Title: A community-scale hybrid energy system integrating biomass for localised solid waste and renewable energy solution: evaluations in UK and Bulgaria

Abstract

Growing pace of urban living is expected to simultaneously aggravate both the waste and the energy crises. This study presents feasibility assessment of a community scale hybrid renewable energy system (HRES) utilising biomass to serve the local energy needs while reducing the household solid waste volume. A modelling framework is presented and evaluated for a biomass HRES, comprising of a Wind turbine-PV Array-Biogas generator-Battery system, applied to two European cities - Gateshead (UK) and Sofia (Bulgaria) - accounting for their distinct domestic biowaste profiles, renewable resources and energy practices. Biogas generator is found to make the most substantial share of electricity generation (up to 60-65% of total), hence offering a stable community-scale basal electricity generation potential, alongside reduction in disposal costs of local solid waste. Net present cost for the biomass-integrated HRESs is found within 5% of each other, despite significant differences in the availability of solar and wind resources at the two sites. Based on a survey questionnaire targeting construction companies and energy solution developers, project costs and planning regulatory red tapes were identified as the two common implementation challenges in both the countries, with lack of awareness of HRES as a further limitation in Bulgaria, impeding wider uptake of this initiative.

***Keywords**: Bioenergy; HOMER; Hybrid system; Renewable energy; Waste to energy*

1. Introduction

The housing sector in the European Union (EU) accounts for approximately 20 percent of the annual greenhouse gas emissions, and is considered as the third largest contributor to global warming, following manufacturing and energy supply activities [1]. Carbon dioxide (CO_2) emissions from the domestic sector remain alarmingly high and the issue of biodegradable waste handling in many European countries is still highly unsustainable [2]. Managing municipal solid waste (MSW) in a more sustainable and environmental friendly way is a critical issue for municipal authorities across Europe. In 2015 for example, on an average about 500 kg of household waste was produced per person in the EU, of which 120 kg got disposed off to landfills, with a lost opportunity for their further use in the circular economy value chain, via energy recover or recycling [3].

Globally, managing waste is one of the main tasks of local authorities. In the UK and elsewhere in Europe, new initiatives are being planned to develop facilities which minimise household waste and use it to produce energy [4], including separate collection system of recyclables and biowastes for better utilisation of the latter [5]. It is estimated that there are approximately 500 waste-to-energy plants in 23 European countries [6]. On average, conventional waste-to-energy plants using mass-burn incineration technology can convert one tonne of municipal solid waste into approximately 550 kWh of electricity [7]. Large-scale projects such as The Eco Park in Surrey and Waste-to-energy plant in Exeter and London have been developed as part of this initiative in the UK. On the other hand, smaller scale waste-to-energy systems, such as gasification plants could help developers and community members in providing a combined solution for tackling local biowaste and household energy supply. A biomass-integrated hybrid renewable energy system (HRES), which combines the production of energy from meteorologically-driven renewable sources (wind, solar, tidal, etc.) and a suitable biomass gasification technology could be an alternative to large scale plants [8–10]. Such small-scale hybrid systems require less time to construct and install, and their performance and reliability is improved compared to a single source renewable system [11]. One tonne of MSW treated in a gasification technology could produce up to 1000 kWh of electricity, which is higher compared to mass-burning incineration plants [7]. This is because in the gasification process municipal solid waste is used as a feedstock rather than fuel. Those technologies are commonly used in developing countries or in remote, rural areas that lack access to grid connectivity [12]. Techno-economic feasibility studies of hybrid solar-biomass system using animal wastes have been recently reported on their cost-effectiveness in supporting grid-connected [13], or off-grid [14] electricity supply in remote locations.

While the majority of energy use in the domestic sector is associated with appliance usage and heating/cooling needs, the amount of municipal waste produced per capita vary considerably across Europe from country to country - ranging from the extremes of over 750 kg in Denmark and Norway to less than 270 kg in Romania and Serbia [15]. Both UK and Bulgaria have intermediate shares of 485 kg and 404 kg respectively [4,16]. An advantage of using domestic waste as feedstock for the gasification plant is that biomass in this form would more likely grow rather than decrease due to the continuous growth of the population and the need for more housing developments. It is also a cheaper option compared to big waste-to-energy plants currently being developed throughout Europe and the UK, with several potential benefits to both the homeowners and the local authorities. These include, but not limited to: use of a renewable resource to provide electricity that is more sustainable and environmental friendly compared to conventional sources, therefore saving on electricity bills; resolve the MSW disposal issue by using it as a biomass feedstock; convert biowaste into a revenue source, by selling excess electricity back to the grid; etc. In addition, if a larger biogas generator is installed and more biomass is available it can be used to replace natural gas supply in the local gas grid.

