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Rich or poor? Who actually lives in proximity to AD plants in Wales?

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Abstract

Many environmental benefits have been claimed for anaerobic digestion (AD) facilities, embracing waste management and multiple energy vectors (generating electricity, heat and useable gas) that could be help create more circular economies. Whether these benefits are realised depends greatly on the sites exploited for AD plants and the social and geographical conditions. To examine this we assess the distribution of AD plants in Wales and the socio-demographic characteristics of the populations that live in close proximity. The results show that farm-fed ADs are predominantly located in rural villages and sparsely-populated settings, while waste-fed AD plants could be found more evenly distributed in both rural villages, towns and cities. In addition, populations living in proximity to AD plants tend to be older, frequently in families without children, and without any central heating (or with central heating based on oil or solid fuels), in neighbourhoods experiencing deprivation in access to services. Our results are significant for our understanding who could be, both positively and negatively, affected by the AD operation and how these facilities could contribute to the social development of communities. Factors affecting the realisation of prospective benefits from farm-fed ADs include public sensitivities to development in these 'rural idyll' locations, and the economics of using AD to re-tool energy systems in more sparsely populated rural sites.

Keywords

Anaerobic digestion plants, Wales, Agriculture, Waste management

1 Introduction

An important set of technologies for re-using biodegradable waste for energy are anaerobic digestion (AD) plants. AD plants are facilities where biodegradable material is broken down by means of microorganisms in the absence of oxygen.AD plants are not just environmentally friendly destinations for waste to be processed, but also sources of renewable energy and heat. Biogas in ADs is most frequently transformed into electricity and supplied to the electricity grid [1].Currently less frequent, but environmentally promising for the future, is the supply of biomethane and its injection directly into the gas grid, which could significantly reduce carbon emissions from domestic heat without changes in infrastructure or consumer behaviour [9], or the usage of biogas as a transport fuel [2]. Moreover, heat as a co-product of AD might be beneficially utilized by settlements in nearby neighbourhoods.

Crucial questions arise from the locational decisions of AD plants. Firstly, if AD is to contribute fully to the creation of new 'circular economies' then facility location greatly affects how far and how efficiently waste input and energy output vectors are exploited. Secondly, questions arise as to how AD plants influence the social development of communities where they are located. There is a big space for policy that could affect the environmentally and socially beneficial operation of AD plants from the perspective of both input materials (as for its structure and origin) and output products (how it will be used and at what price). Communities that host AD plants might experience substantial effects on their quality of life, but these could be balanced by measures to mitigate possible problems. Such 'social acceptance' questions have been extensively examined for some renewable energy technologies (e.g. wind); here we trace their application to AD.As the issue of social acceptance of AD has received little systematic research to date [e.g. [3],[4],[5],[6],[7]], we are trying to fill this knowledge gap.

Wales is a valuable context to examine these issues. It sits among the world´s leaders in waste recycling with more than 60% of municipal waste being recycled. According to the strategy document Towards Zero Waste [8] an ambition of the Welsh Government is to reach a zero waste by 2050 by means of developing a circular economy approaches as an opportunity for wide re-direction towards environmentally friendly economic development.

In Wales, 24 AD plants exist in 2020, with total installed capacity of 15.9 MWe, half of which were completed in the recent years. The AD sector has recently experienced a boom across whole the UK resulting in 473 AD plants with 393 MWe of installed capacity. The boom has been accompanied by a huge utilisation of energy crops (like maize) to be processed for energy instead of waste processing. In Wales, such development was avoided and focus on waste processing has been dominant. 83% of installed capacities of AD plants in Wales are dependent on processing of waste, which significantly contributes to the above-mentioned plans of the Welsh Government.

To keep the economy of AD plants viable, a continuous year-long supply of biodegradable waste has to be ensured. For all 24 Welsh AD plant, the estimation of their annual need of feedstock is around 440,000 tons per year, which means that sufficient input material has to be stored on site or regularly transported. To reduce transport costs, ideal AD plant should be located in proximity of sources of input materials. For those ADs that are based on waste processing, viable locations lie in proximity to reasonably sized settled areas while for those ADs based on farming, location on (or in proximity to) farms is crucial. In both cases it seems that the most environmentally friendly solution is to meaningfully adapt the size of ADs to the size of input material available.

In our paper, we examine the characteristics of Welsh communities where AD plants are located. The main aim our paper is to understand socio-demographic specifics of population that live in proximity of AD plants, and to learn how individual types of AD plants (waste-fed and farm-fed) are distributed in Wales. From this we draw out implications for the relative circularity of the new waste (new energy) economies being constructed.

In the first part of the paper, the location of AD plants in Wales is studied. Then, we compare socio-demographic characteristics for areas with and without AD plants. In the next section, attention is given to individual types of ADs (waste-fed, farm-fed), followed by a focus on farm-fed ADs and the specific characteristics of rural areas where these are predominantly located. In the final part of the paper, conclusions are drawn and recommendations for the suitable location of further AD are defined.

2 Theoretical considerations

As we have already suggested above, understanding of AD plants as facilities that just produce renewable energy is seriously incomplete. There are numerous ways in which individual AD plants might affect places where they are located and, conversely, how local populations might affect operation of AD in their community. It is clear that there are diverse relationships between local populations, AD and wider energy transitions[[3],60]]and might be reported on a spectrum from relations that are mutually beneficial to those that might be described us conflictual[10]. As warned by Bluemling et al. [11], such mutual relations evolve over time consequent upon changes of settings of operation of AD plant (a change in structure of input materials, a change of operator of AD or its maintenance, etc.) or due to technological issues or as a result of social dynamics in hosting community (impact of newcomers to community, changes in governance of the community, shift in acceptance of the usage of particular input material etc.). Influences from within the host community can be highly important [12]as well as external influences (such as supportive policy settings, general public attitudes towards biogas energy, etc.) [13].

