

Evaluating Elements of Demand-Side Policy Imperatives for Biogas from Waste Scheme Diffusion in the UK

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Abstract

Over the last decade, demand-side policies are increasingly implemented to correct market failures and overcome the systemic problem in complex social-technical systems such as energy transition. This paradigm shift in policy approach results from realizing that relying solely on supply-side policy instruments to push innovative solutions into the market is insufficient. As part of the energy transition, many developed countries have considered Biogas from Waste (BfW) based on the Anaerobic Digestion (AD) process as a realistic renewable energy source and aim to create social, economic, and environmental benefits for their communities. Despite several policy instruments in the UK over the last ten years, the growth of BfW schemes remains subdued and faces market failures. This paper aims to evaluate elements of demand-side policies focused on addressing market failures to increase the diffusion of BfW schemes in the UK. We discussed effective demand-side policies related to the biogas sector in other European countries like Sweden, Denmark, and Italy. In the analysis, we observed UK's policy instruments do not effectively address market externalities in the biogas sector. We also observed the biomethane market share in the UK is minimal; there is no market policy for green gas labeling towards demand articulation. The paper also made recommendations for policymakers in the UK to address market failures by proposing a push-pull policy model that combines demand-side policy interventions with supply-side policies.

Keywords: biogas, anaerobic digestion, biomethane, demand-side, externalities, market failures

1. Introduction

1.1 Background

The role of government policies in supporting innovations has changed over the last decade. Public institutions have emerged as major actors in shaping and defining the direction of innovation and applying mission-oriented policies to address complex social-technical challenges such as sustainable transition (Boon & Edler, 2018). Policymakers have evolved from reactive to market externalities to proactive, developing new markets and deploying innovative solutions to overcome social-technical challenges (Borrás & Edler, 2020). This evolution is evident through the development of demand-side policy measures, which focus on the commercialization and diffusion of new technologies, products, and socially beneficial services by overcoming market imperfections and structural barriers (European Union, 2017). According to Edler and Georghiou (2007), demand-side innovation policies are public measures that include (1) diffusion of innovations by increasing market demand, (2) defining product specifications, and (3) articulating demands for a specific technology or product to address social needs. Demand-side innovation policy instruments in social-technical transition include (1) creating an experimental space and (2) supporting pilot projects in collaboration with private firms and universities (Borrás & Edler, 2020). As part of demand-side policy-shaping government plays various roles such as gatekeeper, promoter, lead user, enabler of societal engagement, and takes a systemic approach by combining demand-side policy instruments with supply-side supports (Cunningham, 2009).

European countries have provided policy supports for biogas as an alternative energy source to limit Green House Gas (GHG) emissions and create social-economic benefits. In 2017, Europe alone had more than 17,700 biogas plants; Germany had 10,000 followed by Italy with 1,600 plants, while France, Switzerland, and the UK had over 600 plants (EBA, 2019). Biogas can be generated from multiple feedstocks (solid waste, liquid sewage, landfill waste) and is available in various forms of energy such as biomethane, biofuel, and bioethanol. Among different

schemes, Anaerobic Digestion (AD) plants producing Biogas from Waste (BfW) are considered sustainable and economically viable as they prevent methane leakage to the environment and produce digestate as bio-fertilizer (Lauer et al., 2018). Biogas producing AD plants can digest different bio-waste feedstocks and produce biogas and a range of byproducts; therefore, they can play a significant role in waste management (Fagerström et al., 2018). The European Union (EU) recognized the potential benefits of the AD process and integrated it into their waste management as part of a sustainable development plan (Kampman et al., 2017). The BfW facilities based on the AD process produce biogas and concurrently create financial, social, and environmental values for the local community; the produced biogas can further be upgraded into biomethane for injection into gas grids or biofuel for the transport sector (Fagerström et al., 2018).

As part of a long-term strategy to reduce GHG emissions, promote alternate renewable energy and improve biodiversity, the UK prioritized and supported AD technology based BfW schemes (Adams, Mezzullo, & McManus, 2015). The UK government recognized AD as an effective technology for 1) organic waste treatment to produce renewable energy, 2) nutrient-rich digestate to avoid GHG emissions from landfills, and 3) decarbonization of the national gas grid (IEA Bioenergy, 2020). In the energy sector between 2008 and 2014, the UK introduced various supply-side policy instruments like Feed-in-Tariffs (FIT) and Renewable Heat Incentives (RHI). Due to FIT and RHI supports, the number of AD-based BfW plants increased from 63 in 2011 to around 400 in 2017, and energy recovered from AD schemes increased from 713 GWh in 2013 to 2,470 GWh in 2017 (DEFRA, 2018). To encourage biofuel use in the transport sector, the UK transport department introduced the Renewable Transport Fuel Obligation (RTFO) scheme in 2008, obliging fuel suppliers to mix biofuel in transport fuel supply and claim green certificates. The long-term strategy to promote AD-based BfW schemes is facing significant challenges resulting from the UK government's abrupt shift to quantity-based instruments, lack of investment, absence of waste collection infrastructure, and complexity within the supply chain.

In 2015, the UK government abruptly shifted from price-based instruments to quantity-based instruments. Such a move resulted in uncertainties for less-matured technologies and policy dependent BfW schemes, and the sector's growth has declined since 2016 (IEA Bioenergy, 2017). The withdrawal of FIT support instruments resulted in a drastic decline in the rate of AD plant construction from 109 a year in 2014 to 20 in 2018 and to just one plant in 2019 (IEA Bioenergy, 2020). Instead of investing in new AD-based BfW schemes, the UK government-owned green investment bank chose to make significant investments in incinerator-based energy generations (Peake & Brandmayr, 2019). The incineration process is based on burning biowaste leading to higher pollution levels and adversely impacting the environment and public health, relative to AD processes. In addition to increased competition from alternative renewable energy sources that are less environmentally friendly, BfW plants also face feedstock supply intermittency and lower waste recycling rates due to a lack of waste collection infrastructure. Further, a complex set of sustainability criteria to qualify feedstocks as biowastes makes it difficult to define the feedstock supply chain for BfW schemes.

