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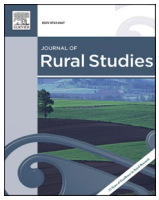

Rural innovation and the green transition: The role of further education colleges

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ABSTRACT

Further Education Colleges (FECs) have been undervalued in discussions of regional innovation, despite their critical role in providing vocational and educational training. This paper argues that FECs in rural areas may be well positioned to lead innovative responses to contemporary challenges, such as those posed by the green transition. The paper focuses on the potential of rural FECs to facilitate transformative innovation. It presents a case study of an FEC in Carmarthenshire, Wales (UK), seeking to identify ways to manage slurry for the benefit of the environment and society. It contributes by illustrating three integrated mechanisms by which rural FECs can develop solutions to the green transition: (i) aligning agendas for innovation and skills development; (ii) orchestrating distributed leadership; and (iii) creating experimental regulatory spaces. The findings highlight the potential of FECs to make a greater impact on the rural economy and contribute towards solutions for grand challenges facing society.

1. Introduction

Further Education Colleges (FECs) have been acknowledged as important providers of vocational and educational training with strong links to regional employers (Hodgson and Spours, 2019; Toner and Woolley, 2016). Yet despite their critical role in education and skills, FECs have been sidelined in discussions of regional innovation, often overshadowed by universities and entrepreneurial firms in rural areas (Charles, 2016; Salomaa et al., 2023). This perception has led to FECs being characterised as Cinderellas[1] of regional development, implying that they have little or no role in the innovation process (Norton, 2012). But recent research has begun to challenge this view. Some researchers argue that FECs can provide significant skill inputs into the innovation process (Nelles et al., 2022; Toner, 2010), whereas others suggest that FECs have the potential to make a greater contribution to the social and economic renewal of places (Buchanan et al., 2020).

The context for these revisionist conceptions is the urgent need to address climate change and find transformative responses to grand social and ecological challenges (Coenen and Morgan, 2020; Moritz et al., 2022). Such developments highlight the systematic and complex nature of grand challenges and call for transformative innovation responses that seek to produce systematic changes (Schot and Steinmueller, 2018). This presents a particular dilemma for rural areas, where concerns have been raised that they may fare worse than urban areas in responding to the challenge of developing a sustainable approach to growth, as denoted by the concept of the green transition (OECD, 2021; Rodríguez-Pose and Bartalucci, 2023). Yet, while FECs have been identified as playing a role in developing the skills required to support the green transition (Simmonds and Lally, 2024; Toner and Woolley, 2016), it remains unclear whether they are equipped to contribute through innovation activities.

The purpose of this paper is to examine the role and outcomes of rural FECs in harnessing transformative innovation in response to the green transition. We draw on the concept of experimentalism, as a component of transformative innovation, to analyse the potential of this role in rural innovation (Bulkeley, 2023; Sengers et al., 2019). Experimentalism has been identified as a place-based and temporal approach to transformative innovation (Evans et al., 2016). This represents an approach to innovation in which local actors work together to identify and develop solutions to societal and ecological problems through experimental trial-and-error processes (Coenen et al., 2010). While the view that rural areas represent innovation laggards relative to urban areas has been increasingly challenged (Bosworth et al., 2016b; Charles, 2016; Shearmur and Doloreux, 2016), the potential for transformative

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[1] The Cinderella metaphor reflects the lack of government and research attention given to FECs as drivers of rural development and innovation activity.

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innovation is less clear. To this end we examine the potential for experimentalism to be adopted in support of the development of innovative approaches to rural challenges.

We illustrate our ideas through an inductive case-study of a rural FEC seeking better solutions to slurry management in Carmarthenshire, Wales (UK). Slurry, a by-product of dairy farming, has been identified as a major contributor to river pollution in rural areas, and has been subject to growing regulatory conditions placed on farmers (Department for Environment Food and Rural Affairs, 2023), as well as tensions among the farming community about their implications for the sector (Senedd Research, 2022). The case-study examines a series of experimental actions established by the rural FEC to better manage slurry and its effects, with partners over a six-year period.

Our findings highlight three integrated mechanisms through which rural FECs can harness experimentalism to catalyse transformative responses to the green transition challenges facing in rural areas: (i) aligning agendas for innovation and skills development; (ii) orchestrating distributed leadership; and (iii) establishing experimental actions. These mechanisms can help FECs produce important innovation outcomes to address rural challenges, such as new products, processes, and skills of current and future farmers. They illustrate the potential role of FECs in harnessing regulatory actors as part of experimental innovation activities. These mechanisms complement FECs' skills development activities (Nelles et al., 2022; Toner and Woolley, 2016) and represent important processes for rural FECs lacking expertise and capacity and provide a route through which outcomes can be validated and disseminated. This potential is not without difficulty because FECs, like other public services in the UK, face ongoing austerity that may impede the sustainability of their activities.

The remainder of this paper is organised as follows. We begin by considering the literature on innovation in rural areas and the role of FECs and introduce the concept of experimentalism. We then examine the results, illustrating how rural FEC experimental innovation actions unfold over time. This is subsequently discussed, and conclusions are drawn regarding the role of rural FECs in orchestrating innovative responses to the green transition.

2. Rural innovation and further education colleges

Rural areas are often viewed as laggards relative to dynamic urban areas, lacking dense interactions, sources of specialist expertise, proximate access to markets, and comparatively poor infrastructure (Bosworth et al., 2020a; Johnston and Prokop, 2021; Shearmur, 2017). The nature and scale of innovation in rural areas has, however, begun to be reconsidered (García-Cortijo et al., 2019; Makkonen et al., 2020). This highlights that rural areas might be able to excel in certain types of innovation, such as social innovation (Bosworth et al., 2016b; Castro-Arce and Vanclay, 2020), and that such innovations may emerge more slowly in peripheral areas (Shearmur and Doloreux, 2016). Others have argued that rural areas far from core urban areas can provide ideal environments to shield the emergence of innovations from early competitive challenges (Grabher, 2018).

