Heat and Electricity Production from Poultry Litter Waste: Downdraft Gasification of Biowaste based on Validated Computational Simulations

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Abstract

Underutilised fuel sources such as wastes, and by-products are currently being investigated for their potential to displace fossil fuels in multiple industries. The Northern Irish poultry industry has the potential to benefit from using the waste generated on-site as a fuel source, significantly reducing the amount of CO_2 produced annually. The results can be achieved through downdraft gasification of poultry-litter, that can be converted into a producer gas for running a combined heat and power or organic Rankine cycle unit. The study was carried out through feedstock analysis, modelling of the process using ECLIPSE simulation software, and experimental analysis of materials in a pilot scale fixed-bed downdraft gasifier. Anaerobic digestate and miscanthus were also investigated for comparing the gasification potential of poultry litter. Models validated through experimental analysis were then applied to a case study based of a typical rural poultry farm in Northern Ireland. Results show that enough poultry waste is generated on site to produce the required heat and electricity for each shed. The choice of using an internal combustion engine or an organic Rankine cycle unit depends on the electricity demand of the farm. A techno-economic analysis of the system was also carried out to understand potential payback period for the system. Downdraft gasification coupled with CHP could have a payback of 10 years given the correct conditions, while downdraft ORC would be around 11 years.

Keywords

Downdraft Gasification; Modelling and Simulation; Poultry Litter; Combined Heat and Power

1. Introduction

The poultry industry has significant output across the island of Ireland and the rest of Great Britain. Over 20 million birds a week are produced for market in the United Kingdom, leading to roughly 1,400 tonnes of poultry litter (PL) by-product per week in an industry that directly employs over 37,000 people across the UK [1]. Sustainable development of this industry is critical for the UK economy, with production value being £2.7 billion in 2019 [2]. While consumer demand across individual industries such as food, textile and energy has increased around the globe due to growing populations, the desire for these demands to be met in more sustainable and environmentally friendly ways is critical for successful development. Clean energy technology has been at the forefront of most industries agendas across the UK since 1990 with government policy and legislation being a main driver [3]. A greater push towards renewable energy has been reasserted in recent years from the government commitment to net zero carbon emissions by the year 2050 [4]. The use of a circular economy method of thinking could help the poultry industry to become more sustainable through utilising their own waste as an energy source [5].

Poultry litter has traditionally been utilised as a fertiliser on neighbouring tillage land for nutrient recycling, or disposed through landfilling with disposal costs approximately £30 - £50 per tonne [6]. The application of poultry waste to land is a viable option for disposal, as it is a successful method of recycling important plant nutrients such as nitrogen (N), phosphorous (P) and potassium (K) [7]. However, an over application of PL to land as a fertiliser can lead to pollution of local waterways from excess nitrates. Northern Ireland introduced the Nutrient Action Programme in 2019 to protect water from agricultural nitrates [8]. Managing the amount of material spread on land is critical to ensure protection against pollution, such as eutrophication of local waterways. Other issues associated with land spreading of PL is the potential for airborne botulism to propagate between farms [9]. Due to the high volume of birds in Northern Ireland and relatively low land area, material has been sent across the border for spreading in the Republic of Ireland. Current waste shipment legislation between Northern Ireland and the UK remains unchanged due to the impact of Brexit, but future changes cannot be ruled out. Delays in ports for shipment of goods means companies may need greater storage areas for their waste before disposal can occur. More sustainable methods of disposal are therefore required, to ensure smooth operation. Advances in gasification technology and producer gas cleaning techniques have opened the door for PL to be used as the on-farm energy feedstock. Previous research on solutions for disposal of PL have been carried out. Re-use of litter between batches in the houses has occurred but only means to delay the issue and increases chances of cross contamination among the birds. Feeding of the material to livestock can also be carried out in some parts of the world, but foreign objects such as plastics and glass can cause issues [10]. Currently, researchers agree that the use of PL as an energy source produces the greatest revenue streams for farms and avoids the previously mentioned contamination and disposal issues through on-site thermochemical treatment of material. Gasification of PL has attracted several interests in recent years. Dayanda [11] investigated the potential of fluidized bed technology in rural India. Jeswani [12] found out through a Life Cycle Assessment analysis that PL gasification had a lower impact in 14 out of 16 categories considered when comparing to fossil fuel alternatives, and Perondi [13] researched the potential of natural catalysts to increase gas yields. Other thermochemical conversion methods for PL researched include pyrolysis [14] and hydrothermal carbonisation and anaerobic digestion [15]. However, there are some studies about the potential of using small gasification combined heat and power systems for onsite energy generation. The paper industry was covered by Ouadi [16], olive oil waste was researched by Vera [17], and the use of gasification by-products for onsite energy was researched by Vakalis [18].