Driven by neo-liberal ideas, the UK aims at multi-technology auctions in the energy market where less matured technology such as the AD process must compete with other established technologies. Moreover, biogas has a higher Levelized Cost of Energy (LCOE) production than wind and solar energy. The biogas LCOE depends on several parameters that are unpredictable such as availability of raw material (bio-wastes), logistic charges, and distribution networks. Therefore, in an auction-based competitive market, renewable energy producers find BfW schemes based on AD technology less profitable than other clean technologies. Additionally, BfW schemes also face an oligopoly of big producers in the gas market. Six large vertically integrated companies, engaged in power generation, supply, and distribution of electricity and gas, control UK's energy market with more than 50% of the market share (IEA, 2019). In the UK gas market, these big six companies promote the carbon offset concept by charging an additional amount of money towards carbon-neutral gas without really mixing biomethane in the gas grids. Therefore, these companies do not contribute to biomethane market demand (Richards & Zaili, 2020). Lack of policy related to green gas product labeling, origin tracking, and certification leads to information asymmetry in the UK's gas market. Therefore, biomethane producers do not have an incentive to increase the production of biomethane.

The current state of BfW schemes reflects policy incoherence between multiple departments, and conflicting policies fail to provide the necessary support for BfW growth in the UK. Although the UK government provided a set of policy supports through RHI and RTFO instruments, these are ineffective to address market failures to create diffusion of AD-based BfW schemes. With the visible gaps in current policies, policymakers in the UK, by having a holistic view, can combine supply and demand-side instruments to overcome market failures and develop an effective push-pull mechanism. This paper aims to evaluate the elements of demand-side policies imperative to address market failures for the diffusion of BfW schemes in the UK.

1.2 Aim of the Paper

This paper aims to evaluate elements of demand-side policy imperatives for the diffusion of BfW schemes in the UK. Using a systemic approach, we argue that policymaker's knowledge and understanding of exogenous and endogenous issues can help them adjust policy instruments to create an effective design of push-pull policy model. In section 1, we briefly discuss the relevance of demand-side policy instruments in complex social-technical systems such as energy transition and argue that these policies, when combined with supply-side instruments, can effectively increase the diffusion of BfW schemes in the UK. In section 2, we discuss the methodology. Section 3 discusses the concept of demand-side policy and the different elements. Section 4 discusses the UK's BfW sector status, policy issues, and the importance of the demand-side policies, which can help increase the diffusion of BfW schemes in the UK. In section 5, we use cross-country comparisons between the UK and Sweden, Denmark, and Italy, who have successfully created a lead market for biogas and supported a business ecosystem to grow the biogas sector significantly. We also compare biogas policies within the UK's member states, England and the devolved state Scotland, to highlight effective policies. We recommend policymakers in the UK play an active role in biogas demand governance by adopting a systemic approach. We conclude our paper in section 6 by highlighting elements of demand-side policies that can address market failures to increase the diffusion of BfW schemes in the UK.

2. Materials and Method

We conducted a literature review of demand-side policies within the last five years. The literature review helped us develop a conceptual understanding of demand-side innovation policy implementation in the areas related to social-technical systems; we also identified various elements of demand-side policy and the role of public institutions in governance. To gain insight into the UK's BfW scheme, we conducted a literature review on peer-reviewed papers and reports on the UK's Biogas sector. We discuss barriers in creating widespread diffusion of BfW schemes. We also identified critical elements of demand-side innovations that policymakers must implement. In the discussion section, we analyzed the UK's policies on the BfW scheme by contrasting them with strategies of other European countries like Sweden, Denmark, and Italy. To decarbonize the gas sector, Sweden, Denmark, and Italy have successfully implemented demand-side policy interventions. Intending to identify best practices being implemented in the member states of the UK, we also analyzed demand-side policies that were effective for BfW growth in the UK's devolved member state Scotland.

3. Demand-Side Policy Concept

Until the late 1990s, public institutions in developed countries generally implemented two policy mechanisms: 1) command and control policies and 2) market-based instruments. However, scholars have questioned the efficacy of both mechanisms in spurring less mature renewable energy technologies. According to Costantini et al. (2015), command and control policy is effective when technologies are mature but ineffective for green technologies. Conversely, market-based instruments alone are ineffective in supporting green technologies; therefore, a policy mix strategy is necessary (Constantin et al., 2015). The beginning of the 21st century marked the emergence of innovation policies when policymakers in developed countries wanted to apply technical innovation to improve economic performance and overcome social and environmental challenges. Innovation policies focused on creating new knowledge through a) fiscal incentives for R&D, b) building capabilities and skills to commercialize innovation, and c) supporting interaction and learning at the national and regional level. The policy instruments were mainly focused on the supply side of innovations at the initial stage; however, recently, the role of demand-side policies to spur innovation has gained attention (Edler & Fagerberg, 2017). Demand-side innovation emerged in Europe when countries found it challenging to convert science-based research outcomes into commercially viable and socially valuable innovations. Additionally, markets are recognized as important drivers of innovation, enabling firms to gain faster and better returns on innovation-related investments (Cunningham, 2009). Demand-side innovation policies are normally used to complement supply-side policy instruments. Innovation experts have suggested that demand-side policies should be combined with supply-side policies in the case of less mature technologies (Boon & Edler, 2018). Combining demand-side instruments with a set of supply-side policy interventions can be strategically more effective in managing complex systemic transitions (Cunningham, 2009).

3.1 Policymix Strategies

Innovation policies have traditionally focused on supply-side R&D activities with support from government grants and subsidies. However, policymakers in developed countries have gradually shifted away from R&D subsidies and employed a policy mix to create market space where firms are rewarded for their innovative solutions (Edler & Fagerberg, 2017). Scholars agree that demand-side interventions should operate in conjunction with, rather than instead of, supply-side measures (Cunningham, 2009). The concept of a policy mix, developed by innovation

policy scholars, has become relevant in the last decade as policymakers apply this concept to improve overall policy effectiveness by creating balance and coherence between technology push and demand-pull instruments (Costantini et al., 2015). The main objective of a policy mix is to improve overall effectiveness through support and coherence of different policy instruments rather than applying them in isolation, where the different instruments may negate each other. Scholars have attempted to highlight dynamics and processes in the policy mix to understand this concept better. Successful policy mix characteristics include consistency, credibility, and comprehensiveness. Inconsistency and incoherence in the policy mix can be detrimental in achieving policy objectives; therefore, policymakers should focus on policy mix characteristics rather than solely relying on policy instruments (Rogge & Schleich, 2018). In sustainability transitions, a certain degree of inconsistencies and incoherence are expected due to conflicting priorities and mutually exclusive interests between different actors; therefore, considering policy instrument interactions in the long-term orientation are essential elements of a policy mix (Rogge & Reichardt, 2016). According to Rogge and Schleich (2018), policy interactions may reduce the effectiveness of the policy mix in stimulating green innovation. The policy comprehensiveness determined by the degree to which all issues related to markets, systems, institutional failures, and barriers are addressed can help policymakers overcome policy interaction issues (Rogge & Reichardt, 2016). The credibility of the policy mix approach denotes to what extent mix policies are considered believable and reliable; it is judged by their ability to attract new investments (Rogge & Schleich, 2018). The higher credibility of the policy mix reflects a commitment from political leadership and a degree of alignment with monetary policies (Rogge & Reichardt, 2016).