While firms have been viewed as the primary agents of innovation in rural and urban areas (Doloreux et al., 2023), the potential for a wider cast of actors to engage in rural innovation is now being recognised (Chen et al., 2022; Guerrero-Ocampo et al., 2024), drawing attention to the role that universities and grassroots civil society actors can play in developing place-based innovation projects (Charles, 2016; Salomaa et al., 2023). Comparatively little attention, however, has been paid to FECs in this context (Nelles et al., 2022), where they have been described as having a Cinderella status relative to knowledge-intensive institutions, such as universities (Norton, 2012). FECs have, however, an important role in the diffusion of technical and vocational skills through courses and apprenticeships (Hodgson and Spours, 2019). This enabling role for innovation is particularly relevant to FECs because of their strong focus on the needs of local industries and students (Toner, 2010).

Their role in contributing to the wider functioning of an economy has also been noted, with economic impacts on wages, jobs, and wider productivity generated as a result of their activities (Department for Business Innovation and Skills, 2011). This, alongside their links to the wider skills agenda in their regional context, suggests that they may also have an 'anchor' status in such settings through their economic impact and leadership links to industry (Nelles et al., 2022; Senior and Barnes, 2023).

FECs in rural areas have been identified as playing an important role in rural development, with some focusing on specialist agricultural skill development activities (O'Donoghue and Heanue, 2018). Here, land-based FECs can support the development of farming skills, including the modernisation of farm practices (Clifton et al., 2020). The broad diversity of FEC operational models (Nelles et al., 2022) and the lack of homogeneity in rural areas (Bosworth et al., 2020a; García-Cortijo et al., 2019) further suggest that they may be able to support sectors beyond farming. However, while FECs have been found to have strong linkages to local industries and skills stakeholders, they have not been viewed at the forefront of novel forms of technological innovation.

It has been argued that FECs may play a stronger role in addressing ecological challenges through the development of green skills (Toner and Woolley, 2016), defined as 'the knowledge, abilities, values and attitudes needed to live in, develop and support a society which reduces the impact of human activity on the environment' (Simmonds and Lally, 2024, p. 1). This challenge is particularly acute in rural areas, with the presence of 'climate sensitive resources' (land and rivers) (Guyadeen and Henstra, 2023, p. 123). It has been argued that rural areas face the risk of greater vulnerability to the effects of the green transition, with the potential for discontent to emerge (Rodríguez-Pose and Bartalucci, 2023). FECs are, however, in a 'significant position to make use of environmental innovations, e.g. in energy, agrifood or in transportation sectors, and to provide feedback effects on the further development of green technologies' (Losacker et al., 2023, p. 308).

Although the potential of FECs to contribute to green skill development and wider innovation objectives has been recognised, it is less clear whether they can play a more direct and catalytic role in the green transition (Toner and Woolley, 2016), where social, ecological, and technological innovation have been highlighted as important grand challenges facing society (Coenen and Morgan, 2020; Schot and Steinmueller, 2018). In supporting innovation, it has been argued that FECs may be able to harness pre-existing assets and cultural support for innovation that may be attractive to partners, such as providing access to business infrastructure and equipment (Department for Business Innovation and Skills, 2011). As Nelles et al. (2022)'s literature review suggests:

> 'These infrastructural assets can be useful in attracting business partners, who may then be willing to extend their relationships with the FEC to setting up apprenticeships, providing work study experience, or encouraging them to invest in shared equipment and develop training programmes' (p. 27).

The role of financial support from government has been highlighted as an important factor in the potential for FECs to contribute to innovation activities (Toner and Woolley, 2016), with national and regional policymakers in the UK introducing dedicated funds to support FECs to innovate (Peacock, 2024; Welsh Government, 2023). However, while calls for FECs to play an enhanced role in their local economies have grown, they have also faced sustained cuts in the UK through austerity (Augar, 2019; Lewis and Bolton, 2023). Their focus on vocational 'mass market' education and training may also present limited opportunities for FECs to engage outside their core remit (Curtain, 2004). This brings their role in transformative innovation into question, limiting both staffing and capacity to engage relative to universities (Toner and Woolley, 2016).

Notwithstanding budgetary and capacity issues, FECs have been

encouraged to work with external partners to support the innovation process (Moodie, 2006). This approach has been adopted in wider place-based community development activities in rural areas, highlighting the deliberative foundations of rural innovation and its context-specificity (Connelly et al., 2006). This has been reflected in the concept of neo-endogenous development, where rural development priorities are addressed by integrating local knowledge and resources with external support to maximise rural development (Bosworth et al., 2016a, 2020b; Gkartzios and Lowe, 2019). Such processes have been identified in a range of local action and local development strategies (Bosworth et al., 2016b; Galliano et al., 2019). It may offer FECs a more collaborative route to supporting innovation activities alongside other public and private organisations to address shared innovation challenges, such as those associated with the green transition.

2.1. Transformative innovation and experimentalism and in rural areas

Transformative innovation has been identified as an approach to addressing grand challenges such as those arising from the green transition. It seeks to move beyond the traditional focus of innovation on economics and growth through a greater focus on innovation to facilitate solutions to urgent social and ecological challenges (Moritz et al., 2022; Schot and Steinmueller, 2018). It draws attention to the direction of innovation actions and the importance of the role of government, firms, and grassroots civil society in innovation efforts (Tödtling et al., 2022). Although much attention has been given to the national and international nature of social and ecological grand challenges, research has also highlighted the potential for localised responses to be developed that meet the needs of local citizens and firms, and offer the prospect of addressing such challenges (Bours et al., 2021).