Even if one adopts a widely accepted definition of term “biogas” as a methane-rich gas that is produced by the anaerobic digestion of organic materials in a biological-engineering structure called the digester [14], it is clear that AD technologies can be woven into a diversity of input-output relations. We can ask questions about structure of input materials that feed AD plants. Are they fed by agricultural (or by households’) biodegradable waste, waste originating in food industries or grass or are they fed by purpose grown crops? Are these materials gathered in place or they are being transported for some distance? How they are gathered?

Similar diversity and uncertainty in relations arise with the outputs of ADs (as its final products). Where biogas (or generated electricity in the next step) as a final product is supplied, who is the user How is a digestate as a fertilizer (a secondary products of anaerobic digestion) stored or distributed? What about heat that is generated by AD plants a by-product? What are the benefits for hosting community? Are there any? What about environmental risks? How might one locate AD plants to maximize their usefulness and minimize risks? A multi-layered understanding of the location and operation of AD plants enables us to think about these facilities as possible tools to support social development of their neighbourhoods[15] and foster more circular economies by converting potentially problematic wastes into useful resources [16].

Given these complex relationships, it is clear that smart planning and operation of AD plants might significantly contribute to the sustainability of localities[17],but poor settings of AD operations might cause so many problems and significantly worsen quality of life for the local population (odour, increase of traffic, decline of property prices, decrease of attractiveness of hosting community, outmigration, etc.). These measures may impact the level of acceptance of biogas energy in hosting communities[18]. This why we need to know who lives in proximity of AD plants.

From the above discussion, we already know that the location of AD plants is an integral dimension of their usefulness. Proximity of AD to the source of input material seems to be crucial for economical AD operation[19]. Biodegradable waste as input material to feed AD, whether from households or farming, is without doubt the most environmentally appropriate source of material for AD [20] as such waste would otherwise stay unused and require costly disposal[21]. Based on this logic, waste-fed ADs should be rather located near population centres or in proximity to suitable food-industry industries, while farm-fed ADs within or in proximity to operating farms. Careful attention has to be devoted to the planning of size of particular, especially farm-fed AD plants as availability of farm waste might significantly differ over the course of the year or due to changes in farm business strategies. Location also affects the efficiency and impacts of feedstock transportation[22]. Another issue is the location of AD in relation to settlements. These are many ways in which the particular location of AD plants might contribute to worsen sustainability in its host communities.

We also already know that the usage of purpose grown crops to be processed for biogas in AD plants can cause controversies among the public [23]as it is perceived as a less appropriate utilization of land. It is also clear the perception of these controversies differs in various socio-cultural contexts as a result of varying levels of environmental awareness[62].Although energetically less rich, grass seems to be a more suitable and less controversial addition to the waste processed in AD. It has to be taken into account that farmers usually express negative opinions concerning utilization of land for purpose-grown crops for AD, on the other hand, supporters could be also found, both in the general public and among farmers[[24],[25]].Such farmers argue that to ensure smooth year-round operation of AD plant sufficient input material has to be delivered [26], and trade-offs have to be sometimes made[27]. However, re-evaluating manure and general agricultural waste from just a waste to valuable waste material that might be processed into energy and thus recycled is necessary [28].

As for outputs of AD plants, alternatives of usage of heat as by-product of anaerobic digestion is widely discussed, however this option is currently rather rarely utilized[29]. It is obvious that this is a typical example of the lost energy with enormous potential that could be well used instead by employing creativity. Various examples of the usage of heat from ADs to heat properties in neighbourhoods and thus to generate important internal savings are well known[[30],[63]].There is no doubt that the usage of by-produced heat in a rich variety of subsequent business activities of AD operators might significantly contribute to job creation that is especially needed in distant rural areas. Reasonable utilization of this waste heat will also reduce the impact of AD sector on global warming of the environment. On the other hand, we know that methane leakages from ADs to atmosphere burden the environment much more[55].

We are also already aware that effects on hosting community are directly dependent on size of individual AD projects, i.e. with increasing size of AD both positive and negative impacts on community are theoretically increased. Some studies propose a solution with farm-fed small-scale ADs sized according to the size of farming activities (and farm sizes) where ADs are located [[31],[32]]. Such option might help to reduce problems with waste logistics (and consequent transport costs) but, on the other hand, it reduces profits from biogas generation for farmers[33].

We declare that AD plants cannot be understood just as facilities for generation of renewable energy as their benefits to local economy, society and environment are highly diversified and cannot be narrowed to particular, although beneficial, elements. A perspective sensitive to the complexities of AD operation is urgently needed so that a full picture could be seen, rather than focusing on individual input output issues. As is stressed in the study of Fagerström et al [56]the concept of AD is highly multifunctional and sustainable as include the processes for treatment of waste, for protection of environment, for conversion of low-value material to higher-value material, for the production of electricity, heat and of advanced gaseous biofuel. The restorative and regenerative concept of circular economies is highly germane to AD plants, given the potential for extracting utility and value from its products, components, and input materials[57]. AD plants are potentially one of basic elements of our future bio-economy where fossil fuels will be replaced by more sustainable renewable energy sources [58, 59], obviating the harms of waste disposal. However, the extent to which these benefits are fully realised, and for whom, is integrally related to the chosen sites of AD plants.

To summarize this part, it might be stated that a significant gap in AD research can be seen in the lack of spatially systematic studies on AD plants, where various social contexts of communities with ADs are taken into account. Based on this research gap, the objectives of our research are: 1) To understand spatial distribution and location of AD plants in Wales. 2) To identify socio demographic particularities of population that live in proximity to AD plants in Wales. 3) To investigate differences in characteristics of population that lives in proximity of waste-fed AD plants and in proximity of farm-fed AD plants.