3.2 Market Development Initiatives

The concept of market development in innovation policy aims to identify and create a market that will define future demand for innovative solutions and technologies. The market base strengthens the demand pull, which benefits firms resulting in better returns on their innovation efforts (Cunningham, 2009). The market development strategy of OECD countries to support green innovation provides price signaling that incentivizes firms to spur innovation and invest in greener technologies. A well-structured market with appropriate taxes and penalties can effectively address the negative aspects of environmental externalities (OECD, 2012). Governments play various roles in supporting and developing new markets. In the promotor's role, the government pushes a specific technology in the market, and in the facilitator's role, the government reduces market imperfections in support of non-state actors. Governments can also play the role of the lead user to create a new market of specific solutions to spur public demand (Borrás & Edler, 2020). Market development policy includes public procurement of innovative products, price-based incentives to consumers, demand articulation, product labeling, and product certification (Boon & Edler, 2018). Among different market-based policies, the effectiveness of public procurement in stimulating innovation has been widely debated and contested. According to Edler and Fagerberg (2017), over-dependency on public procurement may limit experimentation and entrepreneurship, hindering the generation and diffusion of innovation. Public procurement policies are generally considered an old model focused on stimulating the economy. Instead, innovative countries such as Sweden and the UK aim to increase market competition relying on other market-based instruments (Cunningham, 2009). However, within the energy sector niche and less mature technologies like solar and biogas often compete with mature and established fossil and nuclear energy technologies. The degree of maturity, LCOE, and availability of required distribution infrastructure are the critical factors in deciding the most effective market-based instruments. Therefore, the diffusion of niche and less mature technologies require comprehensive and well-defined market-based policy supports. As part of the German Energiewende strategy, Germany supported different green technologies with varying degrees of maturity and costs rather than focusing on the specific and cost-effective renewable energy option (Edler & Fagerberg, 2017). The German strategy aimed to increase market share and reduce green technology costs over long periods through market interventions; the cost of green technologies, which were initially very high, are currently lower than fossil or nuclear energy sources (Rechsteiner, 2021).

3.3 Regional Focus and Cooperation

The policy design aimed at solving societal and ecological challenges evolves through feedback, past failure, and learning from experiments. In contrast, policymakers face organizational barriers, including silo structures, ineffective mechanisms to disseminate knowledge and obtain feedback, and lack of sufficient time for policy learning. Place-based experimentalism is one possible solution to overcome such organizational barriers (Coenen & Morgan, 2019). Many European countries, including Germany, Finland, Denmark, Belgium, Sweden, UK, Netherlands, and Norway, support robust policy discourse and experimentation in demand-side innovation policies (Wintjes, 2012). The place-based approach in policymaking recognizes the value of innovation beyond economic values to include and capture social and ecological values (Coenen & Morgan, 2019). Researchers agree that spatial blindness in policy design may fail to meet its intended objectives; spatial sensitivity, in particular, is an

important factor in social and ecological related policies. The UK set out an ambitious target of achieving net-zero by 2050; however, policy design for green innovation and energy transition is often criticized for being overly reliant on centrally controlled policies with a place-blind approach (Uyarra, Ribeiro & Dale-Clough., 2015). From a socio-technical transition perspective, renewable energy policies have implications for material aspects of energy systems; local authorities with better knowledge of available resources can provide alternative ideas about energy system development (Kuzemko, 2019). With a focus on demand-side innovations, the EU adopted a regional innovation system (RIS) approach conceptualized as a relational, social, and networked process between key actors such as firms, supply chains, governments, and universities (Coenen & Morgan, 2019). As part of demand-side innovation policies, the regional clusters bring together buyers and suppliers of innovations in value chains. Therefore, shifting away from a 'research-driven' approach towards a more 'user-driven' approach, resulting in the co-creation of values and new forms of business cooperation (Wintjes, 2012).

Building on this discussion, we observed that the demand-side innovation concept is still evolving and consists of several key elements. We conclude that demand-side innovation conceptualization can provide a robust framework for reviewing the policy imperatives for BfW scheme diffusion in the UK. The essential elements related to the demand side policies observed through the literature review are 1) policy mix strategy, 2) lead market development, 3) regional focus and cooperation.

4. Waste to Bigas Development in UK

4.1 BfW Significance and Growth

The BfW based on AD technology has the potential to contribute to nine of the 17 United Nations sustainable development goals to be achieved by 2030 (WBA, 2020). In the EU, AD technology contributes to more than 60% of biogas production using different waste feedstocks (Kampman et al., 2017). AD is a natural process in which micro-bacteria digest organic material in oxygen-free containers to produce biogas (mixture of methane, carbon dioxide, and other gases) and a biofertilizer co-product known as 'digestate' (WBA, 2020). Another significant benefit of AD technology is the reduction in GHG gases. The organic landfill waste, which was a major source of methane leakage to the atmosphere, contributed to GHG gas emissions and can now be captured as a source of energy (Lambert, 2017). The landfill directive (1999/31/EC) requires EU countries to achieve a 65% reduction in bio-waste disposal by 2020 relative to 1995 levels, gave rise to AD technology (Zglobisz et al., 2010). The waste and landfill directives in the EU necessitated countries to implement waste collection and processing systems (Kampman et al., 2017). In line with other EU countries, the UK using Land Fill Allowance Trading Scheme (LATS) allowed local authorities to use bio-waste as a resource for renewable energy generation and prevent landfill disposal (Zglobisz et al., 2010). The EU Renewable Energy Directive (RED) necessitates its member states to source 15% of their total energy from renewable sources by 2020. The RED also requires member states to source 10% of renewables in road and rail transport by 2020 and encourages biofuels produced from waste feedstocks. Recognizing the potential of energy from waste, the UK government promoted AD technology as the best available means to produce renewable energy and biofertilizer from municipal wastes and limit landfill disposal (DEFRA, 2014). Alongside organic waste management and limiting GHG emissions associated with landfill disposals, AD technology has emerged as a viable process of biogas and biofertilizers (DEFRA, 2011). The UK government's landfill taxes and gate fee charges payable to waste management companies provided an incentive to set up AD-based waste handling plants (Zglobisz et al., 2010). Between 2008 to 2014, the UK government implemented various supply-side policy instruments to push AD technologies into the electricity and heat sector. As part of the Renewable Energy Act (2008), the UK provided FIT support for a fixed period to small-scale AD facilities (Zglobisz et al., 2010; IEA Bioenergy, 2020). In the heat sector, RHIs were introduced in 2014 to provide a fixed income (pence/kWh) to heat producers from renewable biogas and biomethane (IEA Bioenergy, 2020). The Renewable Obligation Act (2009) supported waste to energy technologies, BfW based on the AD process was eligible to receive two ROCs for each 1 MWh of energy produced while energy from other sources received one ROC (Zglobisz et al., 2010).