Experimentalism has been identified as a central concept in the transformative innovation literature (Ghosh et al., 2021; Loorbach et al., 2020; Schot and Steinmueller, 2018), where it represents an approach to testing and developing responses to grand challenges (Bulkeley, 2023; Sengers et al., 2019). Such challenges draw attention to the importance of the directionality of innovation and its role in addressing urgent social and ecological problems (Schot and Steinmueller, 2018; Uyarra et al., 2019). Experiments are said to be particularly relevant to such challenges, where uncertainty and ambiguity are pervasive and multiple potential solutions are present (Sengers et al., 2019).

While the transformative innovation literature has explored the governance arrangements associated with experimental actions, it has also examined their role in developing and testing innovative responses that have the potential to be scaled (Bulkeley, 2023). Experimentalism also calls for actions that go beyond the lab to develop societal and ecological innovations based on actual practices (Schot and Steinmueller, 2018). Sengers et al. (2019) point to the potential of experimental innovation as a challenge-driven mode of learning-by-doing oriented towards system change. Here, experiments can help avoid repeating past mistakes (Bulkeley, 2021), and support actors in learning about potential solutions, but also the experimentation process itself (Evans et al., 2021). While the literature points to the promise of experimentation to develop and trial innovative solutions through iterative action, as well as wider institutional change, it also calls for participants to acknowledge the potential for failure (Meyer, 2023).

The role of place in such experiments is an emerging area of enquiry (Coenen et al., 2012). Sengers et al. (2019) identify it as a place-based practice that can be harnessed to address everyday problems and challenges faced in places. This calls for action to be inclusive, drawing together multiple stakeholders from firms, governments, universities, and wider civil society. Limitations are, however, recognised in the challenges of scaling successful innovative responses, which is important for achieving grand challenge aims. Social and ecological innovations may also require disruptive actions that destabilise existing activities (such as pollution or high carbon emissions) (Kivimaa et al., 2017). These limitations have led some to question the promise of experimentation, with concerns raised that short-term experimental actions can avoid urgent and pressing challenges and promote a linear, sequential approach to managing innovation actions (Leminen et al., 2012).

Much of the transformative innovation literature, however, adopts an overtly urban focus, viewing experimentation in the context of city responses to grand challenges. Here, the city offers spaces for experimental actions such as living labs, maker spaces, and hackathons (Bulkeley, 2023; Evans et al., 2016). In contrast, the potential for experimentation to provide the basis for innovation in rural areas has been underexplored. However, rural areas are at the forefront of social and ecological challenges (de Boon et al., 2024; Guyadeen and Henstra, 2023). While they may lack the density of interactions, infrastructure, and expertise in dynamic urban areas (Bosworth et al., 2020a; Johnston and Prokop, 2021; Shearmur, 2017), there is growing evidence that they may harness rural resources and assets to support innovative activities (Bosworth et al., 2016b; Grabher, 2018; Shearmur and Doloreux, 2016). This paper seeks to respond to the calls for research to better understand the potential for rural actors and organisations to respond to innovation challenges such as the green transition by examining the role of FECs in experimental innovation actions. While lacking resources and capacities to undertake innovation activities independently, rural FECs may be well placed to work collectively to harness transformative innovation and harness experimentation to test and develop innovation responses to grand challenges. In other words, their position as anchor organisations in rural areas may enable them to work with partners to overcome their limitations through recursive problem-solving action over time. However, the extent to which can engage in such processes, given their resource constraints, remains unclear. This paper thus seeks to address the following questions: How might FECs be able to harness experimentalism to address green transition challenges facing rural areas? And what outcomes can such processes achieve?

3. Study area and research design

3.1. Study area

This study examines FEC innovation activities in Carmarthenshire (Wales), a largely rural area characterised by 61% of the population living in rural wards, as well as a comparatively greater population over the age of 65 than elsewhere in Wales (Carmarthenshire Rural Affairs Task Group, 2019). Part of the wider Swansea Bay city region (Bowen and Webber, 2024) Carmarthenshire has several towns in its southern periphery surrounded by rural areas. Employment in foundational sectors including agriculture, education, health, retail, forestry and fishing all exceed the Welsh averages. Dairy production is particularly significant, with over 470 dairy producers (28% of all Wales producers) (Carmarthenshire Rural Affairs Task Group, 2019). This corresponds to some 193 thousand cattle and calves, making it Wales' second largest herd (after Ceredigion).[2] The size of the dairy herd has grown in recent decades, along with greater progress towards intensification in dairy and meat production and the corresponding decline in horticulture (Wright and Cook, 2021). These trends have identified agriculture as a significant source of excess nitrogen in the environment, 'acting as both (potential) fertiliser and abject organic waste' (Gesing, 2023, p. 2). The county is also home to Wales' longest river, River Tywi, and a range of significant tributaries, making it an important resource for drinking, food and other crops, industry, and leisure. It has been identified as having elevated levels of phosphates and nitrites, exceeding the limits of a healthy river system (Lewis, 2024).

