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Challenges and opportunities for decentralised water technologies in Scotland

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ABSTRACT

The paradigm of centralised water and wastewater services is coming under significant pressure from multiple global factors. Therefore, there is a need to consider the challenges and opportunities for decentralised water and wastewater technologies and systems. This search is particularly relevant within the context of Scotland, where a proportion of the population uses existing decentralised technologies. The Scottish context shows that those using decentralised services struggle to manage their water and wastewater services without appropriate support. However, the global goals of universal access to safe water and adequate sanitation, a just transition to net-zero and community empowerment, provide opportunities and policy pathways towards the implementation and improvement of decentralised technologies and systems.

Key words: Decentralised technologies, Policy, Scotland, Sustainable development, Wastewater, Water

HIGHLIGHTS

- Decentralised water and wastewater systems provide an alternative to traditional carbon-intensive centralised infrastructure.
- Challenges with existing decentralised systems in Scotland are a rural issue due to historical factors.
- Opportunities for improvements to the management of decentralised systems are universal access to water and sanitation, a just transition to net-zero and community empowerment.

INTRODUCTION

The development and implementation of centralised water and wastewater services have been significant achievements of the 19th and 20th centuries, which have led to improved public health and a higher standard of living for those who have access to them (Kiparsky *et al.*, 2013). However, centralised water and wastewater systems are coming under significant pressure due to the global trends of population increases, rising levels of urbanisation and the manifold effects of climate change. Further, the existing paradigm of centralised water and wastewater services is being challenged due to its high carbon, energy, and water footprint (Hering *et al.*, 2013). This has resulted in calls to move away from traditional centralised approaches, and towards decentralised technologies and modes of governance (Makropoulos & Butler, 2010; Rijke *et al.*, 2013; Poustie *et al.*, 2015). Therefore, there is a need to explore the existing challenges in relation to, and future opportunities for, decentralised water technologies and their related governance systems.

The distinction between centralised and decentralised water and wastewater systems is complex. However, the main features of centralised water and wastewater systems include large-scale systems, distant water supplies, and a top-down governance model. The infrastructure is often owned by the public sector but may be operated either by the public sector or private companies. In contrast, decentralised water and wastewater systems are small-scale and use local water sources. There is often multi-level governance involved and the infrastructure can be owned and operated by private individuals (Domènech, 2011). As a result of centralised development, a large proportion of the population living in Western European nations benefits from safe drinking water and safe sanitation. However, not everyone in these nations has access to such services (van den Berge *et al*., 2021) and the reasons that populations do not have access to centralised infrastructure differ between the various regions.

Scotland provides a useful case study for the analysis of the challenges and opportunities for decentralised water and wastewater technologies and systems. Scottish Water is the public corporation which is responsible for water and wastewater service provision. However, not everyone is connected to a centralised service, and there is a proportion of the population which uses private water systems and domestic septic tanks, which are not owned or operated by Scottish Water. Within the Scottish context, and in this article, 'decentralised water and wastewater technologies and systems' (DWWTS) refer to these private water supplies (PWS) and domestic septic tanks.

As of 2021, the Drinking Water Quality Regulator for Scotland (DWQR) reported there are a total of 22,459 PWS which serve 185,850 people across Scotland (DWQR, 2022). Estimates of the number of domestic septic tanks in Scotland range from 180,000 to 468,000 (Ellis & Valero, 2022). DWWTS are mostly a rural phenomenon as the majority of both PWS and septic tanks are located beyond the central belt, as shown in Figure 1. In Scotland, DWWTS are often associated with inconsistent levels of performance, non-compliance with microbiological and chemical quality standards, and complex responsibilities for both users and regulators (Hendry & Akoumianaki, 2016). Further, there is a clear policy agenda to tackle these problems in order to improve the standard of living of people using decentralised systems.

Upon this background, this article presents a policy analysis of DWWTS in Scotland. The historical development of Scottish water and wastewater services is first discussed before an overview of the challenges with existing decentralised technologies is provided. The article then moves on to discuss opportunities in relation to the implementation of decentralised technologies, by analysing the three central themes of universal access to water and sanitation, a just transition to net-zero and community empowerment. This analysis is helpful as an exploration of the context within which DWWTS currently exist as well as which policy considerations are relevant to their implementation and improvement.