3 Methodology

In our research, we worked with census data from the Lower Super Output Areas (LSOA) for Wales (1,910 units with minimal population number 1,000), to understand what if anything distinguishes populations living in proximity to AD plants in Wales. LSOA units were complemented by the Rural Urban Classification (Urban: Major Conurbation, Minor Conurbation, City and Town, City and Town in a Sparse Setting; Rural: Town and Fringe, Town and Fringe in a Sparse Setting, Village, Village in a Sparse Setting, Hamlets and Isolated Dwellings, Hamlets and Isolated Dwellings in a Sparse Setting).

Data on 24 individual AD plants in Wales (types of AD, its electric installed capacities) and their location (zip codes)were obtained from The Official Information Portal on Anaerobic Digestion (www.biogas-info.co.uk). Individual AD plants were linked to particular LSOAs by means of publicly available zip code to LSOA converter and double checked by search of location of individual ADs in LSOA maps provided by statistical service of the Welsh Government.

To fulfil objectives of our research we used the most recent available data on LSOA level (from 2011 Census). We were interested in age, gender and ethnic structures of population in individual LSOAs, in housing types, economic (in)activity, population density, equipment of households (i.e. cars and types of central heating) and number of persons in households. Prior to all analyses all LSOA variables were expressed as the share of total value for each variable excluding data from the most recent Welsh Index of Material Deprivation 2014 (WIMD) and its individual partial deprivation indexes, where the ranks were used (from the most deprived to the least deprived). WIMD is the official measure of small area deprivation in Wales and has been calculated by Welsh Government statisticians from numerous indicators concerning income, employment, health, education, access to services, community safety, physical environment and housing. Both individual and overall WIMD indexes were taken into account.

First we tested the null hypothesis if there are no statistical differences between LSOAs with ADs and all other LSOAs, where ADs have not been localized. Kolmogorov-Smirnov test was used to test null hypotheses as variables are not normally distributed. We can use the values for LSOA units without AD as statistical population and thus, we are testing if the sample of LSOA units with AD are the sample of the same distribution as all other LSOA units. We were able to determine from this analysis if there are differences between LSOA units with AD and all other LSOAs.

The potential differences between LSOAs with farm-fed AD and LSOAs with waste-fed AD were tested in the second step. As the differences among those two samples and LSOA units without ADs were of interest too, a Kruskal-Wallis test with post-hoc test based on Mann-Whitney test with correction of p was used. This enabled us to determine if there are differences between LSOA units with farm-fed ADs and LSOAs with waste-fed ADs, between LSOAs with farm-fed ADs and LSOAs without any AD, and between LSOAs with waste-fed ADs and LSOAs without AD.

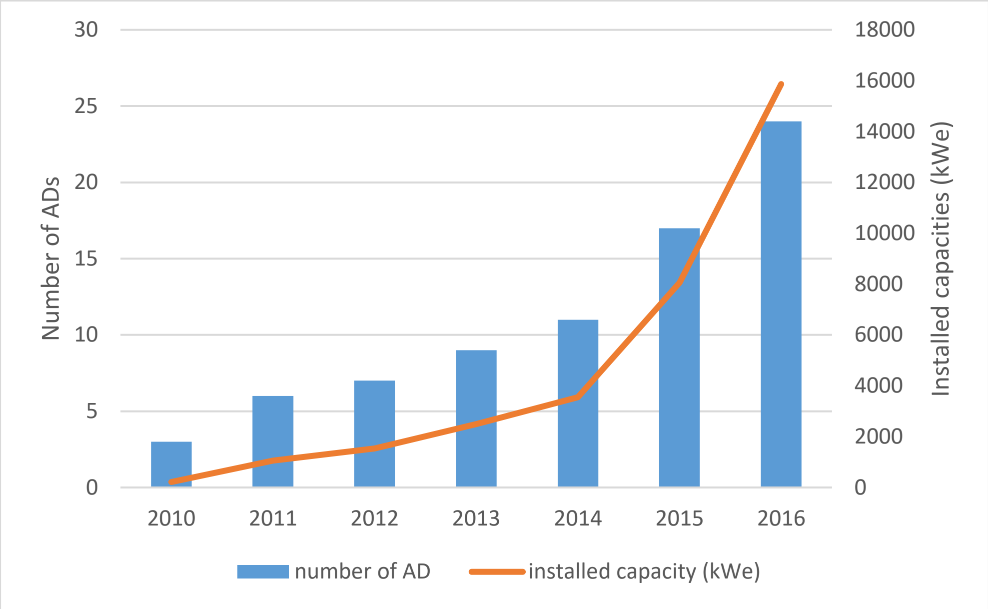
Based on both above mentioned statistical treatment of the data, we found that farm-fed ADs are of very special importance regarding their chosen locations. As farm-fed ADs are solely located in rural settlements, we decided to test if rural LSOAs with farm-fed AD are different from those rural LSOAs without any AD. Thus we have selected rural LSOA regions only (D to F types) before further testing. Then we tested null hypothesis that there is no difference in number of rural LSOAs with farm-fed AD and without AD among types of rural settlements (types D1, D2, E1, E2 are present in Wales only). Fisher exact test was used, as the number of LSOAs with farm-fed AD was three times only 1. Finally, Mann-Whitney test was used to test the null hypothesis that there are no statistical differences between rural LSOAs with farm-fed AD and rural LSOAs without farm-fed AD.

All calculations were performed by R software in the RStudio environment.