In its tenth anniversary report, the UK Committee on Climate Change identified significant achievement in decarbonising electricity generation in the last decade [17]. However, the UK National Grid's "Future Scenarios" report [18] seeks more aggressive application of renewable energy technologies in electricity production, usage and storage from the domestic section through its 'Smart system and Flexibility plan', seeking involvement from every individual and community. This has two fold incentives to the households – one, of reducing the energy-related GHG emissions, and two, cost savings [19]. Using unrecyclable municipal waste as energy source in such way will also help to achieve the 2015 EU Circular Economy legislation targets of gradual limitation of the landfilling of municipal waste by 10% by 2030 and a ban on landfilling separately collected waste [3,20]. Further, landfill can be an expensive option if the cost of environmental pollution and depletion of resources are considered [21] and hence more cost-efficient utilisation of domestic waste is paramount to reach long-term sustainability. Hence, using biomass as a local energy source has been considered pivotal to this mission in offsetting EU's external energy dependence while reducing greenhouse gas emissions from landfilling [22,23].

This paper has evaluated the potential for implementing a micro grid hybrid energy system in a densely populated residential area, utilising domestic biowaste to generate biogas and electricity, and collaterally, to avoid the pressure on landfilling of household biowaste. As a first step, a 'hypothetical' community-scale, biomass integrated hybrid energy system is conceptualised in order develop sustainable solution for household energy and waste management. A sensitivity analysis is conducted to establish the dependence of the proposed biomass integrated hybrid system on different cost and performance scenarios, optimising potential input of the locally available biowaste resource. Thereafter, the conceptual framework is applied to two European case studies - Gateshead (UK) and Sofia (Bulgaria), taking into account their distinct domestic biowaste profiles and energy practices. This is followed by a survey questionnaire designed to assess the pros and cons of the potential uptake of the proposed system in new builds and retrofitted housing projects under real world conditions in the UK and Bulgaria.

2. Materials and methods

2.1. Biomass integrated hybrid energy system modelling

The proposed biomass integrated hybrid renewable energy system include a biogas generator, wind turbine, PV array, batteries and a converter, which was modelled using Hybrid Optimization of Multiple Energy Resource (HOMER Pro®) software [24,25], following recent trends in design and optimisation of solar photovoltaic–wind based hybrid energy systems [26] (**Figure 1**). The design parameters for the wind turbine and the photovoltaic array are acquired from the literature data [27,28]; the configuration shows the renewable components connected to the AC and DC (respectively alternating and direct current) bus of the HRES circuit, with the photovoltaic (PV) outputs providing the DC outputs requiring either conversion to AC, using a converter for operating appliances or directly charging the battery. The biogas generator is assumed to be operated using the domestic waste sourced locally from the residential community, typically arising from 20 houses with assumed occupancy of two adults and two children per house. The scope of this HRES design is to manage the issue with domestic waste alongside supply of stable renewable energy to the community. The location settings in the HOMER tool determine the amount of solar radiance and wind available in the area, as well as the local average annual temperatures.

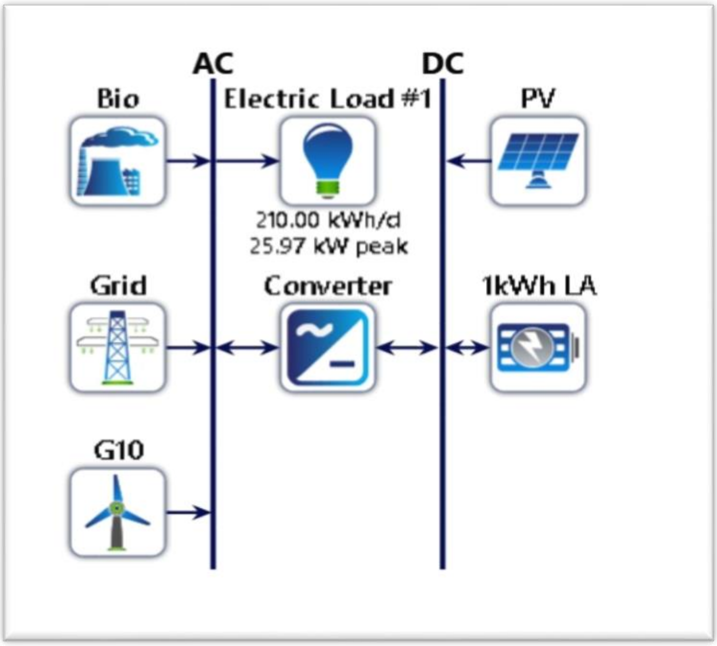

Fig.1 Schematic configuration of the community-scale biomass-integrated HRES.