Gasification technology allows for the conversion of solid biomass material into a producer gas in a low oxygen environment [19]. This producer gas can then be applied to a Combined Heat and Power (CHP) or Organic Rankine Cycle (ORC) unit to produce heat and electricity. Poultry litter has an inherent energy and fixed carbon content, which given the correct conditions can be exploited to meet the heat and electricity demands of rural farms. Changing from traditional energy generation methods such as fossil fuels to downdraft gasification coupled with applicable conversion technique, could potentially save thousands of pounds annually while increasing environmental performance and providing energy security. Environmental issues surrounding the increasing quantities of PL being produced and stored in large piles on site can be avoided using this thermochemical conversion process. These issues can include groundwater leaching from storage piles or land application, visual issues with large mounds, odour complaints and the spreading of diseases [20].

The overall objective of this paper is to analyse the potential to use the poultry litter generated on site through small-scale (<250kW) integrated downdraft gasification and CHP or ORC to fulfil the energy requirements of the poultry farm. This sustainable conversion method would replace the necessity of fuel purchasing with PL as feedstock for production of the required heat and electricity on site. The study is based on a detailed feedstock analysis, lab-scale gasification experiments of feedstocks, and generation and validation of computational simulations using the results gathered. A typical farm in Northern Ireland is used to assess the economic and environmental benefits of the solution.

2. Materials & Methods

With the aim to assess the potential of onsite heat and electricity generation through downdraft gasification of poultry litter we followed the steps below (Fig.1):

1. Analysis of biomass feedstocks for their physical characteristics, including moisture, ash and energy content. Elemental analysis of the feedstock to assess its elemental composition was also carried out.
2. ECLIPSE modelling of the downdraft gasification system was carried out, along with the CHP and ORC unit. Characteristics identified from the biomass analysis were used for the modelling. Through detailed mass and energy balances producer gas composition, emissions and process efficiency can be identified for the entire process.
3. Experimental analysis of the selected feedstocks was carried out in the pilot scale downdraft gasifier. Producer gas composition and LHV was identified as well as conversion efficiency and gas yields.
4. Through the pilot scale experimental analysis, the ECLIPSE model could be validated with the data collected.
5. The model was applied to a case study of a typical farm in Northern Ireland to assess the potential benefits of the gasification system. A comparison of two technologies for energy generation on site was carried out, CHP vs ORC offering a simple payback (SPB) for both.

A more detailed explanation of the steps undertaken is provided below.

