Urban Bioenergy and Air Quality Impacts

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Introduction

Leeds City Council (LCC) is implementing a 170 kW biomass boiler for district heating purposes near the city centre. This switch to bioenergy is good for carbon emissions and climate change, though impacts on air quality were unknown as no Air Quality Impact Assessment (AQIA) was carried out.

The aim of the project was to recommend to LCC on how best to incorporate urban bioenergy into their policymaking and investment decisions for tackling climate change, whilst considering air quality, cost benefits, and design options. The approach considered air quality modelling using ADMS 4 to visualise the pollution dispersion of PM and NO_x, carrying out a cost benefit analysis, and evaluating the mitigation and maintenance methods available. All approaches considered effects from varying design scenarios, relative to each other and the current baseline of electric storage heaters.

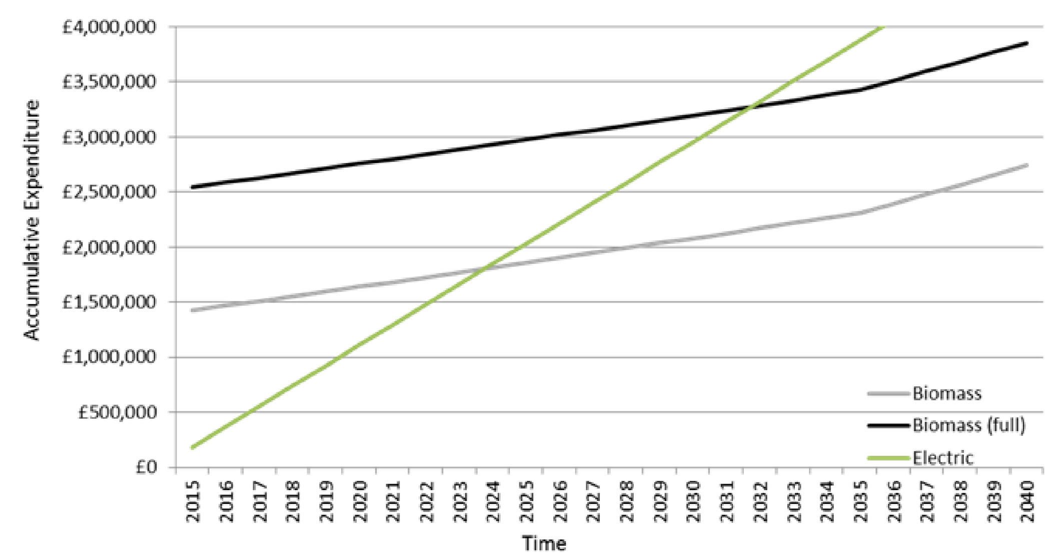
Background
One 170 kW biomass boiler running constantly, backing up to a thermal store, providing 70% of the heat demand. The rest will be provided by three 500 kW gas back-up boilers. The chimney termination will be 2m above the Clyde Grange tower (at 53.4m).
Biomass district heating with Renewable Heat Incentive (RHI) will be a cost-effective way of helping meet CO_2 reduction targets
Biomass combustion leads to emissions of Particulate Matter (PM) and Oxides of Nitrogen (NO_x)
The background pollutant concentrations for the site are 25.6 µgm^{-3} NO_2, and 17.5 µgm^{-3} PM_{10}

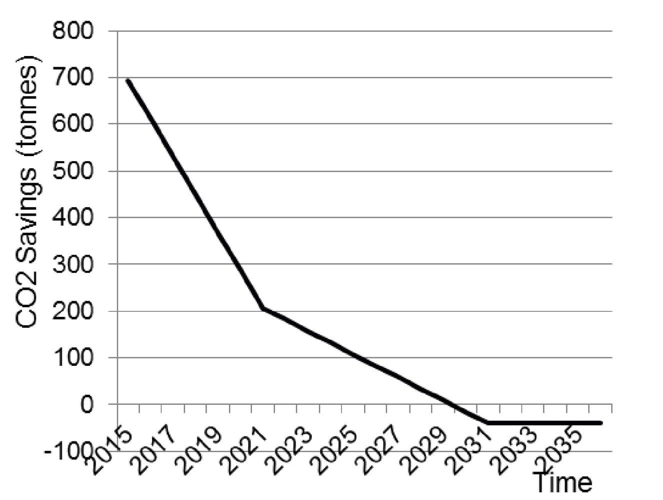
Why no AQIA is a concern
Parts of Leeds downwind has been over the NO_2 annual-mean objective set by the Air Quality Standards (AQS) since 2006
Real-world air quality impacts of RHI developments is unknown
The Clean Air Act memorandum from 1956 is not suitable for calculating stack heights for biomass boilers
The smoke control areas of the Clean Air Act do not directly control emissions of the smaller particles