4 AD plants in Wales

According to the official statistics, 24 AD plants with total electric installed capacity 15.87 MWe are operating in Wales as of 2020. Regulations and financial incentives (like Renewable Obligations Certificates, Feed-in Tariff (FIT), Renewable Heat Incentive (RHI)) have helped enable the AD sector in Wales to grow. The strongest growth of AD plants development in Wales occurred in the period of 2014-2016. As is clearly visible from Figure 1, the development of ADs in Wales has experienced continuous growth since 2010. In this year, we would find just 3 AD plants in Wales with total installed capacity of 0.2 MWe from which two of them were self-built by farmers in 1990s (Bank Farm in Montgomery/ Trefaldwyn in central Wales and Caerfai Farm in St Davids/Tyddewi in the west of Wales in Pembrokeshire).

Fig.1: Development of numbers and electric installed capacities of AD plants in Wales

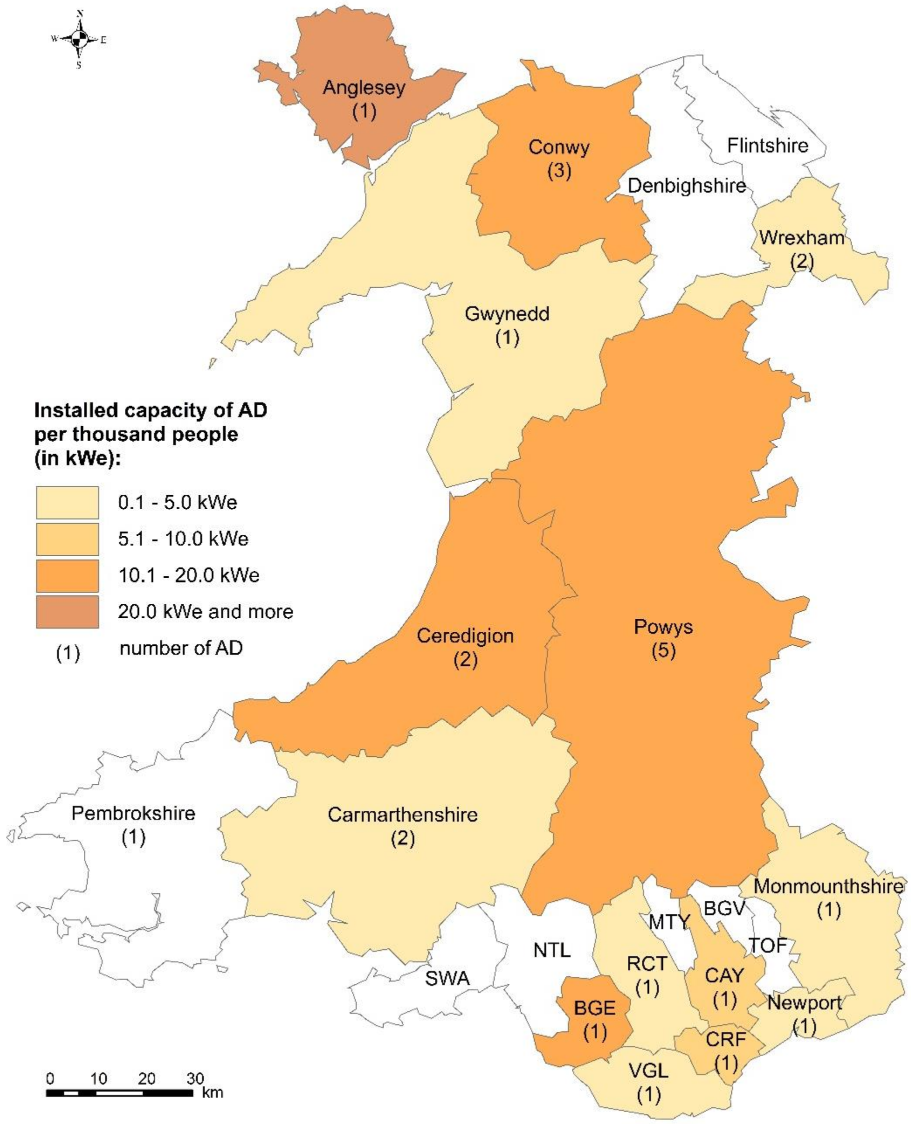


Data: The Official Information Portal on Anaerobic Digestion http://www.biogas-info.co.uk/resources/biogas-map/

There are many similarities in the development of ADs in Wales and in the other part of the UK, but several particularities can be identified for Wales. Due to the high extent of upland landscapes in Wales, and consequently the nature of its farming (extensive sheep grazing), farm-fed AD plants have developed less here than in other parts of the UK. As a result, nowadays, on the area of Wales 12 farm-fed AD plants and 12 waste-fed AD plants could be found with 83% of installed capacity concentrated in waste-fed ADs (13.1 MWe).

Sizes of individual AD plants in Wales vary significantly (see table 1 for detailed information on AD plants in Wales). We can find here from self-build micro AD with the installed capacity of 3 kWe (Bank Farm in Montgomery/ Trefaldwyn) to the largest AD facility in Wales with name Stormy Down in Bridgend in the south of Wales (2,800 kWe). Generally, it might be stressed that average sizes of ADs based on farming (circa 220 kWe) are much smaller than those based on waste processing (1,090 kWe), which is true of Wales and the UK as a whole (520 kWe for farm-fed ADs and 1,540 kWe for waste-fed ADs).Figure 2 shows the spatial distribution of AD in each local authority of Wales, in numbers of plants and installed capacities per capita.