The software uses long-term weather data collected by NASA over the past few decades to estimate the representative natural renewable resource profile for a given site. The waste generator operates on biogas, which is produced by the gasification of the waste. Given the modelled system is grid connected, it allows the sale of excess energy back to the grid, offering revenue generation potential.

Initially, all components of the system have been assumed to be co-located within a single premise, creating a small power station within the borders of the housing development. The converter is required to convert the DC electricity generated by the PV panels into AC electricity, which is the type of power used by the grid and most of the household appliances. However, upon further consideration, it was agreed that due to the size of the PV array required to provide efficient energy for all twenty houses, the system's components have to be disaggregated. Panels placed on each house would also mean that every dwelling will collect and store energy for its own demand. In addition, this allowed for appropriate utilisation of the available roof space in dwellings in a densely populated area. Therefore, the design of the integrated system assumed each house to be equipped with its own PV array, battery storage and a converter system to sell any excess electricity directly back to the grid.

Model sensitivity was carried out to investigate the influence of the following three parameters on the overall performance of the HRES system – (i) daily electricity demand profile (from 180 – 260 kWh); (ii) availability of biowaste (from 1000 – 2000 tonnes annual average); (iii) PV array size.

2.2. Demonstration case studies

The performance of the biomass integrated HRES has been evaluated in the UK and Bulgaria to ascertain the distinct contributions of household waste profiles, socio-cultural practices in domestic waste management, residential energy demands, climatic and renewable resource (solar irradiation and wind) regimes and the emerging community/local government initiatives in the two European countries (if any) supporting the feasibility of the proposed system. The chosen sites were Gateshead, UK (54° 57.2'N, 1° 36.2'W) and Sofia, Bulgaria (42° 41.9'N, 23° 19.3'E), both representing medium-size cities with more than 1 million inhabitants and comparable amounts of domestic biowaste arisings. Based on recent reports issued by WRAP and Eurostats data, it was estimated that an average of 1,500 tonnes of biomass were available per month at both these locations [4,15]. Additional modelling parameters were acquired from a mix of dedicated research databases, publicly accessible reports and journal papers (**Table 1**). Apart from the biogas generator kept identical for the two case studies, adequate sizing parameters were applied to the design of the wind turbine and solar PVs since Gateshead has higher availability of wind resource, whereas Sofia has higher availability of solar insolation (mainly attributed to their geographical locations).

The energy demand profiles for the two sites used for this simulation were adopted from the Household Electricity Surveys carried out by Intertek among 251 UK households [29] and demand profiles from EVN Bulgaria [30]. For the purpose of generating electricity demand profiles, typically householders in both Gateshead (UK) and Sofia (Bulgaria) were assumed to have the following usage patterns: *Weekdays* - spending majority of day outside home during the week (either for work or school), with morning peaks between 7-9 am (when family members prepare to go to work/school) and evening peaks between 5-10 pm (when most occupants are at home for daily activities). Apart from this, a slight increase was applied during lunch hours when some residents have increased electricity demand. *Weekends* - The weekday diurnal pattern was boosted by 30%, assuming the majority of family members spend their weekends indoors.

Table 1. Annual average resource profile and residential energy demand per household for UK and Bulgaria.

Location	Gateshead (UK)	Sofia (Bulgaria)
Resource availability (total annual)		
Wind[#] (at 20 m from ground)	5.5 ms^{-1}	3.92 ms^{-1}
Solar[*] (global horizontal irradiance)	2.61 $kWh/m^2/day$	3.74 $kWh/m^2/day$
Air temperature[*]	9.53°C	9.71°C
Biomass (domestic household arising)	485 kg per capita	404 kg per capita
Typical household energy demand (estimated total)	3850[~] kW	4100[§] kW

[#] *NASA surface meteorology and Solar energy (average of 10 yrs. between Jul 1983-Jun1993; surface roughness = 0.01)*
* *NASA surface meteorology and Solar energy (average of 22 yrs. between Jul 1983-Jun2005)*
[~] *https://www.ovoenergy.com/guides/energy-guides/how-much-electricity-does-a-home-use.html*
[§] *https://ec.europa.eu/energy/sites/ener/files/documents/bul_chp.pdf*

It is noteworthy that the electricity demand for either of the sites has strong seasonal variation, mainly depending on the type of heating and cooling demands and operation of house appliances. Based on the literature and the data sets mentioned above, the daily average electricity demand of the modelled communities at Gateshead and Sofia were respectively 253 kWh and 270 kWh; owing to lack of information, the peak demands were however kept identical at 25.97 kW, assuming similar load characteristics for a medium-size community.