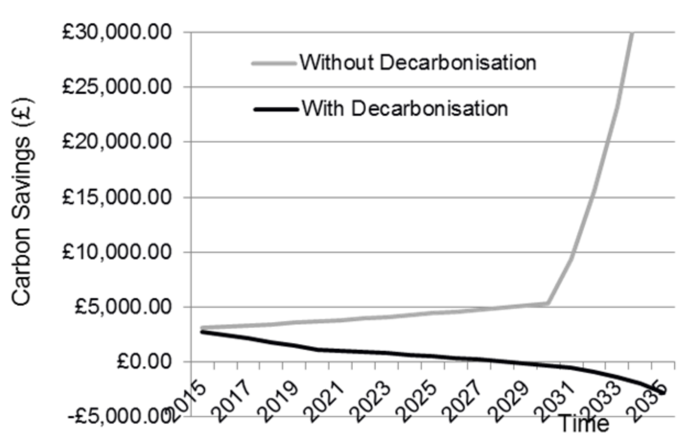
Cost Benefit Analysis

Benefits from the biomass boiler compromised of annual RHI payments, carbon dioxide savings and alleviation of fuel poverty. Whereas the installation, fuel, maintenance, air quality impacts and mitigation options generate the annual costs of the model. The model was adapted for the different mitigation scenarios, which were variation in chimney height and mitigation options. Some of the installation costs for the boiler will be funded by renewable energy grants, therefore a with and without funding case was examined.

The payback period with grants was found to be 9 years, whereas without funding it increases to 17 years. The estimated annual running costs of the electrical heating system was over twice that of the biomass boiler. The figure below shows the effect that this lowering of carbon intensity will have on the tonnes of carbon dioxide saved. The graph shows that around 2029, the carbon savings for the switch become negative. This means that from this point, more carbon dioxide would be saved if the buildings remained electrically heated; this is largely due to the carbon dioxide emissions associated with the gas back-up boilers. However, it is important to note that this is only the case if future predictions of grid decarbonisation are met and until that time biomass heat generation can save hundreds of tonnes of carbon dioxide.







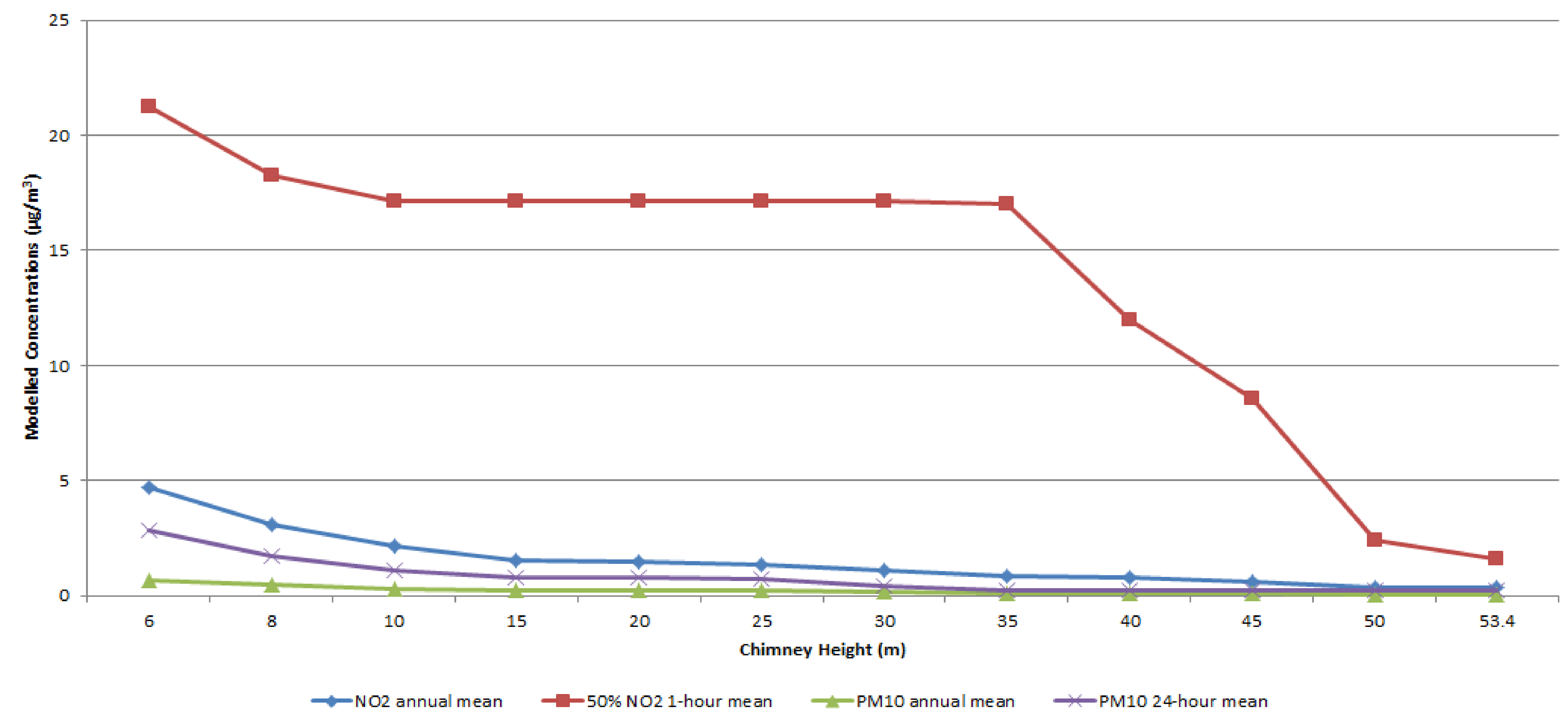
Other important results from the cost-benefit analysis include:

