ISSN 2004-2965 Energy Proceedings, Vol. 24, 2021

International Conference on Applied Energy 2021
Nov. 29 - Dec. 5, 2021, Thailand/Virtual
Paper ID: 603

Quantified Analysis of Interventions: The Anaerobic Digestion Case

Ali Alderete Peralta[1], Nazmiye Balta-Ozkan[1]

1 School of Water, Energy and Environment, Cranfield University, Cranfield, Bedfordshire, MK43 0AL, United Kingdom
(Corresponding author: Ali Alderete Peralta; Email: a.aldereteperal@cranfield.ac.uk

ABSTRACT

This paper aims to quantify the effect of the Feed-in-Tariff (FiT) rates on the installed capacity of anaerobic digestion (AD) plants in the UK. The paper develops multiple Linear Regression models (LR) to understand the effect of the different factors that drive the diffusion of AD plants. Emerging results suggest that among the different incentives for AD, only the FiT has a significant effect. Secondly, this effect comes to play only after the announcements of revisions to the programme. And third, the results confirm that the FiT has a different effect for each plant size where the medium size plants are the most responsive to the programme, whilst the large plants are the least responsive.

Keywords: anaerobic digestion, modelling, policy evaluation, government incentive, FiT, OLS regression.

NOMENCLATURE

Abbreviations

FiT	Feed-in Tariff
OFGEM	Office of Gas and Electricity Markets
DECC	Department of Energy & Climate Change

1. INTRODUCTION

The UK government has set ambitious targets to reduce its greenhouse gases (GHG) to net-zero by 2050 to help mitigate global warming [1,2]. In 2019, agriculture accounted for 10% of the UK's GHG emissions [3], ~55%[1] of which was sourced from methane [4]. An effective technology to reduce this GHG is anaerobic digestion (AD) [5], which uses micro-organisms to break down organic matter (animal or food waste) in an oxygen-free environment, and transform them into biogas and biofertilizer [5,6]. This process does not only reduce methane emissions but improves on-farm waste management [6]. Furthermore, during the last decade, the AD has also been utilised to treat municipal waste, such as food waste [7].

The Government has implemented incentives to reduce the economic and social barriers around the uptake of small scale AD plants [6]. Namely, this type of AD plant is eligible for the Feed-in Tariff (FiT) [5,6], Renewable Heat Incentive [5,6] and Enhanced Capital Allowance[2] [7]. The amount of financial incentives depends on the capacity of each plant, which can be categorized in small, medium and large, having <250kW, 250-500kW and >500kW capacities respectively. In England and Wales, small capacity AD plants are mostly on-farm installations, large plants correspond to food and municipal waste, and medium size tends to use a mix of both types of waste. Although the number of small plants is higher than the medium or large plants, the total installed capacity of medium plants is more than double (~15MW vs ~35MW), whilst the installed capacity of large plants is around 20 times more (~15MW vs ~280MW).

1.1. FEED-IN TARIFF PROGRAMME IN THE UK

Given the Government's ambitious targets towards renewable generation, an intervention was required to stimulate the adoption of renewable generation by industry, organisations and end-users[3] [8]. Then, the

[1] Calculated against 2018 data.

[2] Enhanced Capital Allowance is an incentive supporting businesses to invest in efficient technologies. **Site:** https://www.gov.uk/capital-allowances

[3] https://webarchive.nationalarchives.gov.uk/20121217152311/http://www.decc.gov.uk/en/content/cms/consultations/elec_financial/elec_financial.aspx

Selection and peer-review under responsibility of the scientific committee of the 13th Int. Conf. on Applied Energy (ICAE2021).

Department of Energy & Climate Change (DECC[4]) and the Office of Gas and Electricity Markets (Ofgem) launched the Feed-in-Tariff programme in April 2010. It was also established that such incentive to be reviewed periodically, with the first review taking place in 2013. Although the FiT programme has been revised and evaluated, providing evidence about its impact on the adoption and capacity of small scale AD across the three different capacities, these studies don't offer an assessment of the effectiveness of FiT across different capacities of AD plants [9].

Three common approaches for incentive (intervention) evaluation have been used by Ofgem and DECC [9]. The theory-based evaluation, realistic evaluation, and Context-Mechanism-Outcome (CMO). The theory-based evaluation creates a casual chain of events to estimate the contribution of the intervention [10]. The realistic approach aims to determine to what extent an intervention produces the expected results, for which beneficiaries and under what context [11]. The CMO approach focuses on creating a narrative about in what context a certain socioeconomic driver (a mechanism) produces a certain outcome. Mechanisms refer to the underlying elements of reasoning and reactions to a change given in a specific context. However, these methodologies have been criticised and compared with *black boxes* approaches[5] [11,12]. Firstly, the theory-based evaluation has a linear nature [12], whilst the intervention's impact may present temporal irregularities [10]. The realistic approach is resource and data-intensive, thus, collecting data availability for the outcome (results of the programme) is a key challenge [11]. Then, the CMO approach has been criticised because the concepts of 'context' and 'mechanism' are not clearly defined operationally [13].