2.3 Project implementation survey

While feasibility assessment of stand-alone PV-Wind-Biomass hybrid energy system have been reported previously using modelling studies, there is little discussion on the challenges faced by developers in implementing such projects [9]. An online survey questionnaire was designed, targeting the construction companies to assess the pros and cons to implementation of a biomass-integrated HRES in a newly built, or a retrofitted housing estate, essentially capturing the practitioners' perspectives. This was geared to acquiring professional opinions on the practical limitations and challenges to ground realisation of the conceptualised biomass-integrated HRES facilities. The survey comprised of a combination of open and likert scale questions; a total of eight questions were specifically designed to gather data on the views of engineers, consultants, designers and construction project managers (**Appendix 1**).

The questionnaire was divided into three small sections. The first section acquired general background information about the participants, such as their affiliation, and professional capacity within the company. This ensured participation of only those people who possessed the required knowledge and experience. The second section gathered opinions on the potential of the proposed hybrid renewable energy system, and comprised likert scale questions (allowing numerical interpretation of the responses). The final section contained open-ended questions, specifically seeking wider feedback and experience sharing from the participants. The method used to analyse these questions was different to the one used for the ordinal data. As qualitative data cannot be easily transformed into a numerical form, an alternative 'coding' method was employed, allowing the qualitative data to be grouped together. The data was carefully sorted and similar responses and patterns were put together using the statistical analysis features in SPSS® Statistics Software [31]. While evaluating the responses from the professionals, due consideration was given to country-specific factors (or bias) in the two countries that could affect the outcomes such as cost, legislation, government targets and resources availability. For the purpose of the Bulgarian survey, all questions were translated into the local language to avoid misrepresentation of the text and to ensure greater survey uptake.

The questionnaires were distributed to a variety of construction and building service companies in the UK and Bulgaria. Construction professionals of various backgrounds were approached and invited to provide their professional opinion on the matter, based on their knowledge and experience. A total of 130 survey samples were distributed through email and social media in the UK and Bulgaria (65 in each country). To ensure higher turnover, snowballing technique was employed to select participants, largely seeking a response using a network of existing professional circle of the co-authors in the two countries.

3. Results and Discussion

3.1. Optimised HRES configuration

Optimal biomass integrated hybrid renewable energy system configurations over a 20-year lifespan for the UK and the Bulgarian sites are presented in **Table 2**. The difference between the two optimal systems generated by HOMER is the size of the PV array and the system converter. The optimal UK system consists of 8.48 kW PV array and 8.56 kW system converter, whereas the Bulgarian optimal system consists of 15.4 kW PV array and 11.3 kW converter.

Table 2. Optimal design of a biomass integrated hybrid renewable energy system.

Component	Type	Size/Unit	
		HRES – Gateshead (UK)	HRES – Sofia (Bulgaria)
Biogas Generator	Generic Biogas Genset	25.0 kW	25.0 kW
PV	Flat plate PV	8.48 kW	15.4 kW
Storage	1 kWh Lead Acid	20 strings	20 strings
Wind Turbine	10 kW	1 ea.	1 ea.
System Converter	Generic System Converter	8.56 kW	11.3 kW
Grid	Grid	5.00 kW	5.00 kW

The corresponding net present cost (NPC) of each component for the systems proposed for the two case studies are shown in **Table 3**. The NPC of the system included capital cost, replacement cost, operation and maintenance associated cost, fuel and salvages. The NPC cost of the biogas generator is found to be the highest, followed by the cost of the PV array and the wind turbine. No fuel charge is allocated to all the components due to the renewable energy resources used.

For the UK system, the net present cost is £ 327,644.16 and the levelised cost of energy is £ 0.222 per kWh. For the optimal Bulgarian micro grid system, the net present cost of the system is £ 346,112.87, which is within 5% of the UK system. The corresponding levelised cost of energy is £ 0.245, mainly owing to the higher cost of the converter.