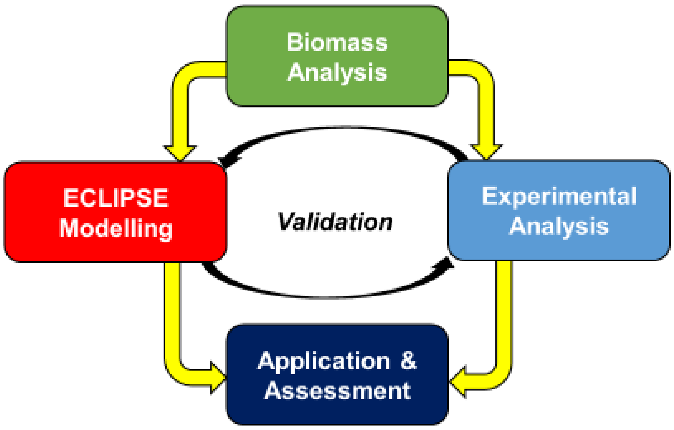

Figure 1 Experimental Flow Chart for Material Analysis

Analysis of the Feedstock

As a feedstock for gasification, poultry litter's physical characteristics will influence producer gas composition and quality. To understand how this will happen, a breakdown of these characteristics as well as elemental composition is required. To recognise the characteristics impact on performance, two other materials will also be investigated to compare the influence of moisture, energy and chemical composition. These will be digestate from a Northern Ireland based anaerobic digestion (AD) plant, and miscanthus. They've been chosen as digestate faces the same disposal difficulties as PL, whereas miscanthus can be grown on marginal land to provide extra income in Northern Ireland [21]. Estimates for digestate production are approximately 2.5 million tonnes available across the UK, with most currently spread on land for nutrient replacement [22]. Research carried out for the entire of the UK predict potential yield of 12 t ha^{-1} for miscanthus, generating between 0.09 – 0.034 EJ/year [23]. All materials are used in pellet form to increase energy density and avoid bridging issues in the grate. The proximate and ultimate analysis, along with calorific value of each material is presented in Table 1 Feedstock Properties. Standard methods of analysis which were carried out include moisture content (BS EN ISO 18134), ash content (BS EN ISO 18122), volatile matter (BE EN ISO 18123) and LHV (BS EN ISO 18125). Elemental components were identified by a PE 2400 CHNS Elemental Analyser, and oxygen was calculated by difference.

Table 1 Feedstock Properties

	Poultry Litter Pellet	**Digestate Pellet**	**Miscanthus Pellet**
Proximate Analysis			
Moisture Content	10.27	7.69	7.15
Ash Content	12.93	11.18	2.51
Volatile Matter	62.15	74.51	83.74
Fixed Carbon	24.91	14.31	13.75
Ultimate Analysis			
Carbon	41.97	44.49	50.53
Hydrogen	5.74	6.56	7.01
Nitrogen	5.08	2.51	1.41
Sulphur	0.43	0.34	0.34
Oxygen	46.78	46.09	40.70
LHV (MJ/kg)	17.20	20.96	19.95

The relatively low moisture content of each material, between 7.15% and 10.27% can be attributed to the pelletisation process that each feedstock has gone through. Pelleting requires relatively dry material, as excess moisture would prevent the material from binding [24]. This low MC% will negatively affect the H_2 content of the producer gas and therefore the overall producer gas LHV, as H_2 in the gas stream is generated from the water gas shift reaction. Less moisture in the feedstock means less moisture for conversion into H_2 [25]. The ash content of PL (12.93%) is higher than the digestate (11.18%) or miscanthus (2.51%), with a much lower volatile matter (62.15%), implying that of the three streams PL will decompose into producer gas the least. Sulphur levels within the PL (0.43%) are relatively low, as is the amount of nitrogen (5.08%) in comparison with other biomasses. This means lower potential for the creation of harmful nitrogen oxides and sulphur dioxides. LHV of materials also has a wide range, from PL (17.20 MJ/kg) to digestate (20.96 MJ/kg). This range is down to the hydrogen content of each feedstock, with PL containing a much lower amount of hydrogen (5.74%) in comparison to the other biomasses, with the miscanthus used containing 7%. The value could be related to the heterogenous mixture of material within the poultry litter such as bedding material, poultry excrement and feed.

Modelling and Simulation

For accurate prediction of producer gas composition along with reliable CHP and ORC system efficiencies, the modelling and simulation work was carried out using ECLIPSE process simulation package. ECLIPSE was designed by the energy research centre in Ulster University and has been used in many previous biomass and waste research projects [26]. It is a computer-based software programme that carries out rapid and reliable mass, energy and exergy balances of complex thermochemical reactions.