The topic of slurry and water quality has been of growing interest among academics (Gesing, 2023; Stiles, 2018; ten Hoeve et al., 2014),

[2] https://statswales.gov.wales/Catalogue/Agriculture/Agricultural-Survey/Area-Survey-Results/total-livestock-in-wales-by-area.

politicians (Senedd Research, 2022), and grassroots civil society organisations in Wales and the wider UK (SS-1, I-7; I-10, II-14). While slurry can support soil health and crop growth, it has also been recognised as a contributor to agricultural pollution, reflecting its 'ambiguous' properties and tensions surrounding its use (Gesing, 2023). Such problems have become increasingly evident in Wales, with growing rainfall due to climate change, as well as the mechanisation of slurry spreading, exacerbated by overspreading (SS-2). Indeed, over 60% of Welsh rivers have been found to be below river water quality targets (Welsh Government, 2022). Managing slurry can also present practical challenges to farmers, such as the costs of housing it (Stiles, 2018). In this context, the Welsh Government introduced new regulations in 2021 – The Water Resources (Control of Agricultural Pollution) (Wales) Regulations (SS-3), limiting the months in which farmers can spread slurry on their land, and setting an annual holding limit on the application of nitrogen from livestock manure.[3] These regulations become an increasingly important political issue among farming groups, with an (unsuccessful) legal challenge brought by a farming union.[4] In response, the Welsh Government sought to mitigate concerns by providing additional support to farming and encouraging technological solutions to agricultural pollution problems (2022).

The study area is further characterised by complex multi-level policy arrangements, with the Welsh Government responsible for priorities such as economic development, the environment and natural resources. This includes responsibilities for water resources and quality regulations in the region, with regulatory enforcement undertaken by the national regulator, Natural Resources Wales (NRW). The Welsh Government is also responsible (along with the UK Government) for supporting innovation in the region through its economic development responsibilities. Carmarthenshire County Council is the municipality in the region and is responsible for the protection and enhancement of biodiversity in the planning system (Sellick, 2014), providing public services to residents and supporting local sectors and challenges faced by the region.

The focus of this case study is on the activities of a rural FEC, Coleg Sir Gar, and its efforts to address the challenges associated with river quality and livestock slurry. Coleg Sir Gar has some nine thousand students in Carmarthenshire, and offers a broad-based further education offer to adults and community learners. Its Gelli Aur campus provides land-based and agricultural engineering studies, incorporating a 211 ha farm adjacent to the river Tywi, with a dairy herd of more than 400 cows and sheep. Further Education in Wales has been increasingly challenged to move beyond its traditional role of vocational education and training provision to 'become a key institutional support of a more ambitious project, as an enabler integrating those delivering Welsh economic and social renewal' (Buchanan et al., 2020, p. 7). Moreover, FECs, like other public sector organisations have an important role to play in addressing the Welsh Government's policy priorities for the sustainable management of natural resources (National Assembly for Wales, 2016).

3.2. The research design

The research adopted a single case-study design to examine the role of FECs in innovating to support the green transition. It was selected as an illustrative case of a rural FEC embedded in the regional setting of Carmarthenshire, seeking to innovate to address green transition challenges through local action. The case-study approach is well established in rural studies of innovation (Georgios and Barraí, 2023; Toffolini et al., 2021) and allows for intensive collection of in-depth information about activities and processes (George and Bennett, 2005). Single case-studies have been identified as a way to test and develop causal mechanisms, as well as allowing sensitivity to contextual factors (Flyvbjerg, 2011). They can also provide the basis for an inductive research approach, enabling analytical concepts to be drawn from case insights (Yin, 2018). The research adopted a single case-study approach to identifying the causal mechanisms by which FEC's can develop innovation in support of green transition challenges.

The case-study draws on a total of twenty interviews undertaken with the FEC and its stakeholders, including public, private, and grassroots civil society organisations (see Supplementary Information). All interviewees were selected based on their in-depth knowledge of the case as well as those with a greater understanding of the policy context of both FECs and the green transition. Interviews were also conducted with representatives of farmers and water and biodiversity groups to provide an understanding of the case from multiple perspectives. Several interviews were conducted more than once to capture the longitudinal development of the innovation activities. Interviewees were identified through a snowballing process (Bryman, 2016), beginning with a number selected from the authors' earlier research for the region's Innovation Strategy (Morgan et al., 2022), with informed consent secured from the participants. Interviews were transcribed and coded by the first author. In addition to the interviews, the research incorporated a review of secondary sources including project reports, monitoring data, and policy statements (see Supplementary Information). Thematic analysis was then undertaken by the authors, and themes were identified inductively (Bryman, 2016). The coding framework can be found in the Supplementary Information.

4. Findings

Coleg Sir Gar has a long history of seeking to play an active role in the wider business community (I-1, I-12). As an important institution in its surrounding area the Senior FEC manager noted:

> 'we employ close to 1000 people … we're very much the 'go to' learning institution, certainly for post 16 … and I would say most definitely, we have a civic mission, which universities have as well [but with] a far closer working relationship employers than a university does' (I-12)

While vocational education and teaching account for the majority of the FEC's activities, it had developed a small research centre - The Agricultural Research Centre based at its Gelli Aur campus delivers applied demonstration and knowledge transfer projects focused on the agriculture sector (I-1; I-13). Project Slurry represented a step change in these activities, with a greater focus on developing a novel technological solution for the green transition, and working with partners to commercialise these. This built on the FEC's role as both a vocational skills provider and farm operator, and its recognition that it had an important role to play in addressing the deterioration of water quality associated with slurry. To this end, it sought to work with a wider range of funding sources and partners to address significant ecological challenges facing rural areas of Wales. With the support of the FEC's senior management, FEC staff developed proposals to harness the skills and natural resources of the FEC (the farm, located adjacent to the river Tywi) and sought funding to address an important challenge facing rural Wales (S-4). The FEC's interests in developing these solutions were not to develop and exploit intellectual property (IP). Instead its aim was to connect the technological solutions to its education and skills agenda and address the systematic nature of the challenges. As the FEC centre manager noted (I-13):

> 'So we were trying to jigsaw the partners and jigsaw the technologies, and then find solutions to the problem parts of the chain that didn't have a solution: electronically, chemically, or physically, just to end up with more concentrated manure and technically clean,

[3] Guidance and rules had also been established in areas of England (https://www.legislation.gov.uk/uksi/2018/151/made) and Scotland (https://www.gov.scot/publications/prevention-environmental-pollution-agricultural-activity-guidance/).