HISTORY OF WATER AND WASTEWATER SERVICES IN SCOTLAND

In the modern-day context, water management in Europe is often characterised by the dominant role of the state as owner, manager, and regulator of both water and wastewater service infrastructure (Bakker, 2003). An important line of scholarship seeks to emphasise the state's role and encourage resistance against the transfer of responsibilities to private companies (Bakker, 2010; Bieler, 2021). However, the state's comprehensive role in water and wastewater service provision is a relatively recent development. The public versus private debate, and the centralised versus decentralised supply debate should therefore be positioned within the relevant wider historical context. This section provides a brief historical overview of the management and governance of water and wastewater services in Scotland from the early 1800s to the present day. It highlights how the implementation of centralised water and wastewater infrastructure has not been universal, and rural areas have been left behind in the process.

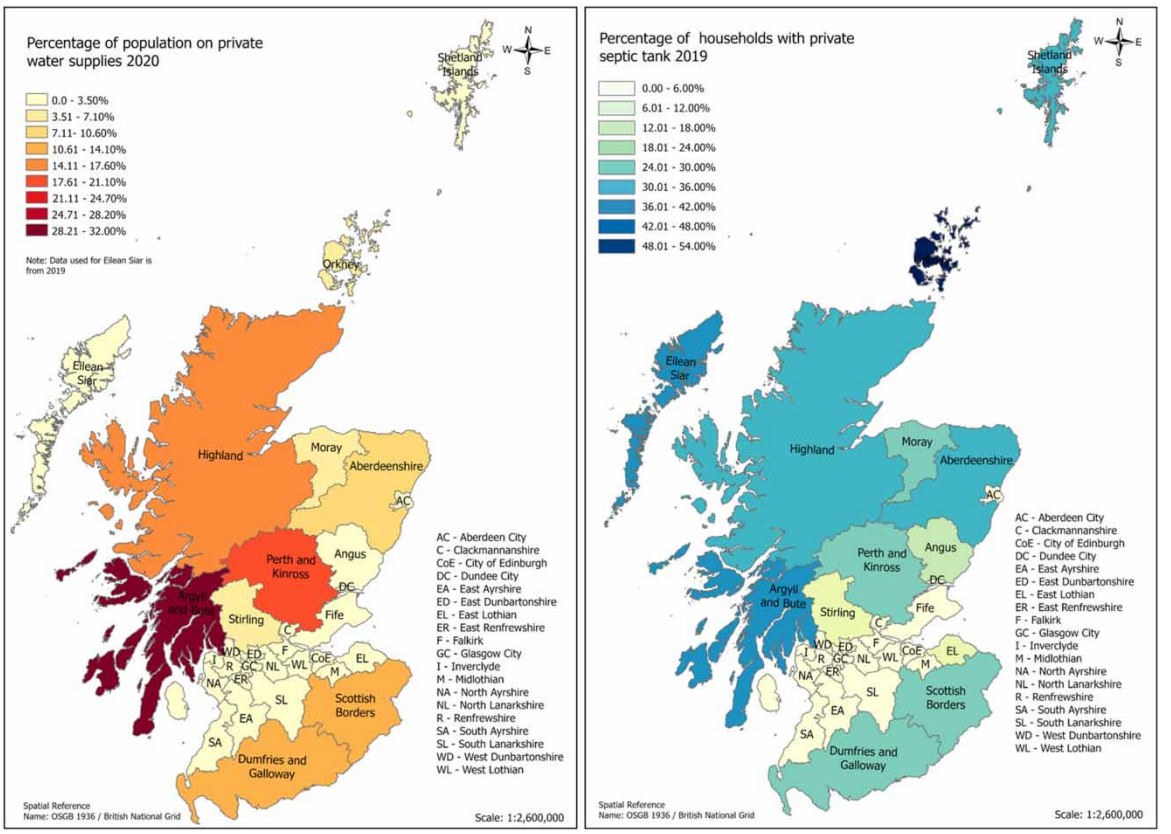

Fig. 1 | Maps showing the percentage of population on private water supplies and the percentage of households with septic tanks.