Initially the entire downdraft gasification process is defined within a flow diagram composed of modules and streams. These modules represent the various stages of the gasification process, where the solid biomass is broken down and converted into their various gaseous species, mainly CO, CO_2, CH_4, H_2 and N_2. ECLIPSE can also accurately predict the tar and char generated during the process. This occurs through the software carrying out the drying, pyrolysis, combustion and reduction stages of gasification. Once the modules have their technical characteristics defined and the input of each stream has been identified, mass and energy balances are determined by enthalpy calculations for each individual stream. To accomplish this, the information within the compound database relates to the input streams and modules. This second stage of processing allows the software to identify critical components within the plant that may display extreme physical and chemical conditions. The final stage of the software allows for the computation of energy consumed by individual utilities within the system, allowing for net power plant output to be calculated. The software can also assess the economy of the solution, by providing capital and operating cost estimates.

Economic modelling and evaluation of the system was carried out through a simplified net present value (NPV) concept. Total capital investment required along with other associated costs such as operation and maintenance fees were included. The lifespan of conventional energy conversion equipment such as traditional fossil fuel systems is approximately 25 years. During this time period components of the system would require regular maintenance and repair. A fixed value of 3.5% of capital cost has been included in economic assumption to agree with previous research in the field. Summarised in Table 3 CHP & ORC Capital Cost Estimates are other key expenses which have been used in the economic assessment of the waste to energy system of interest.

Experimental Set Up

The experimental apparatus selected is a Fluidyne MicroLab Class Gasifier, an air blown fixed-bed downdraft gasifier that operates at atmospheric pressure. Downdraft has been selected for this research as it is widely accepted as the technology of choice for small scale applications with low moisture content material. A simple and proven technology that produces a gas with moderate calorific value, but importantly, low tar content which is critical for successful downstream engine application of the gas. Downdraft also accepts the widest range of biomass materials, ideal for research into underutilised biowastes [27]. The downdraft gasifier of choice is a pilot scale one, for experimental analysis. Six air inlet manifolds allow air into the heart module of the gasifier where the reactor is, with an external handle controlling the flow rate. Solid biomass is converted into producer gas in the hearth, before passing along the system to the cyclones for removal of tar and particulates. From here the gas can pass two ways: to the test flare where gas is siphoned from for further cleaning and analysis or through an internal condenser and filtration system for engine application. Clean-out ports on each module allow for the removal of tar and other unwanted particulates. Manometers and thermocouples are connected to each module to measure pressure and temperature changes across the system respectively. A Grant 2020 series data logger is connected to the thermocouples for accurate recording. Apparatus layout is displayed in Figure 2 Experimental System Set Up.

For producer gas composition analysis, it is fed through the ETG PSS 100 Portable Sampling System Gas Treatment which has a scrubber unit for removal of final tar and particulates. The cleaned producer gas is then fed into an ETG MCA 100 Syn Biogas Multigas Analyzer, which accurately record the CO, CO_2, H_2, N_2 and O_2 as volumetric percentage (vol.%).

