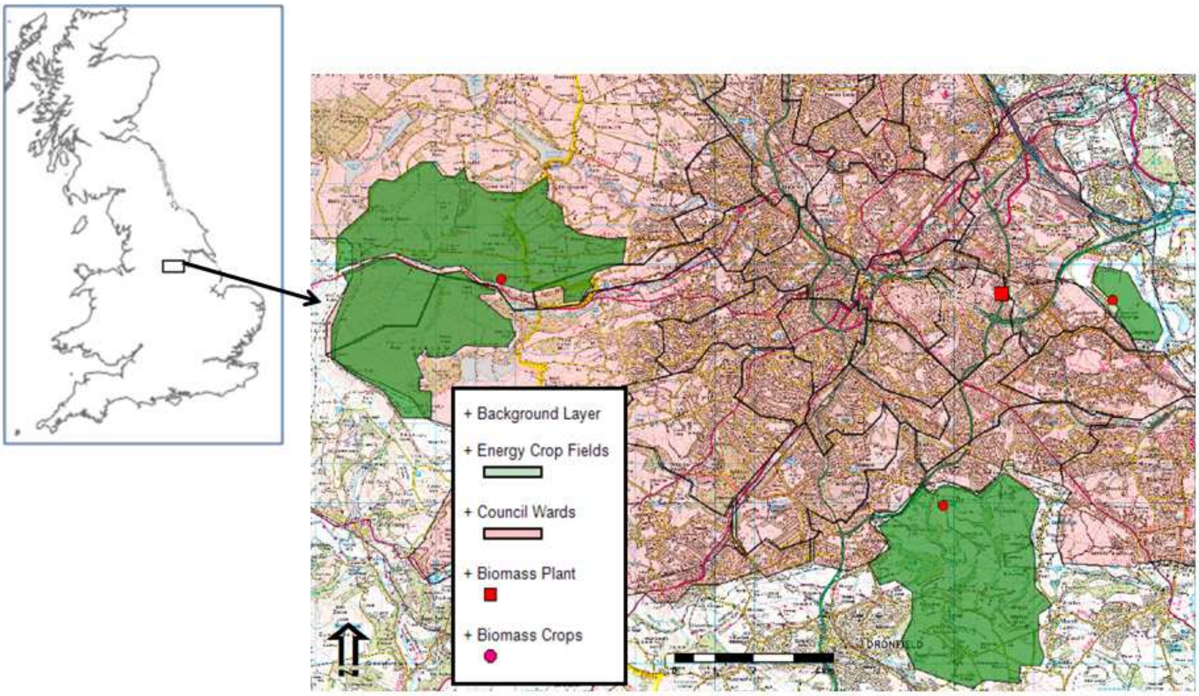

Figure 1. City-scale model domain used in the study showing spatial distribution of the sources – point (Biomass plant); area (Bioenergy crop fields); line (road network).