The UK transport department introduced a quota system in 2008 called Renewable Transport Fuel Obligation (RTFO), where fuel suppliers are obliged to meet a specified quota of adding biofuel as part of their commitment to reduce GHG emissions and push BfW schemes. Under the RTFO act, the Renewable Transport Fuel Certificates (RTFC) are issued to renewable fuels meeting specified sustainability criteria. Biomethane, produced from bio-waste, receives 3.8 RTFCs per kilogram compared to 1.9 RTFCs for biomethane generated from other sources (Department of Transport, 2019). The UK government's use of policy instruments such as the Landfill tax, double ROC, FITs, and RHI, provided much need impetus for the development of BfW plants (Zglobisz et al., 2010). With the help of supply-side price-based instruments like FIT and RHI, the number of AD-based BfW plants increased from 63 in 2011 to around 400 in 2017 (DEFRA, 2018). The UK's policy support encouraged the

construction of new AD plants, and AD processing capacity has tripled since 2012. However, the annual increase in AD capacity and the number of plants peaked around 2014-2016 (IEA Bioenergy, 2020). Due to a lack of policy coherence and uncertainties, BfW schemes' growth has declined since 2016 after the withdrawal of price-based instruments and the emergence of quantity-based instruments (IEA Bioenergy, 2017). Quantity-based instruments such as Contract for Difference (CfD), based on competitive bidding prices, are substantially more favorable to mature technologies like wind and solar farms with much lower LCOEs than biogas.

Table 1. Biogas from waste Policy background in the United Kingdom (ADBA, 2020, IEA Bioenergy, 2020)

Policy type	Department	Description	Issues / concerns
Regulatory-supply side	Waste management	Landfill tax to reduce bio-waste disposal	
Monetary incentive-supply side	Waste management	Gate fee for waste collection	Inconsistent and varies widely
Regulatory-supply side	Climate	Sustainability criteria for AD feedstock	
Monetary incentive-supply side	Electricity sector	Feed-in-tariff payable to energy generated from biogas	From 2020, FIT replaced with market driven scheme 'Smart Export Guarantee' (SEG) without minimum price support
Monetary incentive-supply side	Heat sector	Renewable Heat Incentive (RHI) payable to heat generated from biogas	Inconsistent and varies widely, likely to be withdrawn in 2021
Regulatory-demand side	Transport sector	Renewable transport fuel obligation for suppliers to mix biofuel	
Monetary incentive-demand side	Transport sector	Renewable Transport Fuel Certificate (RTFC) to benefit biomethane producers	Market driven pricing for RTFC, varies widely

4.2 Challenges in UK's BfW Scheme

4.2.1 Lack of Policy Coherence

Development and growth in the biogas sector are affected by a wide range of policies related to climate, renewable energy, waste, the circular economy, and natural gas infrastructure. Many policies are concurrently revised; therefore, coherence and interaction between the various policies should be considered while developing a biogas sector strategy (Kampman et al., 2017). Policy issues related to technology, financing, and market development are the main barriers to developing the BfW sector (Zglobisz et al., 2010). Member states of the EU recognize that policy coherence is crucial to the effective development of BfW (Kampman et al., 2017). According to the Anaerobic Digestion and Bioresources Association (2020), the UK's biogas sector can achieve a 6% reduction in emission level by 2030 compared to today's emission level; however, policies need to be well-coordinated to deliver a significant impact and unlock AD's full potential. Policy inconsistency is evident across different departments within the UK. In contrast to the UK's strategy to utilize its full potential of AD technology, the withdrawal of FITs and reduction in RHI tariffs have adversely impacted new investments in AD-based BfW plants. The number of new plants dropped dramatically from 109 in 2014 to 20 in 2018 and to just one plant in 2019 (IEA Bioenergy, 2020).

Policy support and regulations related to waste collection and management varies across the region. Within the UK, different bio-waste collection systems are applied in different regions. DEFRA (Department for Environment, Food and Rural Affairs) has jurisdiction over waste and recycling policy in England. In comparison, the devolved administrations in Wales, Scotland, and Northern Ireland enact their own local policies for waste collection (Malinauskaite et al., 2017). It can be argued that policy uncertainty in waste collection leads to intermittency in

feedstocks for BfW plants, thus a non-viable business case for entrepreneurs. Lack of funding supports is another challenge faced by organizations in the BfW sector. The niche organizations offering innovative solutions using disruptive design do not receive funding support (Peake & Brandmayr, 2019). In the UK's market-driven policy regime, financial institutions look for profitable business cases to ensure a guaranteed return on project financing (DEFRA, 2014). Therefore, a profitable business model is essential to ensure long-term profitability (ISABEL, 2018). In the UK's market-based policy arrangement, smaller organizations struggle to develop a profitable business model without any support from a business ecosystem (DEFRA, 2014). Policy support in recognizing and nurturing a BfW business ecosystem can allow small BfW operators to explore hybrid and shared ownership business models with private developers.

4.2.2 Externalities and Market Imperfection

Climate experts have recognized the potential of AD technology in reducing GHG emissions. In contrast to other cleaner technology like solar and wind, biowaste-based AD processes not only produce biogas but also help reduce methane emissions. The present policies do not account for emissions avoided through the productive use of biowaste in the AD process, which would otherwise have led to significant emissions of methane and CO₂ (Lambert, 2017). Compared to other cleaner technologies that are carbon neutral, the BfW scheme is a carbon-negative technology and acts as a carbon sink. BfW schemes have a significant potential to provide a 6% reduction in the UK's carbon emission levels by 2030 compared to today's level; however, the current policy support for AD technology in the UK does not recognize AD's potential as a carbon-negative technology (ADBA, 2020). The BfW based on AD has significant potential for increased GHG savings from biomethane implementation in the UK; policymakers should prioritize the pathways which will contribute the most significant GHG reductions (Horschig et al., 2016). AD-based BfW schemes face market imperfections as the positive externality generated from acting as a carbon sink is not internalized in the open energy market; price supports would serve to align the social and private benefits of BfW schemes. Within the transport sector, biomethane can reduce GHG emissions by 70% compared to gasoline (Lambert, 2017). Therefore, policymakers must address the market externalities by increasing carbon floor prices and incentivizing BfW schemes (ADBA, 2020; Horschig et al., 2016). The UK's energy policy which is technology-neutral and market-driven uses tariff and quantity-based instruments solely based on the energy produced and does not effectively incentivize the potential carbon sink in the AD process (ADBA, 2020). Policymakers should recognize the carbon-negative potential of BfW schemes and address market imperfections by applying effective shadow prices to encourage BfW schemes or increase carbon floor prices for other polluting energy sources.

