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Evaluating biomass energy strategies for a UK eco-town with an MILP optimization model

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ABSTRACT

Recent years have shown a marked interest in the construction of eco-towns, showcase developments intended to demonstrate the best in ecologically-sensitive and energy-efficient construction. This paper examines one such development in the UK and considers the role of biomass energy systems. We present an integrated resource modelling framework that identifies an optimized low-cost energy supply system including the choice of conversion technologies, fuel sources, and distribution networks. Our analysis shows that strategies based on imported wood chips, rather than locally converted forestry residues, burned in a mix of ICE and ORC combined heat and power facilities offer the most promise. While there are uncertainties surrounding the precise environmental impacts of these solutions, it is clear that such biomass systems can help eco-towns to meet their target of an 80% reduction in greenhouse gas emissions.

1. Introduction

Cities account for approximately two-thirds of the world's primary energy consumption and 71% of global fossil fuel related direct greenhouse gas emissions [1]. Therefore to ensure that cities maintain their vital social and economic functions, while mitigating global climate change, there is a need to develop urban energy systems that are more efficient and emit less carbon dioxide.

One option is to switch from fossil fuels to renewable energy sources such as wind, solar or biomass. This is typically achieved with national or regional policy initiatives. For example, the European Union has issued a directive which sets an EU-wide target of providing 20% of final energy consumption from renewable sources by 2020. The target is then broken down by member state: the UK, for example, has agreed to increase its renewable energy mix from 1.3% in 2005 to 15% by 2020 [2]. Urban environments are recognized as having an important role to play in delivering these goals. Articles 12.3 and 12.4 of the directive oblige member states to "consider" the use of renewables "when planning, designing, building and refurbishing industrial or residential areas" and to "require the use of minimum levels of energy from renewable sources in new or refurbished buildings". A practical example of such a policy in the UK is the Code for Sustainable Homes, "an environmental assessment method for rating and certifying the performance of new homes". This standard recognizes biomass energy systems, from single

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household boilers to district combined heat and power (CHP) systems, as “low or zero carbon technologies” integral to achieving high performance levels [3].

However, urban biomass energy systems pose a number of practical challenges including the use of specialist technologies, a range of alternative supply chains, and local air pollution impacts. This paper explores these trade-offs in the case of a UK eco-town and demonstrates a software tool that evaluates alternative technological options to identify an optimal (low-cost) urban biomass energy system. The issues that need to be considered in such a model and the eco-town case study are presented in Section 2. An overview of the software tool and the input data is then given in Section 3, before the results are described in Section 4. In the concluding discussion, we consider the implications of the results for the specific eco-town case as well as urban biomass energy systems more generally.

2. Background

This section highlights the diversity of urban biomass energy systems and key findings from the literature. It then introduces an eco-town case study to be used in the subsequent modelling. Note that our focus is on biomass for heat and power applications; we have not examined biofuels for urban transport.

2.1. *Characteristics of urban biomass energy systems*

There are several options to produce heat and power from biomass and these can be generally classified according to criteria such as biomass type, technology type and size, and the degree of decoupling between biomass treatment and conversion processes [4]. When integrating bioenergy into urban areas, the specific concerns are the availability of space for biomass storage and pre-treatment, the emission levels of bioenergy conversion processes, and transport issues including the logistics and costs of biomass supply. These barriers are mainly caused by the low energy density of biofuels, which require additional conditioning processes and consequently result in energy conversion efficiencies lower than what could be achieved via fossil fuel routes. Scarcity and competing alternative uses of biomass feedstocks are also a concern.

Despite these obstacles, bioenergy routes offer potentially high overall energetic, economic and environmental performance in urban areas due to the aggregation of demand and typically high energy costs. Unfortunately the proximity of the energy conversion plants to the load can be a disadvantage since the resulting emissions are also close to people. As power plants are often far from urban centres, new local plants can have a major impact on local air quality [5–7]. On the other hand, the effects of converting heating systems from electricity or gas-fired boilers to pellet heating systems have also been investigated, showing that conversion from electrical heating to pellets does not significantly affect air quality [8].

Urban bioenergy solutions therefore require a trade-off between centralized large plants and distributed small plants: the benefits of the former being high conversion efficiencies, low emission levels and low specific investment and operational costs; while the latter are advantageous due to reduced space requirements, simplified logistics and transport, and ease of plant location. For this reason, several studies have aimed to optimize the location and size of biomass CHP plants on the basis of technical and economic factors [9–12]. For example, a multi-criteria decision analysis methodology was applied to the Metropolitan Borough of Kirklees in Yorkshire, UK, to compare small-scale renewable energy schemes with large-scale alternatives. The results indicated that small-scale schemes were the most sustainable, despite large-scale schemes being more financially viable [13].

The most promising urban biomass energy systems are therefore often characterized by high-density biofuel feedstocks, clean conversion technologies and combined heat and power systems. However local air pollution and the relative costs and performance of alternative system configurations must be considered.

2.2. *The eco-town case study*

This paper presents an optimization model to evaluate alternative urban biomass energy systems. To illustrate its use, we have chosen a case study based on a proposed “eco-town” development in the UK. Given rising demand for housing as well as substantial questions about how the building sector might contribute to national climate change and energy policy goals, the UK government has promoted eco-towns as an opportunity to drive innovation and to demonstrate how these policy goals might be jointly achieved. It has been suggested that the headline targets for these developments should be an 80% reduction in CO_2 emissions (versus 1990 levels) and an ecological footprint two-thirds of the national average. To achieve these goals, eco-towns are likely to run on nearly 100% renewable energy for heat, cooling and electrical demand and at least 50% on-site renewables “should be possible” [14].

Initially twelve eco-town developments were put forward for consideration and this paper considers one of those proposals. The site is located in central England and our analysis has focused on one of the design phases, an area of 87 ha intended to house 6500 people. An initial assessment of the proposal by government-commissioned consultants found that the site “might be a suitable location subject to meeting specific planning and design objectives” but more information was required particularly on the energy strategy for the site [15]. Since then, the developers have commissioned a study of alternative energy systems to address some of these concerns. The report examined a range of renewable supply scenarios including large-scale wind, microgeneration technologies for heat and electricity (micro-wind, solar PV, solar thermal, heat pumps, etc.) before proposing two feasible strategies, based on biomass district combined heat and power (CHP) systems with varying amounts of wind energy. The strategy therefore raises questions about the choice of specific biomass conversion technologies, the structure of the district heating network and the availability of the biomass material (both imports from surrounding regions and local supplies).