- Shorter chimney heights show better benefit-cost ratios (BCR) and internal rates of return (IRR) than larger chimney heights, due to the reduced installation costs
- Post-combustion mitigation options were also found to not have high rates of return

Air Quality Modelling

An AQIA was carried out, finding that for the development as it is, changes in pollutant concentrations were of '*imperceptible*' magnitude and are hence of '*negligible*' significance, according to the Environmental Protection (EP) UK AQIA scaling. The graph below shows all scenarios that were modelled, and it shows that when lower chimney heights were used, dramatic increases in pollutant concentrations were seen. The main threshold for chimney height was 50m, relative to anything below 35m, where there is a tenfold decrease in pollutant concentration.

Process Contribution Summary for NO_2 and PM_{10}

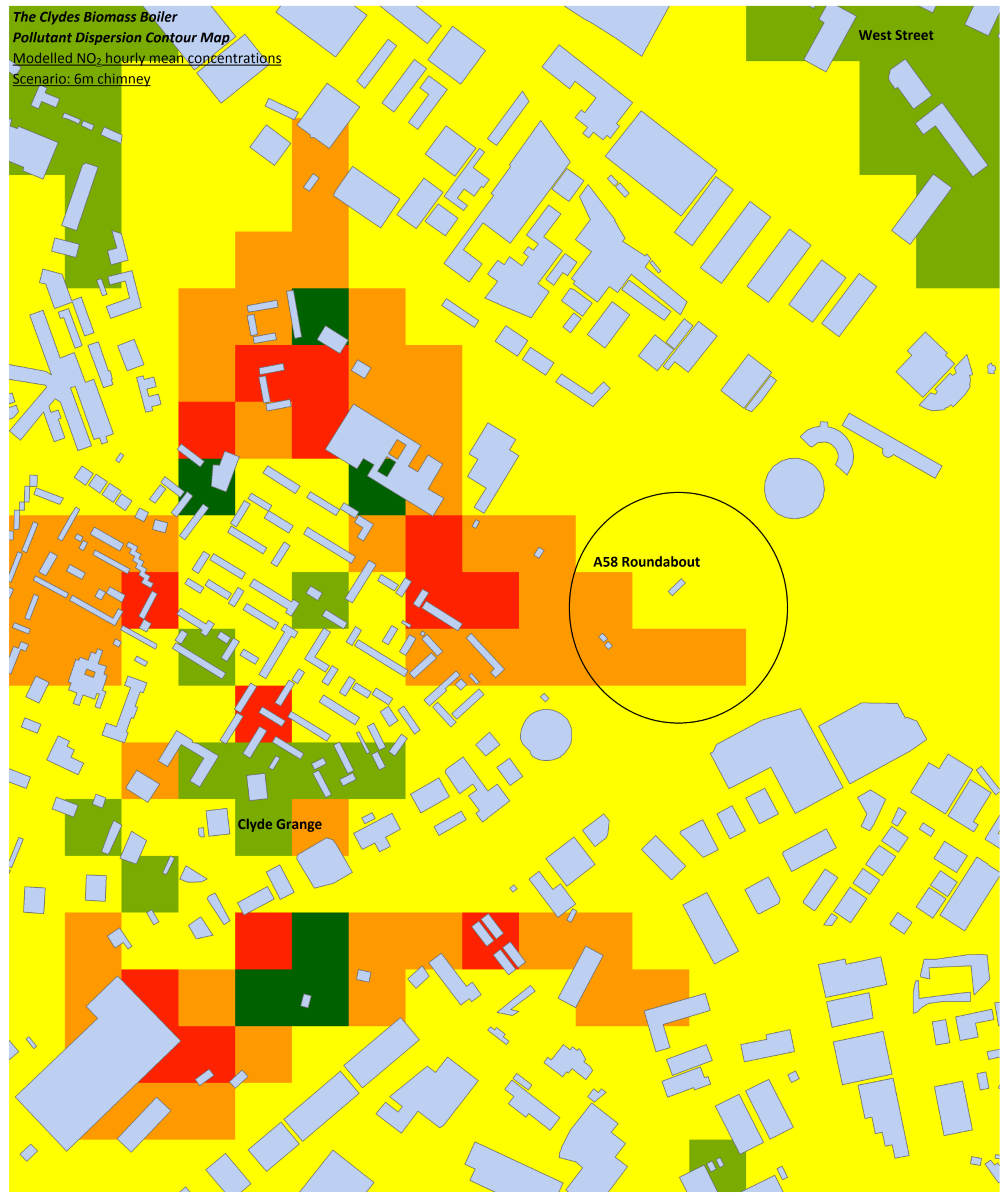


The pollutant dispersion for the development were represented by contour maps produced in ArcGIS. This was carried out for varying chimney heights and both annual and short-term averages, for both PM_{10} and NO_2.

The two figures to the right show the modelled NO_2 1-hourly mean concentrations in µgm^{-3}. The upper dispersion map is for the development as planned with the 53.4m chimney height, and the lower plot is for if a chimney height of 6m was used. The colour coding of the contours is according to the EP UK AQIA Magnitude of Change Scaling (see right).

It can be clearly seen that the range and intensity of the plume dispersion at ground level is significantly greater for the lower chimney height. This trend was the same for both pollutants, at both time scales, highlighting the critical importance of chimney heights for local downwash.

Key
EP UK AQIA Magnitude of Change Scale
NO_2 / PM_{10}
Units µg/m³
0.0 (No Change)
0.0 - 0.4 (Imperceptible)
0.4 - 2.0 (Small)
2.0 - 4.0 (Medium)
> 4.0 (Large)



Mitigation and Maintenance

Boiler types and post-combustion mitigation for PM and NO_x were compared based on their efficiency and their impacts on the emissions emitted (see table below).