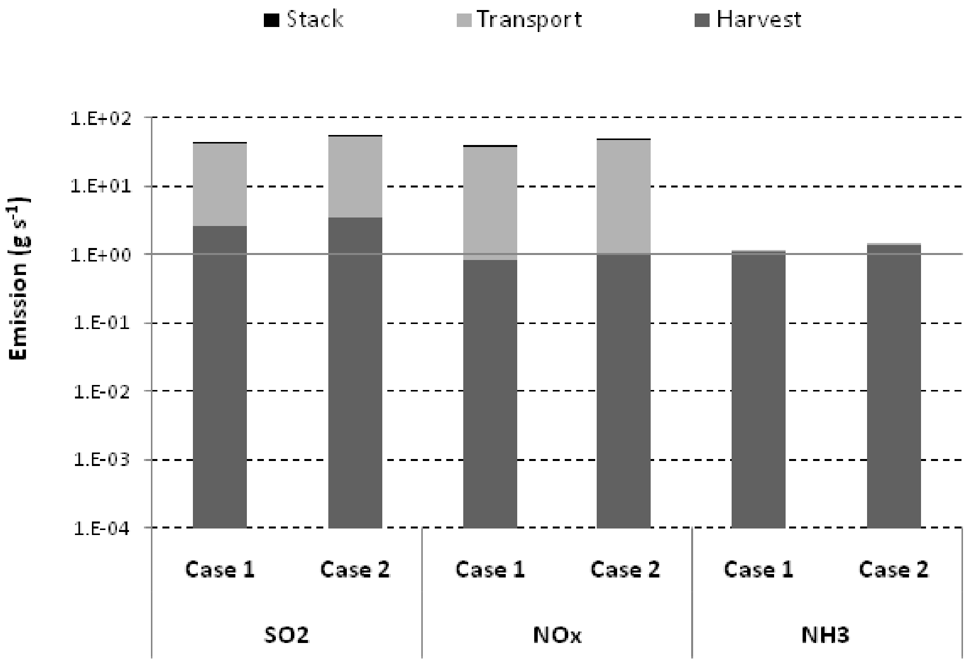

Figure 2: Emission inventory generated for the constituent activities on a life cycle of a CHP system.

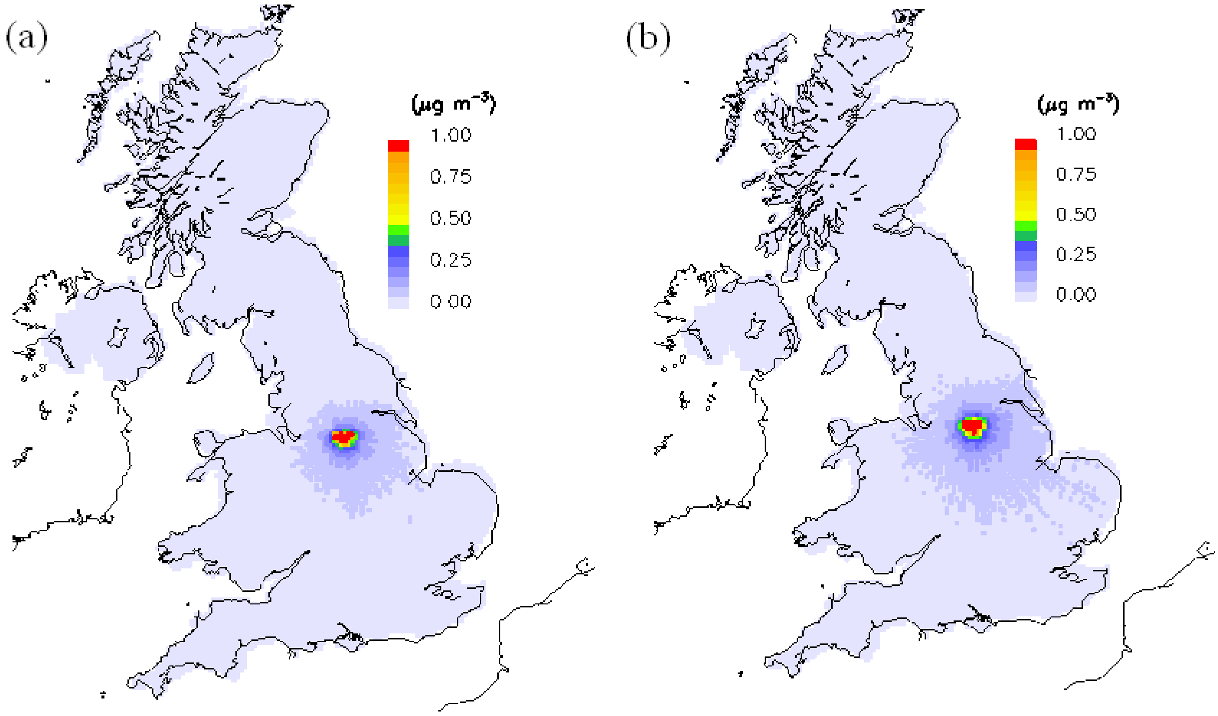

Figure 3: Footprint plot showing the secondary inorganic aerosol loading from photochemical interactions between precursor emissions of the CHP system (harvest, stack and transport) (a) Case 1; (b) Case 2. [Scenario.png]