Fig.2: Electric installed capacities of AD plants in Wales recalculated per thousand inhabitants (in 2020)



Source: Authors processing based on data from The Official Information Portal on Anaerobic Digestion (www.biogas-info.co.uk)

Although the number and electric installed capacities of farm-fed ADs in Wales is rather low, the large potential for growth of this AD type can be seen in dairy farming that is concentrated in the south-west of the country [34]. As manure and slurry that is produced by dairy is energetically relatively rich, further development is expected here. Due to a smaller average size of Welsh farms (48 hectares[35]) we can expect the development of rather small-sized AD projects in future. Securing feedstock for ADs of appropriate amount, quality, mix and frequency is usually described as a significant hurdle to all AD plants. It is expected that strong competition on biodegradable waste and new markets will be developed in near future [36]. Moreover, the distances over which the transport of material is economically viable will require greater consideration.

Tab.1: Basic characteristics of AD plants in Wales (2020)

AD	Developer	Installed capacity (kWe)	Output	Completion	Type	Community (population 2011)
Anglesey Ecoparc	Anglesey Ecoparc Mon	1,900	CHP	2016	Waste-fed	Trewalchmai (1,009)
Stormy Down AD	Agrivert	2,800	CHP	2016	Waste-fed	Bridgend (49,404)
Bryn Quarry	Bryn Power	1,400	CHP	2015	Waste-fed	Hengoed (5,548)
Cardiff Waste Water Treatment Works (Food waste)	Kelda Organic Energy	2,000	CHP	2016	Waste-fed	Cardiff (334,145)
Coomb Farm	S Davies	485	CHP	2016	Farm-fed	Carmathen (14,185)
Burdens Environmental AD	Burdens Environmental	16	CHP	2011	Waste-fed	Llangadog (1,311)
PencefnDrysgol AD	B & J Lloyd	185	CHP	2016	Farm-fed	Tregaron (1,213)
Syrus Energy	Syrus Energy	1,000	CHP	2015	Waste-fed	Penparc (2,308)
Hendwr AD	Philip Hughes	198	CHP	2016	Farm-fed	Llandrillo (580)
Tain Y Foel Farm	HC, FM & IC Williams	0	Heat only	2014	Farm-fed	Cerrigydrudion (740)
Waen Biogas	Biogen	1,050	CHP	2014	Waste-fed	St. Asaph (3,355)
LlwynIsaf AD Plant	Biogen	490	CHP	2013	Waste-fed	ClynnogFawr (997)
Magor ETP AD	Interbrew UK Limited	340	CHP	2011	Waste-fed	Caldicot (11,424)
Rogerstone Park	InSource Energy	484	CHP	2011	Waste-fed	Rogerstone (10,158)
Caerfai Farm	Caerfai Farm	3	Cooking gas	1997	Farm-fed	St Davids (1,841)
Bank Farm	Bank Farm	125	CHP	1991	Farm-fed	Montgomery (1,295)
Glanmeheli Farm	G & A Powell	465	CHP	2015	Farm-fed	Kerry (2,057)
Warren Farm	Powys LTD	227	CHP	2015	Farm-fed	Llangunllo (369)
Sychtyn AD	J & B Vaughan	235	CHP	2015	Farm-fed	Llanerfyl (406)
Great Porthamel Farm	Brecon Beacons National Park	470	CHP	2013	Waste-fed	Llandrindod Wells (5,309)
Tomorrow's Valley	Biogen	1,180	CHP	2015	Waste-fed	Llwydcoed (1,382)

Pancross Farm	VJ Thomas & Sons	482	CHP	2012	Farm-fed	Barry (51,502)
Lodge Farm	FRE-Energy	86.5	CHP	2010	Farm-fed	Holt (1,521)
Lower Parks Farm	FRE-Energy	245	CHP	2016	Farm-fed	Rossett (3,231)

Source: Modified according to The Official Information Portal on Anaerobic Digestion http://www.biogas-info.co.uk/resources/biogas-map/

As Abertheny et al. [53] note, a majority of AD plants in Wales currently solely generate electricity from biogas. Abertheny et al. in their study also state that this amount of generated biogas could be sufficient to supply up to 5% of gas in Wales. Utilization of this energy potential could have enormous impact on gas energy sector. Welsh universities also play an important role in the development of AD sector in Wales, with a strong research profile. For example, in 2008,the Wales Centre for Excellence for Anaerobic Digestion was set up in Pontypridd to provide support to the emerging AD industry. Research units dealing with biogas energy have been operating at the University of South Wales, Swansea University and Cardiff University.

5 Results

In the first part of results, we will focus on particularities of location of AD plants in Wales. Then we will shift our attention to identification of socio-demographic specifics of population that lives in neighbourhoods of AD plant in Wales. Finally, we focus on the population around farm-fed ADs and waste-fed ADs.

5.1 Location of AD plants according to types of settlement

The preliminary results of our spatial analyses show that the distribution of AD plant according to types of urban/rural settlements in Wales is relatively uneven. Their majority are localized in the rural space, while just five of them could be found in urban areas. If we focus more on particular types of rural/urban space (see Table 2) we can see that from types of urban space, just C1 (Urban: City and Town) is represented with 5 units of ADs. In case of types of rural space, the distribution ADs is much more diverse. The majority of ADs are located in the E2 type (Rural: Village and Sparse Setting), other types are usually represented by location of several AD units (3 in case of D1 type with title Rural: Town and Fringe; 2 in type E1 Rural: Village and 1 in D2 Rural: Town and Fringe in a Sparse Setting). From the point of view installed capacity, around half of them are concentrated in urban space whilst more than third is located in rural type E2 and one tenth in E1 type (Rural: Village).

Tab. 2: Distribution of ADs according to types of Rural-Urban Classification

Type*	ADs (number)	Installed capacity (kWe)	Share of installed capacity (%)
C1	5	7,864	49.6
C2	-	-	-
D1	3	672	4.2
D2	1	3	0.0
E1	2	1,532	9.7
E2	13	5,796	36.5
Total	24	15,867	100

Note: A1, A2, B1, F1, F2 types are not represented in Wales.

