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Research paper

Biomass and bio-energy utilisation in a farm-based combined heat and power facility

E.G.A. Forbes*, R.J. Olave, C.R. Johnston, J.D. Browne, J. Relf

Agri-Food and Biosciences Institute, AFBI, Large Park, Hillsborough, Northern Ireland BT26 6DR, UK

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ABSTRACT

Five different renewable energy technologies located at an agricultural and environmental research centre in Northern Ireland, were monitored to assess the cost, performance and efficiency in real-time operation of solar and bio-energy produced from crops and farm wastes utilised for energy generation in industrial grade equipment. Monitoring was conducted over a six year period, with power units running simultaneously or intermittently according to demand from the local district heating system. The purpose of the work was to investigate fossil fuel (oil) displacement, carbon dioxide emission (CO_2e) reductions, financial and environmental sustainability of these technologies in a farm based scenario. Between 2009 and 2014, total heat output from the centre was 7.75 GWh with contributions of 47.2%, 17.1%, 9.8% and 13.5% from the biomass, biogas, multi-fuel boiler and biogas CHP unit respectively. Solar thermal produced 0.49% and the back-up oil boiler 11.9%. Total electrical output was 572.6 MWh with 95.2% generated from biogas CHP and 4.8% from the solar PV system. Fossil fuel and average CO_2e reductions ranged from 20.1% to 54.1% and 23.3–55.7% respectively, reductions that combined with financial savings to present a viable and sustainable renewable energy system.

1. Introduction

The increasing demand for renewable sources of energy for heating and electrical power generation, has been driven by a number of factors but largely by rising costs, fuel security issues and increasingly, environmental concerns [1,2]. The European parliament has been instrumental in addressing these issues across all its member states and seeks to increase the uptake of biomass for energy generation and greenhouse gas (GHG) emission reductions [2]. While this may encourage interest and uptake of sustainable and renewable energy generation, there is often a mismatch in fuel availability and power plant suitability [2,3]. Between the extremes of small scale domestic and large scale regional heat and power generation, there is often a need for intermediate sized plants and this may be particularly applicable for farm based agricultural enterprises [4,5]. Mixed farms, such as those that have both livestock and arable capabilities, can offer high potential for both electricity and heat generation from animal wastes and crops grown specifically for energy crops. Anaerobic digestion (AD) can utilize animal wastes and crops, such as grass silage and maize silage, to produce biogas that can then be used for heat and/or electricity production. A significant and growing number of such plants running on these fuel types are already installed on farms across Europe [6,7]. Farm buildings and their environments are often also particularly suited for solar heating and electricity production [5]. Electricity producing solar photovoltaic (PV) and heat producing solar thermal panels offer reliable and relatively continuous (during daylight hours) electricity and hot water production and are particularly suitable for farms [5]. Heat from biomass is dominated by wood fuels, from waste streams (forestry, sawmill, furniture manufacturing) and dedicated wood crops, particularly short rotation (3 year) coppice (SRC), primarily willow (*Salix* spp) and short rotation (12–15 + years) forestry crops such as poplar (*Populus* spp) and eucalyptus (*Eucalyptus* spp) [5,8]. However, herbaceous crops, such as miscanthus (*Miscanthus* spp) commonly referred to as elephant grass, are also gaining acceptance as alternative fuels for combustion [9].

These types of modern renewable energy technologies are often installed as stand-alone plants though combined technology plants may be feasible on farms, both for primary energy supply and as a potential diversification into energy (heat and power) export [5,10,11]. Where such combined energy generation plants might be

* Corresponding author.
E-mail address: greg.forbes@afbini.gov.uk (E.G.A. Forbes).

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installed, comprehensive computerised energy management and control systems may be essential for reliable and overall efficient performance [10,12]. However, the critical challenge for such on-farm renewable energy schemes is to achieve viable economic energy production that is environmentally sustainable and reduces GHG emissions [10,11].

Agriculture is responsible for an estimated 28% of Northern Ireland's (GHG) emissions and the regional production of electrical energy (from mainly coal and natural gas) contributed 18.8% to total 2011 GHG emissions [13]. In the United Kingdom (UK) targets for GHG emissions reduction (35%), fossil fuel substitution and higher renewable energy reliance have led to an increased interest in renewable energy technologies. The adoption of renewable energy technologies is a mitigation strategy that has the potential to reduce emissions by replacing fossil fuel consumption and a number of incentives have been developed to enable this goal to be achieved. Currently, there are uncertainties regarding the impact of changes in farming practices on emissions from renewable energy crops and the utilisation of conversion technologies. Concerns also exist over potential conflicts between land used for fuel rather than food and the subsequent mitigation of GHG emissions by producing and utilising such energy crops for heat and/or electricity [14].