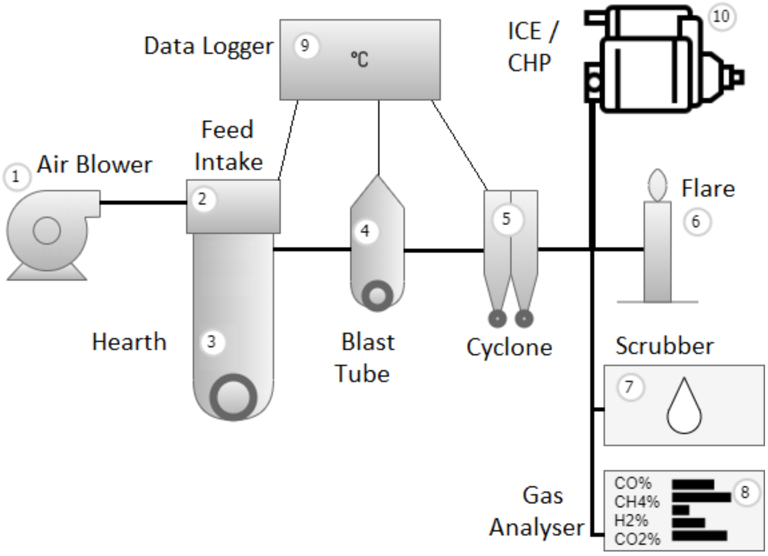

Figure 2 Experimental System Set Up

3. Process Validation

Experimental analysis of feedstocks was performed in triplicate, to ensure the validity of the collected results. Average values for each of the gaseous components of interest (CH_4, CO, CO_2, H_2 & N_2) were obtained. The ECLIPSE model generated was then adjusted to accurately represent the producer gas found. This was carried out through alterations of the mass balance equations until volumetric composition from the ECLIPSE model agreed with experimental results. The mass balance equations within the model could be adjusted to favour particular products from the defined reactions. Increasing or decreasing the percentage of reaction products allowed for accurate composition to be generated. A comparison of model results and experimental results can be seen in Figure 3 Model Results vs. Experimental Results. To ensure accuracy of both the model and the experimental results, the data was compared to that found within the literature of previous research. Results agreed with what has been previously identified as good quality gas. Lower heating value was found for the poultry litter producer gas. Through the use of air as the carrier gas, the resulting gas with diluted with inert nitrogen. Overall producer gas lower heating value (LHV) for the poultry litter pellets was found to be between 2.84 – 4.15 MJ/Nm^3. Gasification efficiency was calculated through sample weight conversion. Ash, char and tar produced during the reaction was collected and weighed to identify total conversion. This was found to be 68%.

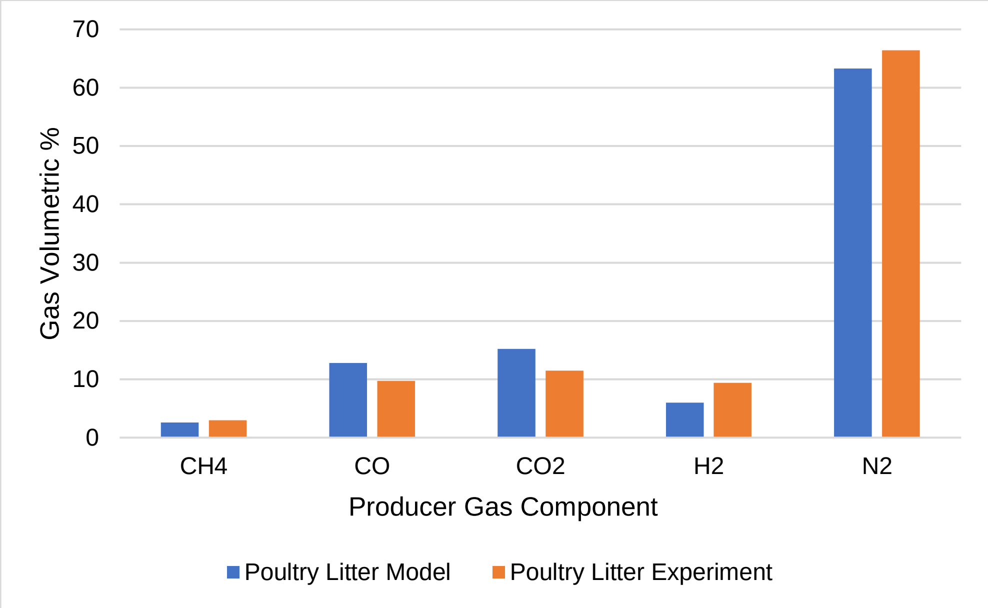

Figure 3 Model Results vs. Experimental Results

4. Discussion

The proposed system was successfully assessed through the utilisation of ECLIPSE simulation package. An overview of the technical and environmental performance of the system is presented in Table 2 System Technical & Environmental Performance. Biomass flowrate in based on a DAF basis, which influences the variation in rate, with PL having the highest flowrate, of 229 kg/h, compared to digestate with the lowest flowrate, 207 kg/h. The reason being that PL has the highest ash and moisture content (12.93% and 10.27% respectively). Ash and moisture content don't have the expected influence on gas production. Miscanthus has the highest volatile matter (83.74%), meaning it breaks down into its gaseous components easiest, but this does not translate into the gas production rate here as digestate creates the highest amount of gas even with its lower VM, of 74.51%.