Table 3. Net Present Cost by component for the HRES proposed for implementation in the UK and Bulgaria (all costs in £).

Net Present Cost by component – Gateshead (UK)						
Component	Capital	Replacement	O&M	Fuel	Salvage	Total
Flat plate PV	25,436	0.00	1,096	0.00	0.00	26,532
WT 10kW	50,000	15,940	6,464	0.00	-8,983	63,421
Biogas Genset	75,000	45,751	96,504	0.00	-2,003	215,253
Grid	0.00	0.00	-2,232	0.00	0.00	-2,232
Storage 1 kWh	6,000	13,951	2,586	0.00	-1,318	21,218
System Converter	2,569	1,090	0.00	0.00	-205.11	3,453
System	159,004	76,732	104,417	0.00	-12,509	327,644

Net Present Cost by component – Sofia (Bulgaria)						
Component	**Capital**	**Replacement**	**O&M**	**Fuel**	**Salvage**	**Total**
Flat plate PV	46,338	0.00	1,997	0.00	0.00	48,335
WT 10kW	50,000	15,940	6,464	0.00	-8,983	63,421
Biogas Genset	75,000	43,712	90,331	0.00	3,790	205,253
Grid	0.00	0.00	2,784	0.00	0.00	2,784
Storage 1 kWh	6,000	14,263	2,586	0.00	-1,077	21,771
System Converter	3,383	1,435	0.00	0.00	-270.16	4,549
System	180,721	75,351	104,161	0.00	14,120	346,113

There is obviously a cost increase in system converter for Sofia compared to Gateshead owing to sheer difference in the converter sizes, respectively at 11.3 kW and 8.56 kW for the two sites. PV array was another component that differed in costs, apart from which the NPC costs for all the other components remained the same for the two countries.

For both the case studies, the biogas generator is found to produce the bulk of renewable electricity (typically over 60% of the share) among all the components included in the HRES (**Table 4**). However, the share of wind and PV productions showed different patterns for the two countries. The difference between the two locations and the amount of electricity produced was mainly due to the renewable resources availability. While in Gateshead, wind turbine contributes to second highest production (approximately 15% of total), this was only just over 3% of the total production in Sofia. On the other hand, while the share of PV in Gateshead was in the third position (approximately 7% of the total), in Sofia PV contributed to second highest electricity generation (approximately 18% of the total), with almost double production compared to Gateshead in terms of annual electricity generation. Thus, the optimal system design in Sofia includes bigger PV array at the study location.

Table 4. Share of electricity production by the different components of the HRES.

Electricity production by component - Gateshead (UK)		
Component	**Production (kWh/yr)**	**Percent**
Flat plate PV	7,799	6.73%
Biogas Genset	74,650	64.4%
WT 10kW	16,261	14.0%
Grid Purchases	17,130	14.8%
Total	115,841	100%
Electricity production by component – Sofia (Bulgaria)		
Component	**Production (kWh/yr)**	**Percent**
Flat plate PV	19,488	17.5%
Biogas Genset	69, 875	62.8%
WT 10kW	3,473	3.12%
Grid Purchases	18,380	16.5%
Total	111,215	100%

3.2. Sensitivity analysis

The sensitivity analysis allowed performance assessment of plausible scenarios deviating from original conditions for the following two parameters - load demands (180, 210, 250 kWh/day for both sites) and biomass availability (485 and 404 kg per capita respectively for the UK and Bulgarian sites) **(Table 5)**. For a 180 kWh/day load demand, the system's overall net present cost (NPC) decreased since the size of the system's PV array also decreased. On the other hand, for the highest predicted demand of 250 kWh/day, the NPC of the system increased. However, the levelised cost of electricity (LCOE) decreased as the system relied on the biogas generator to produce the additional electricity required. Thus, with the growth in demand, the majority of the energy supplied can be produced by the biogas generator, which is cheaper as the biomass used as feedstock is waste produced locally by the housing developments. For the sensitivity tests modelling different biomass availability scenarios, no significant changes were observed since the biomass being a waste has been considered to have nil purchase value.