DECC [9] presents a review on the performance and impact of the FiT programme on the adoption of small scale AD, presenting figures and narratives. The report uses data from the first five years to create narratives that conclude that the FiT has succeeded in meeting many of its original objectives. However, the report does not present statistical evidence on how and to what extent the programme's objectives has been achieved. Moreover, this assumes that any increase in the number of installations is due to the programme. This is why new approaches for the evaluation of the impact of incentives are required. If these methods include quantitative assessments, the results will be more robust and transparent.

2. MATERIAL AND METHODS

This paper proposes a quantitative analysis for the Feed-in Tariff programme, using Linear Regression (LR). The analysis assumes that the only intervention is the Feed-in-Tariff. Although the Enhanced Capital Allowance has also been identified to have a positive impact [7], results presented here show that this is not significant. To calculate the impact of FiT as an intervention, a series of Linear Regression models were carried out, following the general characterisation as follows:

$$NewlyAddedCapacity = \beta_0 + \beta_1 * FiT + \cdots + \beta_n * Var_n + \varepsilon$$

Building upon the fundamentals of the Linear Regression, the R2 scores indicates the percentage of the dependent variable variance explained by the independent variables, while the error term includes the rest of the unexplained variance. Thus, we argue that the R2 of each model may work as a proxy for the total effect of interventions, whilst the effect of each variable is the proportional effect of the sum of the β coefficients.

Table 1 summarises the structure of each model, the independent variables, period of analysis and the number of observations included (sample size). As seen, the dependent variable is consistent across the models, the number of newly added capacity. Then, because of the small number of observations, some of the models introduces dummy variables to account for the difference in sizes and to differentiate the period before and after the revisions were made.

Table 1. Summary table of OLS regression's structure and data definition.

#	Y, log (capacity)	Independent variables	Period	Sample size
1	All plant sizes	FiT, Loans, Size (dummy), Period (dummy)	All	33
2	All plant sizes	FiT, Size (dummy), Period (dummy)	All	33
3	All plant sizes	FiT, Size (dummy)	All	33
4	All plant sizes	FiT, Size (dummy)	Before revisions	12
5	All plant sizes	FiT, Size (dummy)	After revisions	21
6	Small	FiT	Before revisions	4
7	Small	FiT	After revisions	7
8	Medium	FiT	Before revisions	4
9	Medium	FiT	After revisions	7
10	Large	FiT	Before revisions	4
11	Large	FiT	After revisions	7

[4] DECCC together with the Department for Business, Innovation and Skills are the former Department for Business, Energy and Industrial Strategy.

[5] A black box approach is a model that replicates a phenomena only considering inputs and outputs, without considering the context or *why* these inputs produce such output.

2.1. VALIDATION CRITERIA

The analysis assesses the validity of the produced results with the insights and narratives produced by organisations and academics about the effect of FiT on the adoption of AD. Namely, three main insights will be compared:

- **Multiple incentives** – The literature suggests the positive effect of allowances/loans on the number of AD plants [7].
- **Differences in response by plant size** – Ofgem reports different levels of importance for the number of plants and installed capacity across the plant sizes. For instance, the large AD plants are the most responsive, both before and after the rates' revision [9].
- **Effect of reform proposals** – Ofgem reports a shift in the number of registration's applications after the revisions to the FiT was announced [9]. This also extends to the differences across sizes.

3. RESULTS

Table 2 summarises the results of each regression and the R2 of each model. This section focuses on Model 2, which is the model with the largest number of AD plants and all independent variables being significant. Then, the results from the individual methods are combined to show the overall results and compare them with these of Model 2.

Table 2 Summary table of OLS regressions results.