Heat output varies slightly between feedstocks, with digestate gasification producing marginally less heat than PL, 343kW vs 344 kW, while miscanthus has the highest heat output of 348kW. This is noteworthy as despite having a very similar output to digestate, the efficiency for PL is higher. Electrical efficiency of the ICE is 22.82% with an overall heat and electrical efficiency of 54.18% for PL. Although the performance is lower than natural gas fed CHP engines, but in this case, waste is used with the additional advantage of overcoming disposal issues.

CO_2 emissions from the system are a critical reference point, to compare the environmental performance to existing systems. From the authors experience, poultry farms across the UK utilise LPG or biomass systems for their energy needs.

Table 2 System Technical & Environmental Performance

	Poultry Litter Pellet	Digestate Pellet	Miscanthus Pellet
Input (kg/h)	229	207	218
Gas Production (m3/h)	568	525	463
Heat Output (kW)	344	343	348
Electrical Output (kWh)	250	250	251
CO2 Emissions (kg/h)	333	311	304
SO2 Emissions (kg/h)	1.87	1.32	1.27
Electrical Efficiency (%)	22.82	20.77	20.80
CHP Efficiency (%)	54.18	49.25	49.66

Case Study

While gasification at large scale has yet to take off across the UK, there are examples of plants across Europe, North America and Asia that are successfully operational [28]. Small scale is currently a more attractive method for the UK market due to the simpler technology and lack of expertise required to run. The application of this system would be particularly suitable for a rural poultry farm, capable of using their farm waste to generate heat and electricity for the site and avoid any problem of contamination during the transportation of poultry litter. Using the efficiencies found through the ECLIPSE modelling, we have assessed the potential of using biowaste for a typical poultry farm in Northern Ireland. The system will consist of a fixed bed downdraft gasifier, and either a CHP or ORC unit along with related ancillary equipment. Fresh poultry litter will be collected from the onsite sheds and fed into the drying system for processing. Material will be converted into heat and electricity through the gasifier and downstream equipment.

A standard sized poultry shed of 73m x 18m, holds approximately 27,000 birds at any given time. The shed requires 240 MWh_{th} and 35 MWh_e annually [29]. An average poultry farm containing 4 sheds, will have a resulting net annual demand on site of 960 MWh_{th} and 140 MWh_e.

Table 3 CHP and ORC Capital Cost Estimate was generated using values found through the ECLIPSE modelling software. Values were produced in euro and converted to British pound sterling using recent exchange rates (€1 = £1.15 [30]) CHP total capital costs are marginally higher than the ORC equivalent due to the increased cost of the power generation process. CHP system also has an increased grid connection cost due to the amount of electricity generated. Feedstock preparation costs are those associated with drying, commuting or pelleting. The gasification system for both set ups is the downdraft gasifier which would include reactor bed, cyclone, heat exchanger and ceramic filter system. Contingency costs could be any associated works required such as material handling, disposal or filtration. Total installed cost for the proposed CHP system would be £886,285, while the ORC system is lower at £853,617.

Table 3 CHP & ORC Capital Cost Estimate

Gasifier & CHP Cost		***Gasifier & ORC Cost***	
Feedstock Preparation	£43,478	Feedstock Preparation	£43,478
Gasification System	£217,391	Gasification System	£217,391
Power Generation Process (ICE-based)	£195,130	Power Generation Process (ORC-based)	£164,304
Grid Connection Cost	£97,826	Grid Connection Cost	£39,130
Heat Recovery Circuit	£79,235	Heat Recovery Circuit	£119,335
Total Equipment Cost	£633,061	Total Equipment Cost	£609,726
		Gas Burner	£26,087
Integration Cost	£158,265	Integration Cost	£152,431
Contingency	£94,959	Contingency	£91,459
Total Installed Cost	£886,285	Total Installed Cost	£853,617

From table 3 we can see the overall cost of the proposed system for a rural poultry farm based in Northern Ireland. For the case study, we assume that in the standard scenario the heat and electricity currently utilised on site is provided by either LPG or a woodchip fed boiler. The use of woodchip boiler is a more sustainable approach compared to the LPG and it is currently used by many farms across Northern Ireland. To understand the potential of these technologies, the current operational costs associated with a poultry farm are evaluated in Table 4 Operational Capacity and Payback.

