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# Biochar and renewable energy generation from poultry litter waste: A technical and economic analysis based on computational simulations ☆

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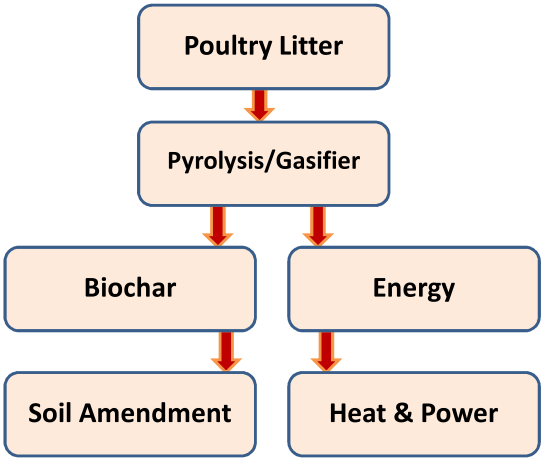
## HIGHLIGHTS

- A techno-economic analysis of the production of biochar and heat and power from poultry litter.
- The bio-waste pyrolysis/gasification system is modelled and simulated.
- The poultry litter biochar production system integrated with a CHP installation offers a significant $CO_2$ saving opportunity.
- Gate fees, Carbon Credits and ROCs have a significant impact on the breakeven selling price of biochar produced.

## GRAPHICAL ABSTRACT

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## ABSTRACT

The technical and economic analysis of generating biochar together with electricity and/or heat from poultry litter (PL) waste is the subject of this study. To carry out this study, the process simulation software ECLIPSE is used. Modelling and simulation have been conducted over the selected system: the pyrolysis/gasification process integrated with an Organic Rankine Cycle (ORC). The facility will be capable of processing 1500 kg of PL every hour. The simulation shows that when a reference PL is used the yield of biochar from the process is around 398 kg/h with a 38% carbon content. Electricity generated by the ORC system is 388 kW $h_e$. Recovered low grade heat for space heating is estimated at 1831 kW $h_{th}$. The results of the economic analysis suggest that when paying £20/tonne for handling and storing the feedstock without any options of selling either heat or electricity, the break-even selling price (BESP) of biochar is around £218/tonne. If the sale of electricity and heat produced is considered to be around £60/MW he and £5/MW $h_{th}$, the BESP will decrease to £178/tonne. The case studies also indicate that when a gate fee of £10/tonne is introduced the BESP can be further reduced to £65/tonne, equivalent to a 63% reduction.

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**Nomenclature**

| | |
|---|---|
| AR | as received |
| BESP | breakeven electricity selling price |
| CAPEX | capital expenditure |
| CHP | combined heat and power |
| CV | calorific value |
| DAF | dry and ash free |
| DCFR | discounted cash flow rate |
| EPC | engineering procurement and construction |
| FC | fixed carbon |
| LHV | lower heating value |
| LCOE | levelised cost of electricity |
| NPV | net present value |
| ORC | organic Rankine cycle |
| O&M | operation and maintenance |
| P | phosphorus |
| PL | poultry litter |
| ROCs | renewable obligation certificates |
| TCI | total capital investment |
| VM | volatile matter |

On the other hand if biochar generated has an average price of £150/tonne in the market and the plant receives one Renewable Obligation Certificate (ROC) from the Government, the Levelised Cost of Electricity (LCOE) for the electricity generation will be £46/MW $h_e$, which is compatible with electricity generated by fossil fuel power plants.



## 1. Introduction

The broiler poultry production in Northern Ireland, UK is a significant part of the local economy, sustaining on-farm employment for over 1400 people, with a further 4600 people employed in processing [1]. Concentrated poultry farms, however, generate large quantities (around 260,000 tonnes per annum) of poultry litter (PL) waste which could rise to 400,000 tonnes per annum within 5–10 years [2] due to the constantly increasing demand, resulting in various problems especially in the environmental pollution and human health risk. The disposal of PL in NI has received a lot of media coverage recently. As things stand, there appears to be no agreed course of action to remediate this issue but with tightening EU legislation, a sustainable solution to deal with the increasing quantities of PL must be initiated as soon as feasibly possible. Common poultry litter, which is produced during the normal poultry farming operation, consists of a bedding material such as wood shavings, sawdust and straw, together with the spilled feed and accumulated droppings. When managed correctly, land application of PL on the farms is a viable and beneficial option to recycle relevant plant nutrients such as nitrogen (N), phosphorus (P) and potassium (K), thereby maintaining the fertility and texture of the soil cultivated. However excessive application of PL waste to land without an appropriate treatment causes serious social and environmental problems, the most prominent of which is the protection of the environmental resources as its leaching into groundwater or washing into surface waters in watersheds [3]. Relying heavily on spreading of poultry litter on agricultural land the poultry farms also create a high risk of transmitting of botulism to cattle which is urged against by DEFRA [4].

To minimise health and environmental concerns in relation to the increasing quantities of poultry litter waste without adversely impacting on the farming communities, it is urgent for the poultry industry to develop and adopt green and sustainable solutions to deal with the issues. Since the poultry farm waste has been shown to be a type of wastes derived from agricultural biomass and contains the relatively high energy content and fixed carbon, the use of PL as a way of producing both bioenergy and sustainable biochar is a promising alternative for waste management [5]. As proposed this project is to produce biochar from PL waste. Different from the direct incineration/combustion process which is typically used to convert PL waste into heat/or power with small amounts of biochar, this option can be implemented by the combined pyrolysis/gasification of poultry litter in an oxygen restricted environment, whereby organic materials are converted into combustible gas (synthesis gas) and the rest is transformed into biochar containing a relatively high carbon content. Because of its high in phosphorous, potassium, calcium and other valuable micronutrients, biochar obtained from the pyrolysis/gasification process can be realised as a soil amendment which boosts soil fertility [6] and has the potential to help mitigate climate change by carbon sequestration in soils [7].

The overall objective of this paper is to perform a comparative techno-economic analysis of the small-scale integrated pyrolysis and gasification of poultry litter to give rise to both biochar and energy products. To achieve these objectives, the work begins with an investigation of the property of PL as a gasification feedstock using the information obtained from experiments. An integrated pyrolysis/updraft gasifier is then selected. Taking extremely high levels of tar content in the producer gas generated by a updraft gasifier into account an Organic Rankine Cycle (ORC) is configured to generate electricity. This implementation can avoid using the complicated scrubbing system, resulting in lower capital costs. Technical data are obtained from the test facilities and European Commission projects to adapt the models for PL waste conversion and applications and to ensure that the models are realistic. The process modelling and simulation are done using the ECLIPSE process simulation package [8]. Based on the results of mass-energy balances, an economic analysis of the options is then carried out together with a sensitivity study.

## 2. Materials and methods

### 2.1. Analysis of the feedstock

As a pyrolysis/gasification feedstock, the PL properties will influence the process operation and biochar product quality. In order to investigate the impact of variations in energy content, moisture level and chemical composition on the overall technical performance of the process two PL samples are chosen for the modelling and simulation. In addition, for the purpose of comparison a willow biomass is also included in this study. The ultimate and proximate analyses and lower heating values of the feedstock used are shown in Table 1. In this study, the PL Sample #2 is selected as the reference feedstock. This PL has a medium ash

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