4.2.3 Biogas Cost Structure

Unlike other renewable energy sources like wind and solar energy, which utilize inexhaustible natural resources, biogas depends on biowaste availability. The LCOE of biogas is influenced by many factors, including choosing between a wide range of feedstock and associated transport costs; the LCOE also depends on the biogas distribution infrastructure (Lambert, 2017). The raw biogas produced from the BfW process contains 15 to 40% of CO₂; therefore, to make it suitable for gas grid injection or use as a transport fuel, the biogas should be upgraded to biomethane. The following costs are necessary elements for biogas to become an energy fuel 1) biogas production from the AD process, 2) biogas upgrade to biomethane, and 3) biogas distribution (IRENA, 2018). The estimated LCOE of power generation from local BfW AD plants ranges from 6-14 USC/kWh. In comparison, onshore wind has an LCOE of 6.8 USC/kWh, and offshore wind has an LCOE of 12.8 USC/kWh (Lambert, 2017). The upgrading and distribution cost of biogas for small-scale BfW plants can be more than 50% of the total LCOE cost of biomethane; however, for large capacity BfW plants, the upgrading and distribution cost could still be in the range of 20-30% of LCOE (IRENA, 2018). The estimated LCOE of biomethane ranges from 4.7USC/kWh to 15USC/kWh; biomethane at the lower end can compete with Europe's natural gas price of 4.3 USC/kWh (Lambert, 2017). However, on the higher side of LCOE, biomethane appears economically unviable compared to natural gas without policy support. UK policymakers should explore new and innovative ways to reduce the higher cost of upgrading and distributing biomethane. According to ADBA (2020), centralized biogas upgrading infrastructure in an area with multiple BfW plants can be one way to reduce the upgrade and distribution cost significantly.

4.2.4 Underdeveloped Biogas Market

Although the UK has set an ambitious net-zero target by 2050, the UK economy is still heavily dependent on fossil fuels for heating homes and industrial processes. Every year the national gas grid delivers approximately 88.1 billion m³ of gas to homes and businesses across the UK (ADBA, 2020). In contrast to this, biomethane production in the UK is significantly lower; there are only 103 biomethane plants with a total capacity of 81,000 m³/h (IEA bioenergy, 2020). EU member states have supported biomethane as an alternative to natural gas. However, the

share of biomethane consumption remains lower relative to natural gas. Creating a market demand for biogas will eventually improve the business case for biogas projects (Kampman et al., 2017). Due to positive externalities associated with biogas, the market must be extended beyond electricity, heat, and transport fuel (IEA, 2020). Policymakers can utilize the carbon-neutral economic potential of BfW schemes to create biogas centric markets (ADBA, 2020). In the UK, bio-waste as a feedstock and digestate as a byproduct are not considered value streams; the feedstock and byproduct must be given marketable values to develop the BfW scheme as a viable product business case (Acharya, 2020). Converting low-valued bio-wastes into marketable end-products requires specific policy support (Donner, Gohier, & de Vries, 2020). Despite the growing recognition of AD digestate as a bio-fertilizer, the market in the UK is underdeveloped (DEFRA, 2015). AD operators in the UK go through complex certification procedures to get digestate certified as a bio-fertilizer. It is evident that under the present policy regime, the biogas market and its products are not clearly defined as profitable business case and lack long-term economic viability. Therefore, policymakers should recalibrate their policies to improve the market potential of the biogas sector by commercializing the products and inducing investments (Malinauskaite et al., 2017).

Between 2008 and 2014, the UK implemented price-based instruments such as FITs and RHIs to support BfW schemes in the electricity and heat sector. Additionally, the UK government introduced a quota-based obligation scheme to push biomethane into the transport sector. However, since 2015, guided by neoliberal ideas, to create a competitive energy market and remain technology-neutral, UK policymakers shifted from price-based to quantity-based instruments. This paradigm policy shift saw large-scale diffusion of mature technologies such as wind and solar energy. Quantity-based instruments such as CfD have emerged with growing support for mature renewable technology that operates with a lower LCOE compared to conventional energy sources. In contrast, biogas and biomethane produced from BfW plants have higher LCOEs; thus, quantity-based instruments do not support this form of energy. Further, the market-driven quantity-based instruments do not internalize the negative carbon potential of AD technology with an effective shadow price that would equate the biogas LCOE with that of other mature technologies. The UK intended to use biomethane in the transport sector to reduce GHG emissions. However, even after ten years of policy supports, the biomethane market is still underdeveloped. Biofuel consumption in the transport sector is around 10% compared to fossil fuels (IEA, 2019). The high cost of biogas up-gradation and lower demand in the transport sector can be attributed to the small biomethane market. Poor waste collection infrastructure, especially in England, and unclear policy for labeling digestate as biofertilizers limit the BfW scheme as a profitable business. Due to a lack of investment supports and R&D funding, the biogas sector has been unable to mobilize small-scale BfW schemes at the community level. Having analyzed present policy barriers in the UK, we aim to evaluate how policymakers can apply different demand-side policy elements to create a demand-pull for BfW schemes. In the discussion section, using a policy mix strategy, we present a push-pull policy model for creating a widespread diffusion of BfW schemes.

5. Discussion

This paper evaluates different elements of demand-side innovation policies focused on addressing market failure to increase the diffusion of AD-based BfW schemes in the UK. Section 3 conceptualized elements of demand-side innovation policies, and in section 4, we identified critical policy barriers leading to market failure for BfW schemes in the UK. In this section, we analyze different demand-side policy elements that can be applied to create a push-pull policy model using a policy mix strategy. We compare the UK's BfW policies with other European nations like Sweden, Denmark, and Italy, which have successfully created a lead market for biogas and supported significant growth in the BfW sector. We also compare innovation policies related to biogas development between the UK's member states, England and the devolved state Scotland, to highlight effective policies that policymakers can apply across the UK.