**Urban: Major Conurbation (A1), Urban: Minor Conurbation (B1), Urban: City and Town (C1), Urban: City and Town in a Sparse Setting (C2), Rural: Town and Fringe (D1), Rural: Town and Fringe in a Sparse Setting (D2), Rural: Village (E1), Rural: Village in a Sparse Setting (E2), Rural: Hamlets and Isolated Dwellings (F1), Rural: Hamlets and Isolated Dwellings in a Sparse Setting (F2).*

If we look at the distribution of AD plants in Wales in detail (see Table 3), we can clearly see different locational characteristics between waste-fed and farm-fed ADs. Waste-fed ADs tend to be located in urban space, but we can also find them in distant rural villages with sparse settings. With farm-fed ADs their rural focus is obvious. From the perspective of distribution of installed capacities, in case of waste-fed Ads, 60% is concentrated in C1 type (Urban: City and Town) and surprisingly almost 30% in rural category E2. Such locations of waste-fed ADs in sparsely populated location could be perceived as a contradiction with the potential eco-efficiency and circular economy benefits of AD. In case of farm-fed ADs, more than 70% of installed capacities of ADs can be found again in E2 type), while D1 type (Rural: Town and Fringe) is represented by 12%.

Tab. 3: Distribution of waste-fed ADs and farm-fed ADs in Wales according to types of Rural-Urban Classification

Type*	Waste-fed ADs (number)	Installed capacity (kWe)	Share of installed capacity (%)	Farm-fed ADs (number)	Installed capacity (kWe)	Share of installed capacity (%)
C1	5	7,864	59.9	-	-	-
C2	-	-	-	-	-	-
D1	1	340	2.6	2	332	12.1
D2	-	-	-	1	3	0.1
E1	1	1,050	8.0	1	482	17.6
E2	5	3,876	29.5	8	1,920	70.2
total	12	13,130	100	12	2,737	100

Note: A1, A2, B1, F1, F2 types are not represented in Wales.

**Urban: Major Conurbation (A1), Urban: Minor Conurbation (B1), Urban: City and Town (C1), Urban: City and Town in a Sparse Setting (C2), Rural: Town and Fringe (D1), Rural: Town and Fringe in a Sparse Setting (D2), Rural: Village (E1), Rural: Village in a Sparse Setting (E2), Rural: Hamlets and Isolated Dwellings (F1), Rural: Hamlets and Isolated Dwellings in a Sparse Setting (F2).*

5.2 Comparison of LSOA with AD plant and those without AD plant

As the first step of our analyses, we compared LSOAs with AD plants (23 units, combining waste-fed and farm-fed ADs) with LSOA without AD plants (1,886 units) to find out if some socio-demographic differences occur. Looking first at the results for demographic characteristics, we found that families with small children (0-9 years), and rather younger age categories (20-29 years, 30-44 years) are significantly less represented in LSOAs with AD plants in comparison to LSOAs without AD plants. LSOAs with AD plants tend to be home to more elderly people, with age groups 45-65 years and older than 65 more strongly represented. As for the origin of the population, people of non-white ethnicity are more represented in LSOAs around AD plants than in LSOAs without ADs. This result might signal classic environmental injustice tendencies in the siting of polluting facilities.

Relatively higher shares of economically active population were ascertained in LSOAs with AD and less unemployment. We also found that ADs are located in LSOAs with significantly lower population densities. It seems that in the neighbourhoods of ADs live households with two and more cars that is linked to their rural location. In LSOAs with AD we also measured more people who live in homes that they own, which is also typical feature for the UK countryside.

Interesting results were gained while examining types of heating in households in LSOAs with ADs. We found that more households without any central heating lives here than in LSOA without Ads, which might also signal a poorer population. As for individual types of central heating, we measured here (in LSOAs with ADs) lower levers of households with gas central heating (this is especially obvious for locations in sparse settlement). On the other hand, we found here significantly more households with electric central heating and even more households with oil and solid fuels (coal, wood) heating. The connection of such households to the gas grid would be enormously expensive in these conditions, but, on the other hand, if connected to local AD by a gas pipeline or using bottled gas, it might significantly contribute to the decarbonisation of peripheries. At domestic heating of households in these areas stands now, it is extraordinarily carbon intensive.

The comparison of Welsh Index of Multiple Deprivations (WIMD) shows that in LSOAs with ADs a generally lower level of deprivation was measured. We also looked at individual components of deprivation that make up the WIMD: income, health and employment indexes. All were lower in LSOAs with ADs, especially so for measures of deprivation concerning safety and education. Only deprivation connected to access to services was higher in LSOAs with AD. This seems to be another measure of the countryside where majority of ADs are located (for detailed results of statistical analyses see Appendix 1).

5.3 Comparison of LSOA without AD with LSOA with waste-fed AD and LSOA with farm-fed AD

Previous tests (reported in section 5.2.) showed, that there are differences between LSOA units with and without AD in almost all studied socio-economic variables. We know (from section 5.1), that the location of LSOA units with AD differ among urban-rural types, too. That is why we tried to find if there are any differences among LSOA units without AD, with farm-fed AD and with waste-fed AD. Analysis of differences among those three types of LSOA units give new insight to the data. We have found three important pieces of information (for results of statistical analyses see Appendix 2).

Firstly, the statistical differences between LSAOs with waste-fed AD and farm-fed AD lie mainly in less interesting variables. But significant differences were found in the issue of heating of households. Households in LSAOs with farm-fed ADs have greater proportion of households without any central heating and greater proportion of households with electricity heating. On the other hand, LSOAs with waste-fed AD have greater proportion of two-person households, which probably signals more households without children around this types of AD plants.