[4] Similar concerns had been raised by farmers in other countries (see SS-4).

reusable water. So we're not quite in the IP world, we're more in the finding a solution to a problem for the agricultural dairy sector.'

It also addressed the growing tensions, evidenced in the concerns raised by farming unions that the regulations were counter to the interests and needs of farmers in Wales and under emphasised the significant sources of other contributors to the water pollution challenges facing the region (SS-1). This represented a complex and challenging setting in which the FEC manager began to formulate plans for the project and identify partners that shared its objectives to develop slurry treatment technologies with the aim of limiting the potential for pollution. Indeed it recognised that it may be able to help to manage these tensions by convening partners from the farming sector, technical experts, regulatory bodies and environmental groups to develop a solution that would address multiple needs, including tourism, economic benefits, river system biodiversity, and fish stocks (I-1).

4.1. The experiments and outcomes

The first experiment set out to establish slurry treatment on the farm, with the help of the commercial partner, to assess the potential for it to be separated from water, producing a dried slurry ('cake') and clean water suitable for use on farms or for return to the river. This sought to maximise the potential to reduce the costs of farm slurry storage and handling and to increase the recycling of nutrients (and reduce the corresponding costs of fertiliser). The project therefore aimed to produce both ecological and commercial value for project partners and farmers in Wales. Initially, funded through the Welsh Government's Rural Communities Rural Development Programme (2014–2020) the FEC manager of Project Slurry worked with a local company (Power and Water Ltd, Swansea), to examine two potential solutions for separating slurry from water: a traditional screw press filter and an innovative separation process. While mechanical separation technologies are well established (Hjorth et al., 2011), the novel aspect of the technological solution was the recombination of technologies - power ultrasound and electrolysis for water treatment (Stiles, 2018). The initial results of the first experiment, however, suggested that the electrolysis technology used in the separation decanter could not separate the slurry effectively. This led to the FEC managers introducing a chemical-based treatment, resulting in a much greater separation rate, with these findings and proposed course of action reported to the funding agency.

The second experiment emerged from a chance meeting between the former Vice Principal of the FEC and a member of the Welsh Government's innovation advisory team (I-8). The innovation advisor felt that the initial experiment (1) had the potential to achieve commercialisation and encouraged the FEC to submit a bid to the Welsh Government's funding for innovation projects (Smart Expertise), the success of which led to the college becoming the first FEC to receive funds from this source. The focus of the project was to further experiment with the efficiency of the treatment process, but also to seek a more efficient solution to cleaning the extracted water ready for discharge into the watercourse. This included the construction of a wetland, with reed beds helping to further reduce the levels of pollution, and meet the Wales Bathing Quality Water Standards (S-5). The FEC sought to work with a wider range of partners from the technology sector and the regulator (NRW), reflecting the growing tensions associated with agricultural pollution of water resources (SS-6). NRW's inclusion in the experiment was initially to provide testing services for the treated water, but it increasingly saw the potential to learn from the project, with a view to future regulatory developments (I-4). As the NRW manager noted, 'we wanted to work towards [the efficient treatment of slurry] because it can't just be regulation … we need to work collaboratively' (I-4). The NRW manager also noted that its involvement was to work with regulators in England to share their experiences with such solutions and their regulatory implications. In contrast, the commercial partner viewed the technology as an excellent opportunity for them to receive expertise and financial support, and "get on the front foot" and refine their product (I-5). Indeed, the company utilised the site as part of its sales process, encouraging potential clients to visit and see the operation of the technology firsthand. Subsequently, the FEC and its partners sought to disseminate the results of the project more widely, including hosting a range of visits to the farm, with interest generated from farmers and regulators (I-4). Indeed, the commercial partner (GEA) was subsequently able to secure six sales of the slurry separation technology to customers in Wales and England.

The third experiment was developed by NRW, Dŵr Cymru Welsh Water (a not-for-profit water company) and the FEC, and sought to engage farmers in introducing slurry practices to reduce agricultural pollution. Here, the partners recognised the limitations of a technology-led solution and aimed, as a result, to place a greater focus on behaviour change in their experiments. Funding was subsequently secured from the NRW Four Rivers for LIFE project, working collaboratively with the FEC. The aim of the experiment was to 'help farmers manage how they work around predicted weather conditions' (SS-5). This enabled partners to install six 'weather stations' on farms in the catchment area of the River Tywi. These weather stations were low cost and were able to provide information on weather conditions, soil moisture and soil temperature 'allow [ing] the farmer to apply nutrients to the land at the right time for optimum growth and lower the risk of excess nutrients entering the river' (SS-7). The FEC's input was to broker links and secure funding for the creation of an app that would take data from the weather stations and to make this available to a wider range of farmers. The app was developed by a local IT specialist (Vindico, Llanelli) and had been distributed to some 210 farmers at the time of the research (I-1). The Dŵr Cymru Welsh Water manager noted that it had also helped farmers prepare for the new agricultural pollution regulations by providing evidence about when it was safe to spread slurry.