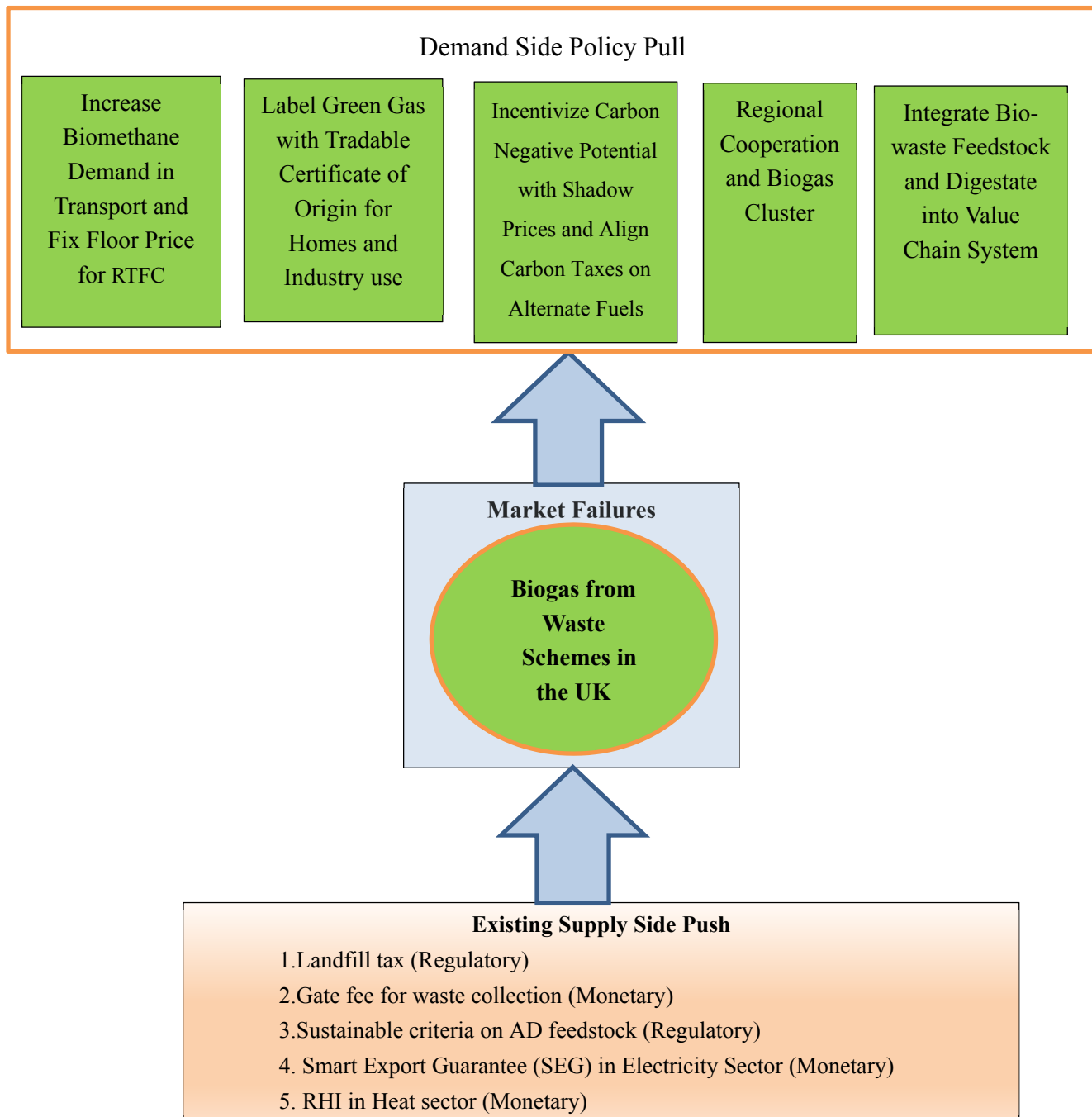


Figure 1. Policy push-pull model to address market failures

5.1 Biomethane Market Development

To support the diffusion of BfW schemes, it is imperative for policymakers in the UK to create a demand for biomethane by establishing a market. The current biomethane market is immature compared to natural gas. Experts have highlighted that increasing demand for biomethane will improve the business case for BfW schemes and bring new investments into the sector (Kampman et al., 2017). The demand for biomethane can be increased in multiple ways ranging from public procurement of green gas-driven public transport to green gas labeling with tradable certificates.

To limit GHG emissions, the UK government aims to restrict all-new diesel and heavy petrol vehicles by 2030 (Primmer, 2020). Also, many UK cities and municipalities are introducing low emissions zones to tackle GHG

emissions and promote green transport. Since technologies like hydrogen fuel or electric vehicles are not ready for the heavy mode of transportation, there is an opportunity for biomethane fueled vehicles (Primmer, 2020). In contrast to the UK, biomethane demand in Sweden's transport sector is very high. The demand for biomethane in Sweden increased four times over the last ten years; 64% of biogas were upgraded to biomethane in 2019 (Klackenberg, 2021). Within the EU, Sweden has lower biogas production compared to Germany, the Netherlands, and the UK; however, with effective policy supports, Sweden has created a market demand for biomethane and upgraded a large share of biogas into vehicle fuel (Ammenberg et al., 2017). Using demand-side policies, Sweden emerged as a world leader in biofuel use in the transport sector. The use of methane in Sweden's transport peaked around 2014 and continues to decline, while biomethane use rose from 10% in 2005 to 95% in 2019 (Klackenberg, 2021). Researchers agree that this scale of growth would not have occurred without the proper policy supports, and studies have indicated a strong link between various demand policy instruments and biogas development in Sweden (Ammenberg et al., 2017).

Table 2. Demand side policies for biomethane in Sweden's transport sector (Klackenberg, 2021)

Policy type	Description
Fiscal incentives (CO ₂ and energy tax exemption)	Biomethane exempted from the CO ₂ and energy tax for transportation fuel until the end of 2030. Natural gas in transport is exempted from the energy tax but pay CO ₂ tax of (~23 €/MWh). Petrol use in transport pay a CO ₂ -tax (~29 €/MWh) and an energy tax (~45 €/MWh).
Bonus system for light vehicles	From July 1, 2018, consumers receive a bonus up to 7000 € when purchasing new low emission cars and new gas vehicle consumers receive a bonus of 1000 €.
Regulations	Environmental zones regulations for cities from January 1, 2020. Cities can create up to three restriction level zones for polluting vehicles. Only new gas vehicles (NGVs), hydrogen, and all-electric vehicles are allowed in all three zones.
Product labeling	Environmental information about all transport fuels, including fuel origin and CO ₂ reduction, must be displayed at filling stations, from October 1, 2021.
Public procurement	Creation of rules and setting environmental criteria for public procurement of fuels and vehicles for public organizations to increase the demand

Public organizations in Sweden take an active role in ensuring the procurement of biogas green vehicle fleets. Stockholm public transport, a public body, plays a central role in biofuel procurement to ensure fossil fuels are phased out successively from public transport and guarantee continuous demand for biogas produced at the municipal BfW plant (Ammenberg et al., 2017). Public procurement has emerged as an effective policy instrument for biogas developed in Sweden, creating enormous demand opportunities for biogas in public transport and taxi services (Energigas Sweden, 2018).