Secondly, LSOAs with farm-fed AD and waste-fed AD do not significantly differ one from another but both are different if compared to LSOAs without ADs. In LSOAs with AD we could find more elderly people, who own 2 and or more cars and their heating is based on oil or solid fuels. At the same time, households are equipped by more than 1 type of central heating (probably combination of solid fuels and oil). The only index of WIMD that differs here is deprivation to access of services that is significantly higher in both LSOAs with farm-fed AD and waste-fed AD. We may also emphasize that LSOAs with farm-fed AD are even more strongly deprived from the point of view of their access to services than LSOAs with waste-fed AD. Logically, this reflects the frequent location of farm-fed AD in more distant rural conditions, while significant part of waste-fed ADs is located in towns and cities where access to services is significantly better.

Thirdly, there are many cases when LSOAs with farm-fed AD are statistically different from LSOAs without AD but in the same time there are differences between LSOAs with waste-fed AD and LSOAs without AD in cases like economic activity, proportion of inhabitants between 30 and 44 years, and many deprivation variables. Thus, for LSOAs with farm-fed AD the analysis identified a lower level of deprivation concerning income, employment, education and safety and in even lower level of deprivation linked to health and safety. Again, the predominantly sparse rural locations of farm-fed AD significantly influence these results. However, this means that LSAOs with farm-fed AD occupy a very special position among LSOAs and hence, we will focus on them more in the next section(5.4).

5.4 Comparison of location of farm-fed ADs and rural LSOAs

We already know that majority of farm-fed ADs in Wales are located in the sparsely settled countryside. However, as is obvious from table 4, farm-fed ADs are specifically distributed within the rural. That is why we have selected for further analyses rural LSOA units only (D1, D2, E1, E2). These LSOAs (607 units) were first analysed according to the frequency of the occurrence LSOAs with farm-fed ADs and LSOAs without farm-fed ADs in rural LSOAs. By accommodation of the contingency exact test (Fisher exact test)we have found significant difference in their distribution. It has been confirmed (see subchapter 5.1) that farm-fed ADs are strongly concentrated into E2 type of settlement (Rural: Village in a Sparse Setting), while in other types of rural settlements in Wales (D1, D2, E1) just one AD is located. On the contrary, to even distribution we would not find farm-fed AD plants in C1 type (Urban: City and Town).

Tab.4:Frequencies of distribution of LSOAs without farm-fedADs and farm-fed ADs (Fisher exact test p=0.003878)

Type *	LSOAs without farm-fed ADs	Farm-fed ADs
D1	251	1
D2	77	1
E1	128	1
E2	139	8

*Note: * Rural: Town and Fringe (D1), Rural: Town and Fringe in a Sparse Setting (D2), Rural: Village (E1), Rural: Village in a Sparse Setting (E2).F1, F2 types are not represent in Wales.*

If we take into account just rural spaces of Wales, farm-fed ADs are located in LSOAs with significantly stronger economically active population and older population groups (45-64 years, more than 65 years) than in general Welsh countryside. Farm-fed ADs are typically located in sparsely populated areas. From the point of view of unemployment we found that around farm-fed ADs live lower share of rural population that have never officially worked. For these areas, more typical are households with 2 and more cars and very limited number of households without any car.

As for heating, in LSOAs with farm-fed AD households are significantly less equipped by central gas heating but significantly more equipped by oil and solid fuel central heating (and more than 1 type of central heating).

If we focus on number of persons in households, most are represented two-person households which, as already stated above, indicates together with age structure more households without children.

Analyses of WIMD showed that the most significant deprivation measure that occurs in LSOAs with farm-fed ADs is access to services while deprivations in income, employment, health, education and safety are lower (see Appendix 3 for detailed results of analyses).

6 Discussion

The results of our research showed significant similarities in socio-demographic characteristics of population that live in neighbourhoods of AD plants in Wales. Based on all of our analyses, the majority of Welsh Ads are located in the countryside. Moreover, we can talk about a special character of countryside where the majority of ADs is distributed - peripheral locations. Majority of locations with AD is typified by a very poor access to services. On the other hand, we can say that areas with AD are not passive, but rather with active approach to its own development. Our analyses showed that in these areas live significantly older but economically active inhabitants. The placing of areas with AD within the WIMD concerning income, employment as well as safety is enormously good. Thus, it seems that local population actively supports local development which is promising for the future of these areas[54]. On the other hand, to the extent that AD plants are located in a ‘rural idyll’, as perceived by elderly population, this might be affected by the realization of a large heating project from AD.

Special characteristics applied to areas where farm-fed ADs are located. These could be found in real rural peripheries of Wales with extremely high deprivation in access to services. In comparison to the rest of Welsh countryside, areas with farm-fed ADs are again special. We may say that population in areas with farm-fed AD sis even older than in rural regions without AD, but more "active" at the same time. Rural regions with farm-fed AD belong to the group of areas with the best ranking in the WIDM concerning income, employment, health, education, and safety (their median rank is almost in all cases more than twice as high as the median of rural regions without AD). This could be linked again to our hypothesis that areas with farm-fed AD are populated by active communities with a strong emphasis on bottom-up approaches to development [37].