Table 5. Sensitivity analysis of performance assessment for plausible scenarios

Daily Load Demand (kWh/day)	***Biomass Availability (kg per capita)***	***PV array size (kW)***	***NPC***	***Levelised cost (kWh)***
180 (UK/BG)	485 (UK)	6.68	£ 290,187.19	£ 0.235
	404 (BG)	12.0	£ 311,482.13	£ 0.260
210 (UK/BG)	485 (UK)	8.48	£ 327, 644.16	£ 0.222
	404 (BG)	15.4	£ 346,112.87	£ 0.245
250 (UK/BG)	485 (UK)	0.395	£ 372, 406.03	£ 0.197
	404 (BG)	18.1	£ 388,292.08	£ 0.229

3.3. Survey feedback to implementation challenges

This section reports on the questionnaire survey outcomes, mainly targeting construction companies, on the plausible challenges to implementing a PV-Wind-Biomass hybrid energy system into either a new built housing estate or for retrofitting applications. From the 130 survey requests, only 30 (about 23%) were returned fully completed, including qualitative responses to open-ended Q5-8. Nevertheless, all of them responded to the majority of Questions 3 and 4, respectively seeking opinions from stakeholders on return on investment potentials and on the potential impact generated by the proposed system to the local community. The respondent cohorts from the UK were mainly Project Managers and Building Surveyors, while the majority of Bulgarian respondents were Technical Assistants and

Service Managers. For Question 1, both the UK and the Bulgarian respondents expressed costs (including implementation, operation and maintenance costs) as the main concern, followed by efficiency of the system and issues pertaining to adaptation of the existing dwellings (in case of retrofitting). This is in agreement with recent studies, which have considered financing of the investment as the main hurdle to ground realisation of such implementation plan [9]; specifically, in Eastern/Central European countries where primary focus of waste management is on deriving low-cost options [32]. Additional country-specific concerns mainly alluded to stringent regulatory frameworks for stand-alone energy generation installations currently in place in the UK, which could adversely affect such investments. Additionally, in Bulgaria the other major concern was the lack of skilled personnel and adequate training to build the required taskforce.

For Question 2, where the respondents were asked to suggest/propose a viable alternative (i.e. relatively simpler scheme), which could be more cost-effective and appealing to the construction companies in terms of return on their investments and at the same time address the waste minimisation issue, the UK respondents alluded to a crucial role of government incentives and local authority approvals, while Bulgarian respondents could not suggest an alternative to make the process of decision making easier. On the question regarding future potential of the proposed biomass integrated hybrid system, 67% of respondents in Bulgaria positively agreed while remaining 33% had no fixed opinion. On the other hand, 80% of the UK respondents felt that the proposed integrated system has future in the UK housing sector. It is noteworthy, none of the respondents in either of the two countries out rightly declined the proposition of integrating biomass with mainstream renewables (**Figure 2**).

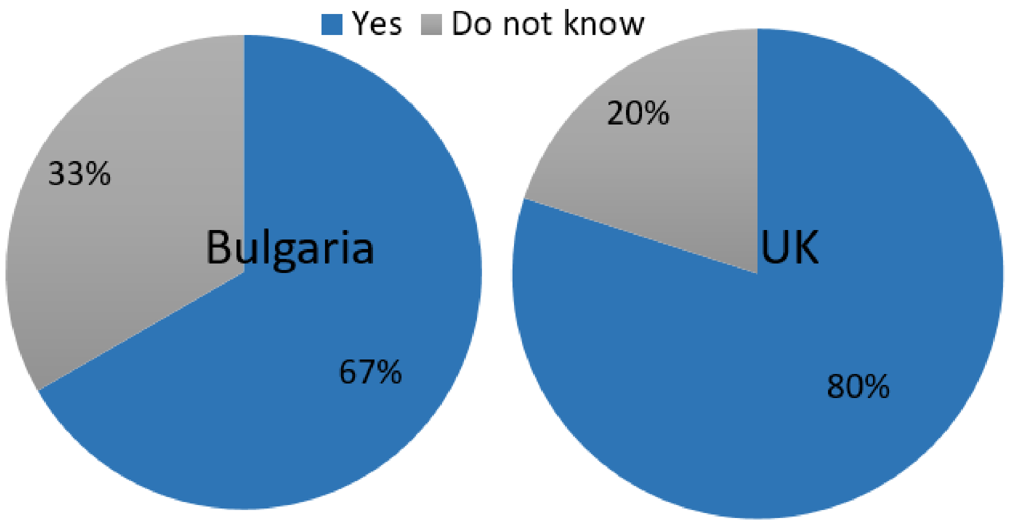

Fig. 2. Survey response to potential use of biomass integrated community-scale (n=130).