Despite having a good gas distribution network across the UK, the biomethane share in the domestic and industrial sectors remains marginal compared with natural gas. In the UK, almost 90% of homes are connected to the gas grid; however, biogas share was below 1% of the total gas volume consumed in 2017 (Richards & Zaili, 2019). The main reasons for the lower demand for biomethane are a) lack of cost parity with natural gas and b) absence of demand-side incentives for biomethane use. In the UK, gas suppliers promote carbon-neutral gas based on the carbon offset concept without creating any physical demand for biomethane. Some gas suppliers also charge a high premium for mixing a small percentage of biomethane with natural gas. The biomethane RHI supports in the UK aimed to provide price guarantees face frequently fluctuating rates and lack a floor price. According to ADDBA (2020), the current RHI rate failed to create enough demand to bring investment for new plants; therefore, either a higher tariff rate or a new demand-side policy that effectively stimulates the demand for biomethane is required. In the UK, large gas suppliers do not offer actual biomethane; instead, they promote carbon-neutral gas based on

the carbon offset concept. Such schemes remain questionable and create market imperfections (Richards & Zaili, 2019). Thus, it is imperative for UK policymakers to label biomethane as a value product, articulate the demand, and create a green gas certificate exchange allowing producers and consumers to trade and claim their green credentials. According to ADBA (2020), with RHIs due to close in 2021, the UK government needs to urgently replace the RHI scheme with a new policy designed to account for the true social benefit of biomethane. A demand-side policy mandating gas suppliers buy biomethane and allowing producers, suppliers, and consumers to benefit from a competitive and transparent tariff structure using the green gas certification can provide much needed market pull (Richards & Zaili, 2019). In contrast to the UK, Denmark and Sweden use demand-side policy supports to create market pull for biomethane in the domestic and industrial sectors. According to IEA bioenergy (2019), Denmark has a biomethane share of 10% in the national gas grids; Denmark is estimated to become independent from fossil natural gas by 2035. Denmark provides demand-side policy supports to reduce the biomethane cost and create market demand. According to the Green Gas Initiative (2017), Energinet, a public institution in Denmark, has worked with market actors to reduce biomethane costs since 2011. Energinet has cofounded the Renewable Gas Register with neighboring countries to create a cross-border market and allow claims for green credentials. Similarly, Sweden provides a fiscal incentive for biomethane in the domestic and industrial sectors. According to Energigas Sweden (2018), Sweden aimed to become the 1st fossil fuel-free country by quickly transitioning to green gas by 2030. The Swedish government exempted biomethane from CO₂ and energy taxation until the end of 2030 to promote biomethane in the domestic and industrial sectors, while natural gas is assessed a CO₂ and energy tax of around 32 €/MWh (Klakenberg, 2021).

5.2 Incentivizing Carbon Negative Potential

Policymakers have largely ignored the negative carbon potential of BfW schemes. In the UK's open energy market, biogas competes with other renewable technologies that are carbon neutral. BfW schemes can cut methane leakage from the waste and agricultural sectors and produce nutrient-rich fertilizer. These environmental benefits are not factored into financial models; therefore, policies do not effectively monetize the biogas sector for its social and environmental value contributions (ADBA, 2020). The RED II (revised renewable energy directive) issued by the EU in 2018 recognizes the negative carbon potential of AD-based biogas production from waste (Zhu et al., 2019). Using a carbon tax on fossil fuels and natural gas, Sweden effectively addressed the negative externalities in the gas market (Zhu et al., 2019). Although biogas producers in the UK are exempted from the energy tax, which is levied on fossil fuels, the effectiveness of this exemption depends on the carbon price floor (Kampman et al., 2017). A carbon price floor enhances the economic case for biomethane consumption; carbon prices of \$50 per tonne of CO₂ can improve the economic viability of BfW schemes (IEA, 2020). In contrast, the carbon price floor in the UK is around \$33, which is well below the estimated global carbon price of \$100 (ADBA, 2020). Sweden introduced a carbon tax in 1991 based on the average carbon content in each fuel; in 2021, the carbon tax was \$134 per ton, well above other European countries (Swedish government, 2021). The carbon tax in Sweden is based on the polluter pays principle. The biogas sector in Sweden does not receive any direct subsidies but has benefited from GHG reduction and negative carbon potential (IEA bioenergy, 2018). According to ADBA (2020), an appropriate carbon price in the UK could significantly improve the business potential of biogas. Policymakers can apply either a) suitable carbon tax on emissions or b) a system for tradable carbon quotas, making biomethane more cost-competitive than fossil fuels.

5.3 Regional Cooperation and Value Chains

Research and knowledge development in the biogas sector requires the cooperation of market actors such as biogas producers, technology providers, intermediaries, and industrial and domestic consumers (Nevzorova & Karakaya, 2020). The EU recommends platforms for biogas best practices involving farmers, economic actors, municipalities, and policymakers; the EU also recognizes that a lack of knowledge about biogas technologies among financial stakeholders can be a barrier to obtaining project financing (Kampman et al., 2017). Many European countries use a decentralized approach and involve municipalities and city councils for regional and rural development of the biogas sector. In contrast, the UK government's policy approach has been typically top-down (Markantoni, 2016). The UK assumes the techno-market fix with centralized energy systems can create diffusion of AD technology using market-driven policy instruments; however, such an approach has been criticized for being over-simplistic and lacking participatory decision-making (Levidow & Ramon, 2020). As part of the national biogas strategy, Sweden uses a decentralized approach to involve municipalities and regions in the decision making process to convert local wastes into biogas to meet local energy demand; this allows Sweden to deliver socio-economic benefits at the local level (Energigas Sweden, 2018). Sweden created a local circular narrative to shape the market involving municipalities, public transport authorities, biogas producers and distributors, technology firms, and researchers; this provides a platform for experimentation and validation critical for biogas development (Ottoson

et al., 2020). Similarly, Italy created regional cooperation. The Italian Composting and Biogas Association provides a platform for bio-waste compost producers to collaborate with local authorities, equipment constructors, research bodies, and innovators (Italian Composting and Biogas Association, 2017). Within the UK, Scotland's devolved government has developed a regional strategy to support BfW schemes. The Scottish Government (2016) has set up biotechnology innovation centers to support biogas growth, develop local business hubs, and fund innovation activities. Zero Waste Scotland supports regional development of the biogas sector by sharing knowledge on waste resources, composition, and availability of feedstocks which is essential in creating a value chain system (Attard et al., 2020). In Scotland, organizations like Zero Waste Scotland and the Industrial Biotechnology Innovation Centre provide platforms bringing together biogas producers, technology providers, researchers, policymakers, and investors (Pitcairn et al., 2017).