The responsibility of Dŵr Cymru Welsh Water lies in providing water to households and business users. While its role did not concern slurry directly, its responsibility for the importance of drinking water quality meant that it was interested in limiting the costs of processing/purifying water prior to delivery to customers. In managing the project, the project manager of Dŵr Cymru Welsh Water highlighted its approach as one that relied on a flexible approach to leadership: 'sometimes we can be supporting their projects because they have a positive impact on water. Sometimes we might be wanting to lead because we want that to change practice or whatever' (I-6). Such an approach was particularly relevant to Dŵr Cymru Welsh Water because it owned only a small proportion of land in the catchment area, leading it to seek opportunities for partnership. This was equally recognised by the FEC's Centre manager who noted that while for many of the projects it had been in the lead, it was '… also aware that sometimes being a good part of a bigger team is also a great position to play' (I-13). This reflect the willingness of the FEC and its partners to adopt a shared approach to leadership in the experimental activities.

The Dŵr Cymru Welsh Water manager recognised that there was a need to raise awareness among the farming community. It subsequently sought to work with local farming groups, such as Young Farmers,[5] to introduce them to the weather station data and the possibilities of managing water resources through this means. This represented a demand-side approach to address the challenges of agricultural slurry in the watercourse, and was one that partners, notably the farming unions, supported and made use of in their lobbying for the sector. It enabled them to make the case that the weather station data could be harnessed by farmers and slurry contractors to inform the spreading of slurry, contrasting this with what they saw as 'broad brushed' regulatory conditions placed on farmers (I-7).

While the commercialisation of the slurry treatment technology and

[5] Although it was recognised that raising digital skills amongst the older farmer population was likely to be more challenging.

the activities to support behaviour change had begun, the FEC manager began to explore the potential for regional treatment hubs that would offer farmers an alternative mechanism for processing slurry away from their farms. While the NRW expressed interest in the potential for such a solution (I-4), they were also concerned that it faced substantial regulatory hurdles associated with the biosecurity of farm waste, designed to reduce the potential for diseases to spread (cf. foot and mouth, some decades earlier[6]). Additional concerns were expressed that despite the potential benefits of the technology to farmers (in managing slurry and producing slurry-based fertiliser), the ongoing intensity of farming and slurry spreading practices could still see an increased risk of runoff to rivers, particularly in areas of steep topography (I-15, I-16). That is, the benefits of the technologies remained contested when viewed in the context of challenges of climate change and the dominant model of agriculture in the region.

The connection of the project activities to the wider vocational and skills agenda represented an important outcome for the FEC. Across each of the experimental stages the FEC made use of the facilities for vocational education purposes. By educating FEC students about the safe treatment of slurry the FEC was able to link the technology development to important challenges that prospective farmers are likely to face in their careers. Indeed it was noted by the FEC centre manager that the connection to the vocational education of students was an important rationale for the experimental activities, providing opportunities for students to engage with practical farming challenges. Examples of learning, here, included students being challenged to identify solutions to river water pollution, and comparing this with the FEC's own response, 'they'd critically analyse our thinking, and we challenge them on their suggestions and learning processes through open dialogue' (I-13).

The experiments established as part of the FEC's innovation activities are summarised in Fig. 1. While presented as a sequential linear process, feedback loops were present between the different experiments, reflecting the iterative learning that characterises experimental processes, with results reflected on in the peer review process (on submission of project reports to funders).

5. Discussion

While FECs have often been viewed as Cinderellas in regional development processes (Norton, 2012), our findings suggest that they can play a more catalytic role in regional innovation than previously recognised. In the context of the growing urgency of the green transition and the challenges it presents to rural regions (OECD, 2021; Rodríguez-Pose and Bartalucci, 2023), the role of FECs in innovative responses is potentially significant, given the lack of dense networks of entrepreneurial firms relative to urban areas. Additionally, the focus of this innovation activity on addressing a mundane but important topic, such as slurry, highlights the importance of innovation in addressing rural place-based problems.

The role of FECs in vocational education and skills for innovation has been acknowledged in the literature (Nelles et al., 2022; Senior and Barnes, 2023), alongside calls for them to play a much wider role in driving social and economic renewal (Buchanan et al., 2020). Our results suggest that they can contribute to these calls by actively harnessing transformative innovation to address green transition challenges, in particular by leveraging experimentalism. FECs are well placed to convene actors around such processes to tackle rural challenges and to innovate iteratively, thanks to their position as anchor organisations and a degree of independence in their rural context. This iterative approach to innovation is recognised as being well suited to addressing grand challenges such as those associated with the green transition (Sengers et al., 2019; Suitner et al., 2022). In contrast to the urban focus of much of the experimentalism literature (Bulkeley, 2021; Evans et al., 2016), our findings indicate that experimentalism may be particularly relevant to rural FECs that do not have sufficient expertise or resources to undertake more extensive innovation actions, such as those more typically associated with universities or large firms. Rather, addressing provisional goals through small experimental steps allows for potential solutions to be studied, findings discussed, and new directions adopted in addressing important rural challenges, particularly where potential solutions are complex and uncertain. They also indicate that rural FEC's, harnessing experimentalism, may be able to mediate tensions through this iterative process, by working collectively, incorporating multiple rural stakeholders from within the farming sector, including policymakers and regulators. While this may not fully eliminate tensions between farmers, river users and policymakers the results illustrate how an experimental process can enable partners to develop solutions that address multiple needs.

We highlight three integrated mechanisms through which rural FECs can harness experimentalism to engage in transformative innovation activities to address green transition challenges.