For Question 3, outcomes to likert scale questions ranging from ‘Very likely’ to ‘Very unlikely’ (Q3.1-3.6) were mainly geared to acquire professional opinions from commercial companies on return on investment potentials. Similarly, Question 4 likert scale questions (Q4.1 to 4.4) scaled respondent opinions from ‘Strongly agree’ to ‘Strongly disagree’ on the potential impact generated by the proposed system to the local community. **Tables 6 and 7** respectively provide the distribution of responses to Questions 3 and 4 for UK and Bulgaria as percentage share of respondents for each category.

Table 6. Survey response seeking professional opinion on return on investment opportunities. The split share of responses between very likely and very unlikey are shown as percentage for the two countries (n=130; the most dominant response in each category shown as italics).

	Very likely	**Likely**	**Neutral**	**Unlikely**	**Very unlikely**
3.1 In your opinion how likely is it for construction companies to install Wind-PV-Waste to Energy systems in new housing developments?	11% (UK) 8% (BG)	*42%(UK)* *38%(BG)*	37% (UK) 31% (BG)	10% (UK) 15%(BG)	0% (UK) 8% (BG)
3.2 How likely is it for such HRES to improve the environmental impact of new developments managing unrecyclable biowaste?	25% (UK) 23% (BG)	*40% (UK)* *38% (BG)*	17% (UK) 23% (BG)	18% (UK) 15% (BG)	0%
3.3 How likely is it that the system would generate income?	17% (UK) 15% (BG)	*52% (UK)* *46%(BG)*	31% (UK) 38% (BG)	0%	0%
3.4 How likely is it that installing Wind-PV-Waste to Energy system would increase property prices?	28% (UK) 23% (BG)	*52% (UK)* *46% (BG)*	17% (UK) 15% (BG)	3% (UK) 15% (BG)	0%
3.5 How likely is it that houses equipped with HRES will be more appealing to new buyers due to the long-term savings they would provide?	11% (UK) 8% (BG)	*48% (UK)* *46% (BG)*	34% (UK) 38% (BG)	7% (UK) 8% (BG)	0%
3.6 How likely is it that local authority approval and legislation could affect construction company's decision on whether to install biomass-integrated HRES?	37% *(UK)* *50% (BG)*	*44% (UK)* 37% (BG)	19% (UK) 13% (BG)	0%	0%

Table 7. Survey response seeking professional opinion on potential impact generated by the proposed system to the local community. The split share of responses between very likely and very unlikey are shown as percentage for the two countries (n=130; the most dominant response in each category shown as italics).

	Strongly agree	**Agree**	**Neutral**	**Disagree**	**Strongly disagree**
4.1 Providing new developments with biomass-integrated HRES would enable construction companies to deliver on sustainability promise.	27% (UK) 23% (BG)	*69% (UK)* *62% (BG)*	4% (UK) 15% (BG)	0%	0%
4.2 Biomass-integrated HRES would aid in achieving government targets in terms of carbon footprint reductions.	25% (UK) 23% (BG)	*62% (UK)* *58% (BG)*	13% (UK) 19% (UK	0%	0%
4.3 Correctly sized and installed systems could provide communities with more sustainable living.	41% (UK) 35%% (BG)	*55% (UK)* *47% (BG)*	4% (UK) 0% (BG)	0% (UK) 18% (BG)	0%
4.4 Biomass-integrated HRES could also be extended to commercial developments to deal with biowaste produced by local businesses.	21% (UK) 15% (BG)	*78% (UK)* *61% (BG)*	1% (UK) 24% (BG)	0%	0%

Based on the survey, the UK construction professionals showed a more positive response to the potential feasibility of a biomass-integrated HRES into the residential sector. On the other hand, the respondents in Bulgaria appeared unsure of its implementation potential in the immediate future. These differences could be mainly attributed to the level of awareness of the problems by the workforce involved in construction industry in the two countries. Furthermore, there seems an apparent lack of information about the deployment of hybrid renewable energy systems in Bulgaria. However, participants from both countries have identified project costs and legislative red tapes as the main hurdles to wider realisation of the proposed biomass-integrated HRES on the ground.

It is noteworthy, like any survey, the responses acquired represent only a limited subset of the industry perspective on this issue. Additional aspects could be explored if greater number of participants had responded to the survey and could provide their answers to all the questions asked.