The material produced on site is approximately 378 tonnes of wet PL per shed, as material contains an as received moisture of approximately 60%. This equates to 226 tonnes of dried material per shed when reduced to 15-20% moisture, giving a total of 907 tonnes of dry material per annum. Downdraft gasification of this material can produce 2,565,105 kWh/annum, enough to meet the heat and electricity demands of the site, as well as covering the excess needed for material drying.

When considering the CHP engine for heat and electricity production, a large proportion of the electric generated will need to be sold to the grid as the demand onsite is only 16.5% of the amount produced. Selling 83.5% of the electricity generated, or 706 MWh_e could cause a congested electricity grid. This means that a grid connection may be difficult to achieve, as well as excessive costs associated with the connection for the transformer required. This solution could also limit replicability in the area. Heat generated from a CHP engine is much closer to that of the onsite demand, with 90.3% of all heat produced required for heating of the poultry sheds or for pre-treatment drying of PL. Excess heat generated here could be used for further heating onsite, to increase poultry comfort, to supply hot water for cleaning or other specific onsite needs.

To avoid the large excess of electricity and potential grid connection problems, an ORC system can be utilised. This allows for a more flexible system where the power to heat ratio can be adjusted. Under the conditions modelled, 45.5% of the electric generated would cover onsite demand, meaning a significant amount for export is still generated. Further adjustment to the power to heat ratio can take place to reduce the excess electricity. In terms of heat, 68.7% of the heat energy supplied from the ORC system will be used on site.

The proposed systems will save the case study farm heating costs (£0.03/kWh), grid electric costs (£0.12/kWh) and waste disposal costs of £30/tonne. If a selling price ranging from 0.025 to 0.055 £/kWh_e could be agreed with a local supplier, and the system qualified for the renewable heat incentive (RHI) of 0.0315 £/kWh_{th} the investment would be profitable and characterised by a SPB of between 10 and 13.2 years for the CHP system, or slightly higher 11.4 – 12.2 years for the ORC depending on agreed tariffs [31]. Both systems offer a swift payback, with each having their own benefits. CHP offers a lower payback period given the correct conditions, but the ORC system flexibility may be more attractive to prospective investors.

Table 4 Operational Capacity and Payback

	CHP	ORC
Tonnes/Year (Dry)	907	
Calorific Value (kWh/kg)	4.159	
Biowaste Energy (kWh/yr)	3,772,213	
Producer Gas Energy (kWh/yr)	2,565,105	
Electrical Efficiency (%)	33.0%	12.0%
Thermal Efficiency (%)	80.0%	80.0%
Electric Generated (kWhe/yr)	846,485	307,813
Thermal Heat Generated (kWhth/yr)	1,374,896	1,805,834
Energy for Drying (kWh/kg)	0.207	
Total Drying Energy (kWh/yr)	281,215	281,215
Electric Used on Site (kWh/yr)	140,000	140,000
Heat Used on Site (kWh/yr)	960,000	960,000
Net Electric for Grid Export (kWhe/yr)	706,485	167,813
Total Excess Heat (kWhth/yr)	133,681	564,618
Heating Fuel Price (£/kWh)	0.03	
Electric Cost Price from the grid (£/kWh)	0.12	
Export Electricity Tariff (£/kWh)	0.025 – 0.055	
Renewable Heat Incentive (£/kWh)	0.0315	
Waste Disposal Cost (£/tonne)	30	
Total Electric Payment (£) (at the price of £0.055/kWh)	38,857	9,230
Total Electric Payment (£) (at the price of £0.025/kWh)	17,662	4,195
Heat Savings (£)	28,800	28,800
Total Heat Payment (£)	43,309	56,883
Electricity Savings (£)	16,800	
Avoided Disposal Charges (£)	27,210	
Total Income (gross) (£)	133,781	133,888
Annual Insurance Cost (£)	13,294	12,804
Annual O&M Cost (£)	53,177	51,217
Payback Period (Years)	10.0 – 13.2	11.4 – 12.2