First, *Aligning agendas for innovation and skills development.* FECs represent important vocational and education skills providers in rural and urban areas (Buchanan et al., 2020). Our findings illustrate how they may be able to harness experimentalism to address green transition challenges by aligning their existing skills development agenda with transformative innovation actions. Here, the link between these skills development activities and innovation is well known, with FECs developing many of the technical skills that underpin innovation in firms (Nelles et al., 2022; Toner and Woolley, 2016). Our study suggests that FECs can extend their impact by creating opportunities for students to engage directly with transformative innovation actions within the college environment. In the rural development context, such alignment can significantly harness young minds (e.g., future farmers), providing them with exposure to novel solutions for pressing rural challenges associated with the green transition. This strategy can therefore not only equip students with practical knowledge but can also help to validate and disseminate innovation practices. Furthermore, the potential for amplifying rural innovation through FECs' vocational education and transformative innovation actions represents a more direct and impactful route for addressing rural challenges than previously anticipated in the FEC literature. This alignment of educational activities with real-world innovation actions highlights FECs as critical agents in the rural green transition.

Second, *orchestrating distributed leadership* enables rural FECs to convene partners to address rural innovation activities. As important anchor institutions in rural settings (Senior and Barnes, 2023), with extensive linkages to local industry, policymakers, and stakeholders, FECs are well-placed to harness social relations and respond to the shared urgency of challenges faced by rural actors. While FECs' roles in vocational education, skills, and qualifications are widely acknowledged (Buchanan et al., 2020; Nelles et al., 2022; Senior and Barnes, 2023), our results suggest that they can extend their activities beyond this traditional role to develop a leadership role in transformative innovation activities. This is consistent with the acknowledgement IN NEO-ENDOGENOUS THEORY of the importance of integrating external funding sources and influence with local rural challenges (Bosworth et al., 2016a). It adds to this by highlighting how FECs may be able to share the leadership ROLE over the course of such transformative innovation projects, as evident in Dŵr Cymru Welsh Water's leadership of the weather station project. Adopting a distributed leadership approach allows actors with the most appropriate expertise to lead such activities (Aranguren et al., 2022), which is particularly important for rural FECs engaged in complex transformative innovation projects in the green transition. This mature stance to leadership reflects FECs' potential need to bring in multiple, multi-level forms of expertise (e.g., national government, private enterprise, and grassroot civil society),

[6] https://www.theguardian.com/science/2021/feb/21/foot-and-mouth-20-years-on-what-an-animal-virus-epidemic-taught-uk-science.

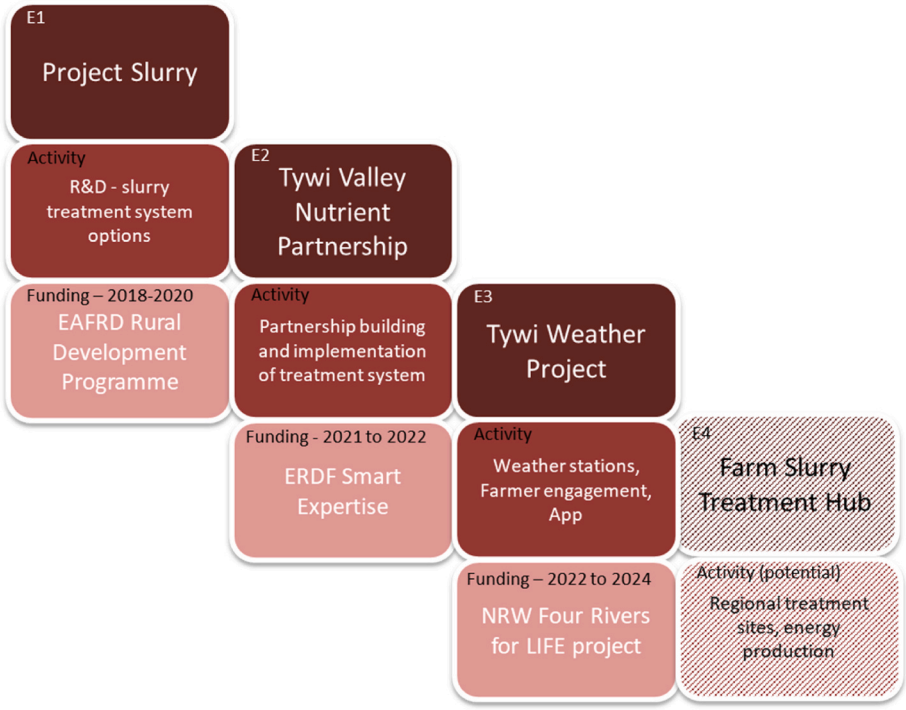

Fig. 1. Coleg Sir Gar green transition experiments. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

helping to mitigate contestation (Wanzenböck et al., 2020).

Third, creating an *experimental regulatory space* can help align innovative solutions to rural challenges with regulatory conditions. This is particularly important in settings where regulatory conditions are important, for example environmental actions. Although regulations have been recognised as constraints to actors seeking to engage in experimental innovation (Morgan, 2018), our findings illustrate how rural FECs may be able to convene spaces of experimentation in which regulatory actors can work alongside the FEC, technical firms, farmers, and grassroots civil society organisations to address the complex, messy, and uncertain challenges associated with the green transition in rural areas. While regulatory spaces or experiments have been effective in digital and financial sectors where regulatory actors test new products by relaxing regulations (Pontikakis et al., 2022), our findings suggest that rural FECs may create bottom-up regulatory spaces where rural actors learn about the effects of innovative actions and evaluate their regulatory implications. This process involves regulators recognising the novelty of the process and adopting a learning approach to understand the possibilities for amending regulations. It contrasts with the traditional enforcement role of regulators and highlights the potential for regulators to adopt an enlightened interlocutor perspective in novel and complex responses associated with the green transition. This does not mean that rural FECs can secure regulatory agreements for innovations, as illustrated by the FEC plans for a regional treatment hub, but suggests a more studied approach to harnessing regulatory dynamics in rural innovation projects. Indeed, such outcomes may play an important role in such projects alongside traditional outputs such as new products or processes.