4. Conclusions and Future work

This study presents a conceptualised framework for utilising domestic biowaste in developing an integrated hybrid renewable energy system (HRES) to serve the community scale energy needs, typically for a housing estate with 20 houses, assuming occupancy of two adults and two children per house. Its implementation potential is evaluated for two case studies, one in the UK and the other in Bulgaria, considering the two European cities offering distinct cultural and climatic influence on the performance of the proposed system and its overall operating cost. For both the case studies, the share of biogas generator remained between 60-65% of the total renewable electricity generation potential, hence offering a stable community-scale basal electricity generation potential for the proposed HRES. On the other hand, the PV array produced more energy in Sofia whereas the wind turbine accounted for more energy in the UK, mainly attributed to the difference in availability of the corresponding renewable resource driver at the case study locations.

An online survey questionnaire was designed, targeting the construction companies to assess the pros and cons to implementation of a biomass-integrated HRES in a newly built or retrofitted housing estate, essentially capturing the practitioners' perspectives. Based on the survey, the UK construction professionals showed a more positive response to the potential feasibility of a biomass-integrated HRES into the residential sector. On the other hand, the respondents in Bulgaria appeared unsure of its implementation potential in the immediate future. These differences could be mainly attributed to the level of awareness of the problems by the workforce involved in construction industry in the two countries. Further, there seems an apparent lack of information about the deployment of hybrid renewable energy systems in Bulgaria. However, participants from both countries have identified project costs and legislative red tapes as the main hurdles to wider realisation of the proposed biomass-integrated HRES on the ground.

A limitation to this study is that the optimisation results used literature data on solar irradiance, wind speed, domestic waste figures and temperature, acquired from available inventories. The model outcomes could be enhanced using input data from actual surveys. In addition, the cost data of the individual components of the system was also set by the HOMER software and the calculated results could differ from the actual cost. Further, this evaluation assumed a community housing development of twenty houses; larger developments evidently will have to be scaled up accordingly to balance their waste-to-energy flows to ensure their cost effectiveness. The type of building is also important as newly built houses have better insulation and normally more efficient appliances compared to old houses. Also, some uncertainties in terms of biogas gasifier performance on that scale are currently present, therefore extended research can provide more accurate figures that can be used in future studies.

Further research is also needed in the following areas: holistic impact assessment of the proposed system in terms of reducing CO_2 emissions by minimising/offsetting the transportation and treatment demands of the domestic waste; quantitation of the economics of waste-to-energy flows in terms of monetising the gate fees levied on biowastes in future (if any); qualitative appraisal of the policy gaps and provision of adequate planning permissions to encourage construction companies to implement such proposals, etc.

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Appendix 1: Example survey questionnaire template

Instructions: The short survey aims to research the possibilities and potential of a hybrid renewable energy system (HRES), consisting of Wind, Photovoltaic and Waste-to-energy for domestic application. The waste-to-energy component of the system will be used as a back-up to the other two components but also to manage unrecyclable domestic waste. The HRES will be included in a simulation involving a new housing development of twenty 3-4 bedroomed dwellings. The survey is designed to gather information and gain opinion from construction professionals on implementing such system in new housing developments.

Please answer all questions to the best of your knowledge and experience. Please complete the questionnaire as soon as possible, as a timely reply is critical for my analysis.

1. What company do you work for?

2. What is your role within the company?

3. Based on your knowledge and experience please answer the following questions.

    3.1 In your opinion how likely is it for construction companies to install Wind-PV-Waste to Energy systems in new housing developments?

    3.2 How likely is it for such HRES to improve the environmental impact of new developments managing unrecyclable biowaste?

    3.3 How likely is it that the system would generate income?

    3.4 How likely is it that installing Wind-PV-Waste to Energy system would increase property prices?

    3.5 How likely is it that houses equipped with HRES will be more appealing to new buyers due to the long-term savings they would provide?

    3.6 How likely is it that local authority approval and legislation could affect construction company's decision on whether to install biomass-integrated HRES?

4. Please consider the next statements and provide your opinion for each one

    4.1 Providing new developments with biomass-integrated HRES would enable construction companies to deliver on sustainability promise.

    4.2 Biomass-integrated HRES would aid in achieving government targets in terms of carbon footprint reductions.

    4.3 Correctly sized and installed systems could provide communities with more sustainable living.

    4.4 Biomass-integrated HRES could also be extended to commercial developments to deal with biowaste produced by local businesses.

5. From a professional perspective what would be the main concerns associated with investing in this type of hybrid system?

6. Do you have any other suggestions, which might affect construction companies in deciding whether to invest in this type of system?

7. Do you think that Wind-PV-Waste to Energy HRES has future in the UK housing sector? Yes/No

8. Please use the space provided below for any further comments.