The aim of this paper is to describe and assess the measured outputs and overall performance of the inter-linked and wholly contained multiple energy production units on a large scale farm and environmental research centre in Northern Ireland. Further objectives of this study are to estimate the fossil fuel use reduction, GHG emissions and carbon savings of the research centre from its activities during a period of 6 years. This follows the adoption of renewable energy technologies in 2008 to substitute a significant proportion of fossil fuel use.

2. Materials and methods

2.1. Site description

The schematic (Fig. 1) shows the outlay of the purpose built energy centre located within the research farm estate of the Agri-Food and Biosciences Institute, (AFBI) at Hillsborough (54.4° N and 6.0° W) in Northern Ireland.

The research farm estate has 310 ha of land with a total grassland area of 292 ha used by dairy, beef, sheep and pig production and 10 ha for biomass crop research (Fig. 2). There is also ~200 ha of mixed broadleaf and conifer woodland, the latter being largely commercial forestry stock. The Energy Centre building (370 m^2) which was constructed in 2007/8, is a double height block and steel construction designed to meet national building standards and fire containment specifications. The building contains all the energy production units as detailed (Fig. 1). Developed primarily as a demonstration facility for commercial standard on-farm renewable energy technologies, the centre also provides facilities for renewable energy and environmental research. The technologies installed were solid biomass thermal conversion units, an anaerobic digestion plant for biogas production from cattle slurry, a biogas powered combined heat and power (CHP) plant for heat and electricity production and solar generated electricity and thermal energy. A district heating system was also installed for heat distribution while new electrical systems were installed for connection and integration of renewable electricity to the mains network. Along with this development a major refurbishment was completed of existing offices and conversion of old agricultural buildings to office and corporate facilities that were eventually linked to the district heating system. A schematic of the general farm area, buildings, biomass crop areas and district heating loop connections to the renewable energy centre is shown in Fig. 2.

2.2. Electricity and heat generation

The normal heating and electrical base loads of the whole farm and research centre in 2008 were ~600 ± 250 kW and 100 kW respectively with consistent seasonal electrical demand (150 kW peak summer, 250 kW peak winter). Heating was originally supplied solely from 18 oil boilers attached to various buildings throughout the farm estate. Based on an economic appraisal of

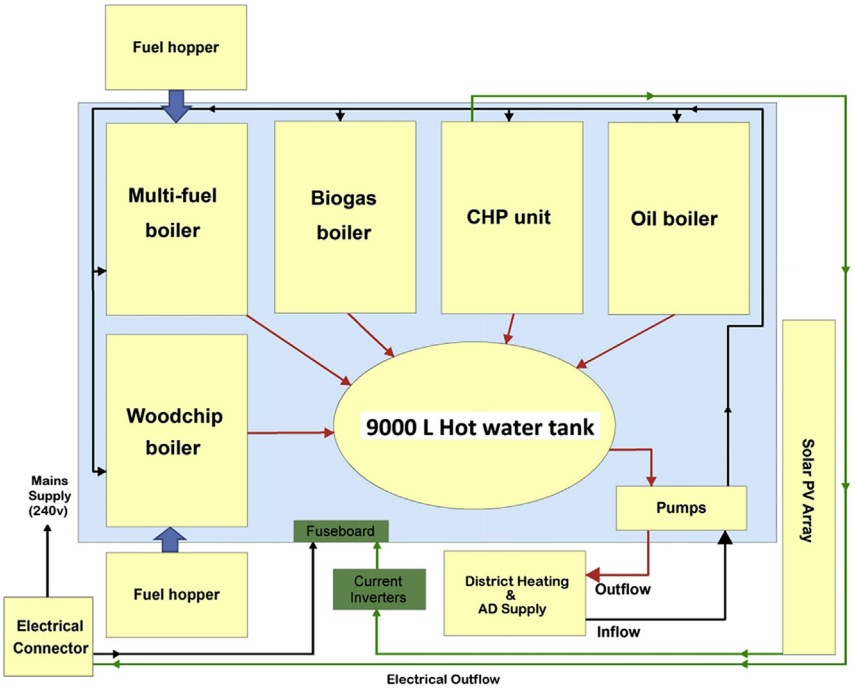

Fig. 1. Schematic of the environment and renewable energy centre (EREC) at AFBI Hillsborough.

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