Although these mechanisms may provide the basis for rural FECs to engage in transformative innovation actions our findings highlight the role of pre-existing links and skills, including prior activities such as technology demonstration and links to regional knowledge intensive firms. They may provide important moderating factors that could potentially shape the ability of a rural FEC to effectively harness experimentalism to innovation in the green transition. This may also require some rural FECs to build such capabilities in advance of such activities, although many may have built up such capabilities as part of their core operational activities (Nelles et al., 2022).

In identifying the rural FEC as an actor capable of supporting transformative innovation processes, we acknowledge the potential financial and capability difficulties it may face, as highlighted by Toner and Woolley (2016). Here, the results suggest that the FEC has established an experimental process to address green transition challenges faced by rural areas. However, sustaining this dynamic presents challenges, especially where FECs do not have the expertise to securing funding and IP benefits. Ensuring change in the wider farming community via the app represents an ongoing challenge, including recognised weaknesses in access to and take-up of digital technologies amongst farmers (Bowen and Morris, 2019; Marshall et al., 2020). Further challenges relate to the regulatory context of developing a regional solution for slurry management problems. While the proposals have generated interest among regulatory and policymakers, regulatory changes can be relatively infrequent and difficult to achieve. That is, although rural FECs may be able to draw the regulator into experimental processes, they lack the power to unilaterally reshape regulations.

6. Conclusions

In this paper we provide evidence of how FECs might be able to play a more catalytic role by harnessing experimentalism to develop solutions to green innovation challenges in rural areas. In doing this we contribute to research that has called for a reappraisal of the nature of innovation in rural areas (Chen et al., 2022; Guerrero-Ocampo et al., 2024) and the role of actors beyond firms and universities. We respond to emerging research that is examining how FECs can play a stronger role in innovation and argue that this may provide opportunities for all regions (Nelles et al., 2022; Toner and Woolley, 2016). We contribute by identifying how FECs can harness experimentalism to engage place-based partners in an iterative approach to learning about potential solutions to rural challenges in a learning-by-doing manner.

Based on a granular case-study of a rural FEC seeking to innovate in response to the challenge of agricultural pollution through the lens of

slurry, we examine the processes and outcomes of these activities. We find that rural FECs might be able to leverage their role as an important regional anchor organisation and harness their infrastructure and natural resources to engage in transformative innovation. Three integrated mechanisms by which rural FECs can support such activity are identified (i) aligning agendas for innovation and skills development; (ii) orchestrating distributed leadership; and (iii) creating experimental regulatory spaces. Through these integrated mechanisms we find that rural FECs can work to produce transformative innovations that address important rural challenges associated with the green transition. Here our findings illustrate how FECs may be able to employ these mechanisms to produce conventional innovation metrics – product/process – and show how they are able to train current and future farmers, and draw in regulatory actors into this process and engage them in experimental learning activities, allowing them to adopt an enlightened stance to the outcomes. These mechanisms may be moderated by the degree to which an FEC has prior knowledge and linkages. Moreover, the outcomes associated with such activities do not mirror those of traditional university commercialisation projects, with a strong focus on IP and equity. Instead, they highlight the FEC's role in seeking to find PRACTICAL solutions to real life challenges faced by rural areas. While our findings highlight the significant but under-researched role of rural FECs in transformative rural innovation, we acknowledge their limitations in such activities, particularly in the sustainability of funding and staffing. These limitations present significant challenges for FECs in light of austerity cuts and the availability of staff able to engage in such activities outside of teaching and management duties.

Our findings also cast light on the mundane, but important topic of slurry, which is an important, but everyday feature of the rural economy and a vital by-product of the farming process (Gesing, 2023; Stiles, 2018). The study highlights how slurry represents a contested concept at the local and national level, with multiple, conflicting interests surrounding its impact on water resource quality. Indeed, while agriculture's role in river pollution through slurry is well established, others have also been implicated in the degradation of water resources, not least the UK water companies and their discharges. The role of slurry as an 'ambiguous' concept is evident in our research, with it representing both an important nutrient to be harnessed to support the quality of soil through effective spreading techniques but also a potential pollutant (Gesing, 2023). The FEC mechanisms identified in this study, however, offer the potential to quell (if not eliminate) the tensions surrounding slurry, but also to manage the ambiguities of slurry in a way that benefits multiple stakeholders in rural areas.

Several research implications arise from our study. First, our findings highlight the role of everyday public services, specifically rural FECs. These institutions operate under varying models with differing contexts, suggesting that exploring the potential role of FECs as innovation actors in other rural settings could therefore help researchers and policymakers better understand the innovation capacity and potential for innovative actions in addressing other grand challenges. Second, our research emphasises the significant role of FECs in engaging regulators, particularly in the context of the rural green transition. Future research should investigate different configurations of authority and hierarchy in rural settings, especially where regulators may act as greater obstacles or favour unsupported solutions. The importance of regulatory capacities may also be found in other domains such as the marine sector, forestry, energy, waste and processing in rural areas. Research in such areas has the potential to address the limitations of a single case-study method by expanding research in different geographical areas and organisational domains. Finally, our findings draw attention to the critical issue of agricultural pollution, specifically slurry management, a highly neglected topic despite its societal significance. Further exploration in this area could provide valuable insights into rural innovation practices, not least in better understanding their ambiguous nature and how potential conflicts can be managed. By addressing these areas, future research can build on our findings to further understand and enhance the role of rural FECs in driving transformative innovation in the green transition.

CRediT authorship contribution statement

Dylan Henderson: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Kevin Morgan:** Writing – review & editing, Investigation, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jrurstud.2025.103565.

Data availability

The authors are unable or have chosen not to specify which data has been used.

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