Prior to the mid-nineteenth century, state involvement in water service provision in Scotland was limited (McLeish, 1980). Historically, water management in Scotland was considered a local issue (Sewell *et al.*, 1985). There were wells in many towns and cities, but the supply was often insufficient or polluted. Some water supplies were provided by private companies, but there were complaints of corruption and much of the population could not afford to pay for these services (Chadwick, 1843). Multiple typhus and cholera epidemics then resulted in reform of the law related to water and sanitation from the mid-nineteenth century onwards.

Initially, in response to the need for action in the interest of public health, administrative bodies for the most populous areas, known as Burghs, were empowered to adopt a 'police system' that would be overseen by 'commissioners of police'. Duties of police commissioners included improvements to water supplies and the prevention of infectious diseases, which were outlined in a series of Burgh Police Acts dating from 1850 to 1892 (Sewell *et al.*, 1985). Although such acts indicated the recognition of a need for publicly provided water and sanitation services in towns and cities, similar progress in rural Scotland was delayed by the lack of any similar administrative body (Sewell *et al.*, 1985).

The need for water and sewerage services was repeatedly considered most urgent in towns and cities, but there was a condition on the obligations imposed by legislation that it was dependent on services being provided at a reasonable cost. The costs of providing water and sewerage services to rural areas were noted as a problematic

issue from this early stage (Templeton, 1956; Sewell *et al*., 1985). The Public Health (Scotland) Act 1867 marked the beginning of water services as a public responsibility across Scotland. The act created Special Water Supply Districts (SWD), which were to be the basic administrative unit for water services for areas outside of towns and cities. The formation of such districts was based on the notion that these services should be financed locally through special rates. However, the value of rateable properties in the boundaries of rural districts was often too small for enough revenue to be created for SWDs to undertake projects on their own (Sewell *et al*., 1985). Amendments to legislation allowed County Councils to subsidise SWDs through the introduction of a public water rate, but few Councils took advantage of this, leaving SWDs unable to provide the level of service given by their urban counterparts. At the time, the emerging governance system worked for those in more densely populated urban areas, but not for those in rural spaces. This was the start of rural water and wastewater supplies being left behind.

The inequality of service provision in rural spaces continued to be an issue at the turn of the 20th century. Sewerage services lagged even further behind than water services, and domestic sewage was a chief cause of river pollution at the time. Throughout the 1930s, a lack of sufficient infrastructure was also emphasised as an inhibitor of industrial development (Sewell *et al*., 1985). A severe drought in 1933 was a catalyst for greater scrutiny and in 1934, the Committee on Scottish Health Services noted that water supplies in many rural areas were inadequate (Department of Health for Scotland, 1935). This resulted in the Rural Water Supplies Act 1934 which enabled contributions from the central government to the local government to provide, or improve, water supply in rural areas. At this point, it became clear that the central government would need to become more and more involved in water and sewerage services.

UK-wide changes which took place as part of the process of planning for post-war development contributed to changes made to water supply and provision in the early 1940s. Sewell *et al*. (1985) refer to two reports that were highly influential in such a shift in the management and provision of national services. The first of which was 'The Report of the Royal Commission of the Distribution of the Industrial Population', more commonly known as the 'Barlow Commission' (Royal Commission on the Distribution of Industrial Population, 1940), which proposed ways of rectifying the imbalances in opportunities for employment between different areas of the country. The second, and most influential, was that of 'The Beveridge Report on Social and Allied Services' (Beveridge, 1942). This report urged that independent of location or social standing, fundamental needs with regard to education, health services, and housing should be a public responsibility. The Beveridge Report is considered the foundation of the post-war British Welfare State (Whiteside, 2014) which in turn helped shift 'national focus from central supervision over local powers, to central direction of the activities of local authorities in their various functions, including water supplies' (Sewell *et al*., 1985, p. 39).