The results show that Northern Ireland's poultry industry is a perfect candidate for the proposed system, due to the need to address the problem of PL disposal as soon as possible as a result of Brexit [32]. The large number of birds nationally, and relatively low amount of land for spreading means the use of material on the site of production is the most environmentally and economically sustainable method of disposal. If poultry waste can no longer be transported across the Irish border, the only available option may be to transport to the island of Great Britain for disposal through either landfilling or spreading. Handling and transport costs for shipping to rest of GB are significant, with prices being £30 per tonne in 2012 and potentially rising due to higher gate fees [6]. With over application of nutrients to land already an issue in Northern Ireland, gasification coupled with downstream application offers a practical solution to avoid high disposals costs, as well as ensuring the sustainability of the industry. Further justification of the system is the lower CO_2 emissions per kWh generated from PL gasification than an LPG boiler system. In total downdraft gasification of PL coupled with heat and electricity production generates 0.03 tonne CO_2/kWh. This is significantly lower than that produced by an LPG boiler with 1.05 tonne CO_2/kWh produced, and lower too than woodchip boiler alternatives that produce 0.20 tonne CO_2/kWh [33].

There is a possibility of the system not qualifying for the RHI, due to the suspension of the Non-Domestic RHI to new applications within Northern Ireland. The only systems that would remain profitable under these conditions would be CHP with the higher electric tariff of £0.055/kWh although a significant increase in the payback period would be seen as can be seen in Table 4 Potential Payback Scenarios. CHP payback would increase by 9.6 years to 19.6, while the ORC system would require over 47 years for a SPB, an unsustainable period longer than the lifetime of the equipment. While this could potentially detract from the appeal of the system, if the gate fee for disposal increased from £30/tonne to £50/tonne payback with RHI would be 8.3 years for the CHP proposed system, and 9.2 years for the ORC. Without receiving the RHI tariff this would be 13.9 years for the CHP system and 23.6 years for the ORC.

Table 4 Potential Payback Scenarios

	CHP System	**ORC System**
Total Income without RHI (the export tariff = £0.055/kWh)	£45,195	£18,019
Payback Period (Years)	19.6	47.4

Total Income without RHI (the export tariff = £0.025/kWh)	£24,001	£12,984
Payback Period (Years)	36.9	65.7
Total Income with RHI (PL disposal cost = £50/tonne)	£106,645	£93,043
Payback Period (Years)	8.3	9.2
Total Income without RHI (PL disposal cost = £50/tonne)	£63,336	£36,159
Payback Period (Years)	13.9	23.6

5. Conclusion

The use of poultry litter for onsite heat and electricity production is an interesting example of circular economy. The paper has investigated the potential of using small-scale downdraft gasification along with a heat and electricity production unit on a rural poultry farm in Northern Ireland. The elemental analysis of three types of pellets was carried out (poultry litter, AD digestate and miscanthus) to understand their potential as a fuel for gasification. Simulation modelling of the gasification reactions along with heat and power systems were carried out and validated using the average results obtained from experimental analysis. Gasification efficiency was found to be 68% for material conversion. The use of poultry litter shows the highest overall efficiency for heat and electricity production through a CHP unit, with electrical efficiency and thermal efficiency of 33.0% and 80.0%, respectively. The results from the validated model were applied to assess the benefits of the solution for a typical Northern Irish poultry farm. Comparisons between CHP and ORC were carried out to identify the optimum solution, with differing heat and electrical loads generated through the two systems. Under current conditions payback for the gasifier and CHP system could be between 10.0 – 13.2 years depending on incentives available, while the gasifier and ORC systems payback ranges from 11.4 – 12.2 years. On-site waste conversion for energy generation purposes was found to be both financially and environmentally sustainable compared to the current system of energy generation, with lower CO_2/kWh emissions from gasification of poultry litter than LPG or woodchip boiler systems. Within the UK, 0.23 kg CO_2 is generated per kWh electricity produced [33]. If all poultry farms in Northern Ireland converted to the gasification system over 10,300 tonnes of CO_2 emissions could be avoided from grid electric alone.

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7. Disclaimer

The views and opinions expressed in this paper do not necessarily reflect those of the European Commission or the Special EU Programmes Body (SEUPB).

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