#	Y, log (capacity)	Independent variable significance at P>|t| (0.5)								R2
1	All plant sizes	**FiT**	0.00	**Loans**	0.00	**Size (dummy)**	0.00	**Period (dummy)**	0.00	0.59
2	All plant sizes	**FiT**	0.00	**Size (dummy)**	0.00	**Period (dummy**	0.00			0.58
3	All plant sizes	**FiT**	0.39	**Size (dummy)**	0.003					0.28
4	All plant sizes	**FiT**	0.27	**Size (dummy)**	0.48					0.86
5	All plant sizes	**FiT**	0.00	**Size (dummy)**	0.00					0.88
6	Small	**FiT**	0.20							0.63
7	Small	**FiT**	0.00							0.94
8	Medium	**FiT**	0.46							0.29
9	Medium	**FiT**	0.00							0.94
10	Large	**FiT**	0.09							0.81
11	Large	**FiT**	0.00							0.88

Figure 1 and Figure 2 show the installed capacity of AD plants attributed to the FiT incentive, multiplying the annual installed capacity for the R2 of each model. The cumulative installed capacity related to FiT by 2020 is around 265MW (86% of the total), whilst the total number of AD plants is 282. On the other hand, when considering the individual models these figures drop almost by half. The installed capacity resulting from the FiT is 170MW (54% out of the total) by 2020 and the number of AD plants is 171. The results from models 6-10 (individual models) are different from Model 2 in two ways. Firstly, models 6-10 results suggest that the FiT has not a significant impact before the revisions done to the FiT rates. Secondly, the effect of FiT in the individual is larger than in Model 2. This could be because the LR tries to fit the entire data set and has limitations to adjust to changes in the data behaviour.

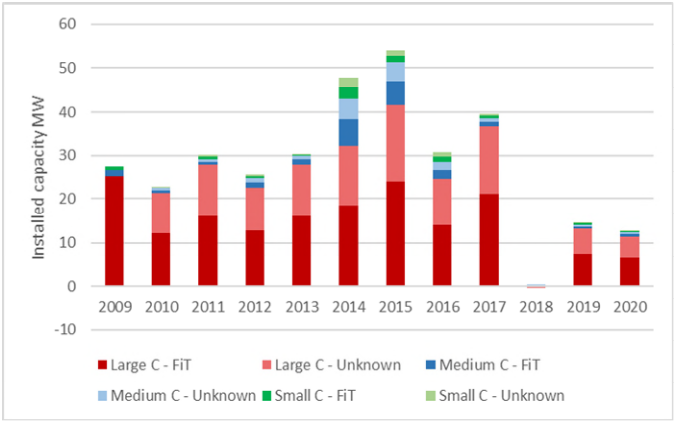

Figure 1. Annual newly added capacity by AD plant size and FiT effect - Model 2

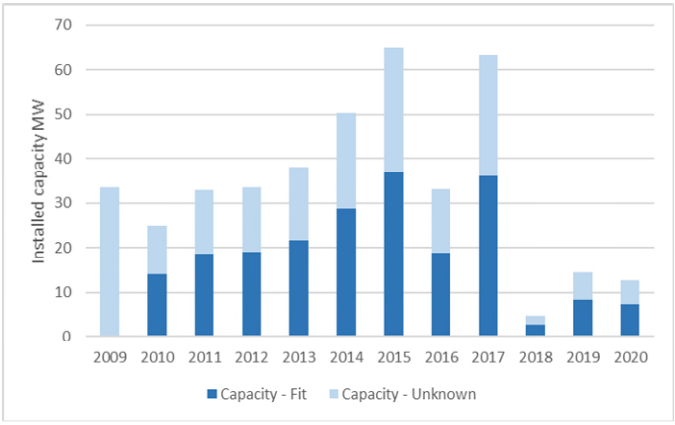

Figure 2. Annual newly added capacity – Model 2.

4. DISCUSSION

4.1. MULTIPLE INTERVENTIONS

Evangelisti et al. [7] mention that the FiT and Enhanced Capital Allowance are the main incentives supporting the uptake of AD in the UK, whilst DECC [9] acknowledge the increase in the number of AD plants cannot be attributed to entirely to the FiT programme. Nevertheless, neither of these authors provide a

quantified measure of the impact of FiT or other incentives. Results in this paper are paragon for the evaluation of the FiT on small scale AD because they show that FiT is the only incentive with a significant impact on installed capacity.

4.2. Differences in response by plant size

DECC [9] notes that different plant sizes evolved at different paces, this suggests that the FiT influence may also vary among the plant types. Thus, this analysis aims to identify this difference in two ways: a dummy variable for each plant type in the aggregate model and characterising three individual models for each plant type. Firstly, the aggregated model with the dummy variables identifies a significant effect of the plant type. Because the nature of the dummy variable is categorical rather than ordinal, the analysis can only assume that the influence of the FiT is proportional to the value of the dummy variable. This means that the effect of the FiT for medium size AD plants is double that for the small plants. On the other hand, the individual models can quantify the impact of the FiT. Although the sample sizes for the individual models is lower than 20, the results are indicative of the difference in the impact of FiT. A higher R2 coefficient for the medium size AD plants suggests that these are the most responsive to the FiT, whilst the small and large plants are 12% and 44% less responsive.