The bio-waste feedstock and digestate as biofertilizer are two important streams that must be recognized as part of the value chain to create a viable business case for BfW schemes. Biogas recovery depends on feedstock quality and composition; AD operators must map waste resource availability, price, and logistic costs of feedstocks into their business model. They should also be aware of the market chains of digestate customers and farmers. Transformation of low-valued bio-wastes into marketable end-products requires specific value chain strategies (Donner, Gohier, & de Vries, 2020). Lack of long-term visibility of revenue streams is the main barrier to the economic feasibility of BfW schemes (Reim, Parida, & Sjödin, 2019). The UK government uses gate fees to assign commercial value to bio-waste feedstock and ensure supply continuity. The gate fee is seen as a revenue stream to waste recycling companies; however, the gate fee for UK AD-based Biogas plants has declined since 2015 and was an average of £27/tonne in 2018 and drifted towards the negative side (WRAP, 2019). The continuous decline in gate fees reflects a lower supply of bio-waste (WRAP, 2019). There are significant regional differences within the UK regarding waste collection; England has the lowest household bio-waste collection of around 45% compared to around 70% in the devolved states of Scotland and Wales (Banks et al., 2018; Purnell, 2019). Devolved administrations implemented clear policies for separate household food waste collections (Banks et al., 2018). Scotland amended the Waste (Scotland) Regulations 2012 to improve the food waste collection and legal obligation to ensure that bio-waste is managed to promote high-quality recycling (SEPA, 2016). In England, local authorities hire private companies to construct and operate waste treatment infrastructure; due to budgetary constraints and fiscal austerity, waste collection is a lower priority (Banks et al., 2018; Purnell, 2019). In order to improve biowaste collection, Italy has biowaste separation at a source-target of 65% for municipalities (Italian Composting and Biogas Association, 2017). Local municipalities in Sweden are responsible for waste separation and collection; Sweden has set a national target to achieve a 75% recovery of household biowaste by 2023 (Klakenberg, 2021).

Another barrier to BfW growth is the lack of efficient channels to the bio-fertilizer market (Reim et al., 2019). Despite the growing recognition of AD digestate as a bio-fertilizer, the market is underdeveloped and not defined as a value chain (DEFRA, 2015). AD operators must get through a complex digestate certification process to gain access to the UK market. It is evident that under the present policy regime, the BfW scheme in the UK remains under pressure and lacks long-term viability. AD digestate as a bio-fertilizer can support the circular economy model as it recovers nutrients from biogas feedstocks; this should be recognized as a revenue stream for AD plants but is not yet valued in the UK (ADBA, 2020). Therefore, policymakers must understand the business potential of the AD process, re-calibrate their policies to commercialize the products, and attract investors (Malinauskaite et al., 2017). Sweden has introduced quality assurance regulation for biofertilizers to provide market access for digestate. In 2016, more than 2 million tons of biofertilizer were produced from AD plants and farm waste (Energigas Sweden, 2018).

6. Conclusions and Recommendations

We used a cross-country comparison to understand demand-side policies required to create a diffusion of BfW schemes in the UK. We compared the UK with other European countries like Sweden, Denmark, and Italy, which predominantly use the biowaste feedstock for biogas generation. To maintain comparability between countries, we did not include Germany who uses a significant portion of energy crops as feedstock. We observed two distinct features; firstly, the UK's gas market is centralized and controlled by six large companies who sell carbon-neutral gas based on the carbon offset principle without creating actual demand for biomethane. Therefore, the gas market results in an oligopoly. Second, to reduce the subsidy burden, the UK abruptly moved away from price-based policy instruments to quantity-based instruments without effectively addressing market externalities. Policy continuity and stability are considered key for biogas development; studies have noted that volatile and unpredictable policies are the most significant barriers to developing biogas sector (Gustafsson & Anderberg, 2019). In contrast to the UK, countries like Sweden, Denmark, and Italy aim to replace natural gas with biomethane

in the transport, home, and electricity sectors through long-term policy interventions. Also, Sweden, Denmark, and Italy use demand-side policies to create a market pull for biomethane. Biogas production and utilization involve multiple departments such as waste management, climate, agriculture, electricity, heat, transport, and industry. Policy coherence across multiple departments is essential; supportive policies in one sector could become ineffective when combined with policies in other sectors. Hence, policymakers must take a holistic view to create coherence between policies and instruments across different sectors (Zhu et al., 2019). We observed Sweden and Denmark using biogas sector-specific policy mix strategies to create coherence and improve policy effectiveness across multiple sectors. Policy mixes in the biogas sector are often dynamic and variable; policies may be withdrawn and re-introduced again or changed over time (Gustafsson et al., 2019).

The UK shifted to market-driven policies to reduce energy prices through competition; this change saw large-scale diffusion of matured technology like wind and solar power. However, this shift was detrimental to the biogas sector, which is less developed and contains unaccounted externalities. Policymakers should develop a policy mix strategy to address market failures for widespread diffusion of BfW in the UK. We make five recommendations for UK policymakers to address market failures and incentivize the BfW scheme appropriately to achieve a net-zero target by 2050. First, the biogas sector in the UK is currently concentrated around the heat and electricity sector; policymakers must rapidly increase biogas use in the transport sector. Second, policymakers must create a green gas label and link domestic and industrial users with the market through tradable green gas origin certification. Third, policymakers should make biomethane competitive with other fuels such as natural gas by applying a carbon tax. Fourth, we recommend that policymakers take a participatory approach and act as a change agent to improve the market demand for biomethane using regional clustering and local cooperation. One way to improve consistency, credibility, and comprehensiveness of policy mix strategy is to have policy learning and feedback. Last, we recommend biogas policymakers in the UK overcome policy impediments through consultation and negotiations.

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