The control of temperature and thermal efficiency has dramatic effects on the combustion performance and emissions released. Excess air near the stoichiometric conditions and temperatures of less than 1300°C also result in lower emissions factors.

Comparing these emissions factors to the CORINAIR Solid Fuel Emissions Factors, these values are much cleaner than heating via smaller-power units i.e. stoves or fireplaces.

Scenario		Efficiency (%)	Emissions Factors NO_2 (g/GJ)	Emissions Factors PM_{10} (g/GJ)
Post-combustion mitigation	SNCR	70	45	30
	SCR	99.9	0.15	30
	Fabric Filter	99.9	150	0.03
	Ceramic Filter	95	150	1.5
Boiler Category	Stoker Burner	82%	150	36.6
	Moving Grate	99%	150	30.3
	Plane Grate	75%	150	40

Conclusions

The recommendations to LCC are that focus should first be on developments where the chimney can be placed at least 50m above ground level (15 storeys), and below this height; mitigation, maintenance, and a detailed AQIA are necessary with increasing significance.

For developments with these lower chimney heights, it is recommended to install SNCR for NO_x control, fabric filters for PM control, and to chose the moving grate burner as the biomass boiler. From the cost-benefit analysis, it is recommended that local authorities have planning policies in place to encourage high-rise chimneys or the mitigation measures above, to encourage use as though they aren't the most cost-effective option. Also, carbon savings from this installation are found to be limited to 15 years due to the decarbonisation of power generation, however thousands of tonnes of carbon dioxide will be saved prior to this change.

Overall, when local authorities are planning for urban bioenergy they will have to tackle air quality and climate change at the same time if they are to minimise cumulative negative impacts on human health and the environment, and for them to be holistically sustainable in their efforts to decarbonise.

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