4.3. Effect of reform proposals

DECC [9] notes that the reviews and reforms[6] to the interventions may result in peaks in the number of registrations which is noted for both the RHI (2014) and FiT (2013). In the case of the RHI, this variable cannot be integrated into the model because the RHI report does not provide details on the installed capacity of the associated plant. Moreover, it is recognised that a plant can change from electricity only to heat only or a mix of both. This means that a plant that has been originally planned to produce electricity can move entirely to heat, yet, still, be registered under both programmes. Therefore, this study recognises the limitations to entirely characterise the individual and synergetic effect of multiple incentives on the uptake of small scale AD. Nevertheless, the study attempts to minimise this limitation by excluding those plants that exclusively produces heat, and recognises the need for a model and data that captures the dynamic nature of the AD plants outputs.

The models developed here characterise the effect of the reforms/reviews in two ways: i) introducing a dummy variable that accounts for the periods before and after changes to the FiT rates were introduced (Model 2); and ii) individual models for each of these periods (Models 6-11). Model 2 shows the significance of the dummy variable, showing the significant difference in the data behaviour in these two periods. Yet the results do not provide a measure of how different the FiT effect is before and after. On the other hand, Models 6-11 show that the FiT is not significant before the revisions. Although these results have a limited number of observations, the results are complementary to Model 2 and suggest that they are not subject to Type I statistical error[7].

5. Conclusion

This paper proposes an alternative approach to current intervention evaluation methods by measuring the impact of FiT on the total installed capacity of Anaerobic Digestion (AD) plants quantitatively. This paper demonstrates that from the different incentives available for AD, FiT is the only one with statistical significance. The model can extend the narratives created for the AD uptake, providing a quantified measure of the influence of FiT. First, the results show that among the different incentives for AD, only the FiT has a significant effect. Secondly, this effect comes to play only after the revisions to the programme. And third, the results confirm that the FiT has a different effect for each plant size, being the medium size plants the most responsive to the programme, whilst the large plant the least responsive.

REFERENCE

[1] Gummer RHJ, Brown B, Bell K, Chater N, Forster P, Heaton R, et al. Net Zero The UK's contribution to stopping global warming Committee on Climate Change. 2019.

[2] Department of Energy and Climate Change. The Carbon Plan: Delivering our low carbon future. 2011.

[3] Department for Business E& IS. 2019 UK greenhouse gas emissions, provisional figures. 2020.

[4] Affairs D for EF& R. Agricultural Statistics and Climate Change. 2020.

[5] Jones P, Salter A. Modelling the economics of farm-based anaerobic digestion in a UK whole-farm context.

[6] The results suggest that at least one of the independent variables of the linear regression is significant. If this would be false, because of data limitations, the analysis would be rejecting a null hypothesis that is in fact true (Type I error).

[7]

Energy Policy 2013;62:215–25. https://doi.org/10.1016/j.enpol.2013.06.109.

[6] Ackrill R, Abdo H. On-farm anaerobic digestion uptake barriers and required incentives: A case study of the UK East Midlands region. J Clean Prod 2020;264:121727. https://doi.org/10.1016/j.jclepro.2020.121727.

[7] Evangelisti S, Lettieri P, Borello D, Clift R. Life cycle assessment of energy from waste via anaerobic digestion: A UK case study. Waste Manag 2014;34:226–37. https://doi.org/10.1016/j.wasman.2013.09.013.

[8] Decc. Consultation on Renewable Electricity Financial Incentives 2009 Foreword by Minister of State. Transport 2009.

[9] Department of Energy & Climate Change. Performance and Impact of the Feed-in Tariff Scheme: Review of Evidence. 2015.

[10] White H. Theory-based impact evaluation: principles and practice. J Dev Eff 2009;1:271–84. https://doi.org/10.1080/19439340903114628.

[11] HM Trasury. Supplementary Guide: Realist Evaluation. n.d.

[12] Woolcock M. Toward a plurality of methods in project evaluation: a contextualised approach to understanding impact trajectories and efficacy. J Dev Eff 2009;1:1–14. https://doi.org/10.1080/19439340902727719.

[13] Pedersen LM, Nielsen KJ, Kines P. Realistic evaluation as a new way to design and evaluate occupational safety interventions. Saf Sci 2012;50:48–54. https://doi.org/10.1016/j.ssci.2011.06.010.