AD plants might serve as a tool for supporting development for the local population by means of utilization of AD products. Such solutions could be also beneficial from the environmental perspective due to connection to local energy production (from locally generated wastes) and consumption. As we discussed above, there are many ways howt o adjust the operation of AD plant to positively influence their environmental performance (e.g. suitable selection of waste inputs, minimizing of transport, reduction of carbon emissions - [38]). We also clearly see social (heating of households, distribution of a digestate as fertilizer) and economic benefits of AD operation (generation of heating, drying of agricultural products, jobs creation [[39],[40]]. A balanced combination of all three aspects might potentially contribute to sustainable development of these areas[41]. As Massaro et al. [42]argue, such projects might be more viable with assistance of public incentives policies. Community ownership of AD is frequently mentioned as a way forward [43]. On the other hand, size of AD[44], availability of waste[45], suitable location of AD and proper operation technology have to be seriously taken into account.

Mutual communication between AD operators and the local population at each stage of planning of the AD project is a crucial part of conflict free operation of such facility [46]. Generally, support for eco-innovations (as for example AD plants) is highly dependent on socio-demographic variables of population of hosting communities [47] and vary in different socio-cultural conditions [[48],[61]]. As Florkowski et al. [49] found in their study that support among population for waste to energy processing in local AD is closely linked to their education, gender, age, household size, and employment status. The population affected by effects of operation of AD plants might experience changes in the quality of lives[50].

Christidis et al. [51] found in their study that population would prefer to live close to a wind farm but not so close to a biogas plant. This is caused by various levels of perceived environmental risks that are connected to various types of renewable energy projects [52]. On the other hand, benefits provided by AD plant to host community might counter-balance such risks. Thus, co-existence of AD and host community could then be mutually beneficial. However, it has to be stated that the proximity per se does not necessarily mean that there is easy scope for active exploitation of outputs of AD. Moreover, the remoteness of many AD plant locations – as we observe in the context of Wales - might militate against heat re-use and may also make off-site use of the gas difficult.

There is no doubt that usually remote locations of especially farm-fed ADs create a great space for strengthening of energy transition in these areas. New energy-related economies could be driven by ADs and form new participative links among AD and local population. We also know that the persistence of high-carbon energy systems in distant rural areas means that there is a need for public action[64]. In the case of Wales, this is massively important given the Welsh Government commitments to a net zero waste by 2050by means of developing circular economy approaches. On the other hand, the relative sparseness of the population in these areas, and absence of public institutions (connoted by poor services in such rural areas) might militate against the scope for the kind of economically efficient and collaborative activity required to bring all the circular economy benefits into existence.

7 Conclusion

The aim of our paper was to identify socio-demographic specifics of neighbourhoods where AD plants are located, in order to deliver on three main objectives.

With the first objective we were striving to understand spatial distribution of AD plants in Wales according to settlement characteristic types. We found that the distribution of AD plants is quite uneven. The overwhelming majority of Welsh ADs are located in rural space, while just a couple of them could be found in towns and cities. The picture is clearer when we consider waste-fed ADs and farm-fed ADs separately. Then, farm-fed ADs are smaller and tend to be located in rather sparsely populated rural settings (70% of electric installed capacities of all farm-fed ADs is located here), while 60% of electric installed capacities of waste-fed ADs (that are significantly larger) could be found within urban settlements. Waste-fed ADs in Wales are more evenly distributed and thus could be found on both cities, towns and in sparsely populated parts of the country. Farm-fed AD are surprisingly less represented in south-west Wales (just two ADs) where due to the developed dairy industry conditions for operating farm-fed ADs seems very positive. As sizes of farms in Wales are rather lower, focus on development of small-scale farm-fed ADs tailored to individual sizes of farms could be beneficial.

The second objective was to identify socio demographic particularities of the populations that live in proximity to AD plants in Wales. It has been ascertained that in areas with AD plants live significantly more elderly population, with a higher ratio of population being economic active. It has also showed in our analyses that two-person household are proportionally more represented in areas with AD; less so, families with children. The analysis also revealed differences concerning in types of central heating that are used by households. Around Welsh AD plants were significantly more households without any central heating and households whose central heating system is based on electricity, solid fuels (wood or coal) or oil. This reflects the weak development of gas networks in such sparsely settled areas. Access to services was generally lower in areas with AD which is another concomitant phenomenon of the remoter rural locations.

The third objective was to search for differences in characteristics of population that lives in proximity of waste-fed AD plants compared to farm-fed AD plants. Here, the main significant difference lay in types of heating of households. Households in LSAOs with farm-fed ADs have greater proportion of households without any central heating and greater proportion of households with electricity heating. For LSOAs with waste-fed AD greater proportion of households with two persons appeared, which probably signals more households without children around these AD plants. For LSOAs with farm-fed AD we measured lower level of deprivation (WIMD) concerning income, employment, education and safety and in even lower level of deprivation linked to health and safety which can be contextualized with their predominantly sparse rural locations. In general, LSOAs with farm-fed AD more significantly differ in comparison to other groups of LSOAs that were analysed. Even if compared with all rural LSOAs in Wales, we would find in LSOAs with farm-fed AD to hold a more economically active population, older population groups , two-person households and lower unemployment. Households that live around farm-fed AD plant are more frequently equipped by central heating based on oil or solid fuels.

This spatial analysis offers important insight for understanding and realising the potential for AD technologies to help foster circular economies. On the one hand, there is a large scope for policies to support a circular economy approach in places where AD might be a central element of the development of communities. Communities and farms might operate as sources of materials (biodegradable wastes) to be processed for energy in AD plants; they might also be a destination for outputs of AD (biogas, electricity, heat). Potentially at least, the mutual co-existence of communities and ADs might significantly contribute to decarbonisation of AD localities; especially perhaps sin peripheral areas, where diffusion of innovation is usually more complicated. On the other hand, the siting characteristics of AD plants to date, in Wales, create challenges for constructing these virtuous circles. One factor is the perception of ‘rural idyll’ desired by local population, which needs taking into account and respecting while selecting localities for AD as they might significantly affect the quality of life of local population. This is where our future research is going to be focused on.

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