In 1944, a White Paper on a UK-wide National Water Policy (A National Water Policy, 1944) was presented to the UK Parliament by the Minister of Health, Minister of Agriculture and Fisheries and Secretary of State for Scotland. At the time it was stated that 'the problem is not one of total resources, but of organisation and distribution' (BMJ, 1944, p. 598). It was re-emphasised that many small water supply systems in rural areas remained severely lacking in treatment and water availability during dry spells (Sewell *et al*., 1985). The Rural Water Supplies and Sewerage Act 1944 again made central government money available to assist in meeting the cost of providing water and sewerage services in rural areas. This time the funding had a transformative effect. A survey by the Scottish Housing Advisory Committee in 1936 of three rural areas found that 67% of the houses had no internal water supply (Sherriff, 1944). The total amount available in grants gradually increased from £6.4 million in 1944 to £60 million in 1969, and by 1971, Sewell *et al*. (1985) claim that 98% of the Scottish population had a piped water supply. It is, however, important to note that although large-scale improvements had been made across rural areas, there were still people in Scotland without access to centralised water and wastewater services.

The legal provisions on water services up to the mid-20th century were piecemeal and *ad hoc* until the Water (Scotland) Act 1946. This comprehensive piece of legislation stated that local authorities had a duty 'to provide a supply of wholesome water to every part of their district where a supply of water is required for domestic purposes and can be provided at a reasonable cost'. The act also gave local authorities powers to combine with other authorities for the purpose of any provision of the act. There was a focus on the amalgamation of water supplies in order to increase the efficiency of supply across regions. The continued issues with water and sewerage services began to be considered less of an issue for public health, and more of one for economic development.

A major re-organisation in water governance in Scotland took place between 1966 and 1973. Thirteen regional water boards and a Central Scotland Water Development board were established. The Water (Scotland) Act 1967 transferred the functions in relation to water supply previously exercised by local authorities to the newly created boards. The creation of such boards meant that specialised water authorities across Scotland could now rationalise supply systems on a regional scale (McLeish, 1980). Despite their perceived success, the Local Government (Scotland) Act 1973 again reformed local authorities, establishing nine Regional Councils and three Island Councils (Sawkins & Dickie, 2008). The regional water boards were dissolved, and the water service function returned to multi-purpose local authorities because it was determined, at that time, that water and wastewater services were a core responsibility of local government. The Water (Scotland) Act 1980 made provision for the establishment and duties of the water authorities based on the then-existing nine Regional Councils and three Island Councils. As the responsibilities of local government grew, water and sewerage were often ranked low on the list of priorities. The responsibility to connect households to centralised infrastructure has also always been conditional on the connection being provided at a reasonable cost. This meant that rural households faced greater hurdles, due to the costs, to be connected to centralised services.

The Local Government etc. (Scotland) Act 1994 separated water and sewerage responsibilities away from local government once again and created three regional Public Water Authorities, which were the North of Scotland Water Authority, West of Scotland Water Authority, and the East of Scotland Water Authority (Hendry, 2003).

Then finally, in 2002, the Water Industry (Scotland) Act 2002 created Scottish Water as a single public corporation which is responsible for the centralised water and wastewater services. Therefore, since the early 1800s, the governance of water and wastewater in Scotland has evolved from small-scale service providers managed at the very local level, to a national public system that is centrally funded and operated. The implementation of centralised infrastructure has meant that the majority of the Scottish population has access to centralised water and wastewater services. However, there is still a small minority who have been left out of this implementation, due to not being prioritised and the high costs of connection to centralised systems. With the greater centralisation of the governance of water and wastewater services, this minority who live predominantly beyond the central belt remains neglected. The following section provides an overview of the current governance structures for both centralised and decentralised water and wastewater systems in Scotland.

PRESENT-DAY SCOTTISH WATER SECTOR

Currently, Scottish Water has responsibility for centralised systems, while decentralised systems are primarily the responsibility of the users and owners, with the local authorities and the Scottish Environment Protection Agency (SEPA) as regulators. The Sewerage (Scotland) Act 1968 states that Scottish Water has a duty to provide public sewers and sustainable urban drainage (SUD) systems to effectively drain domestic sewage, surface water, and trade effluent. The legislation also requires them to deal with the contents of sewers and SUD systems by means of sewage treatment works. However, this duty is conditional on the provision being at a reasonable cost. The Water (Scotland) Act 1980 also imposes a duty on Scottish Water to provide a supply of wholesome

water where water is required for domestic purposes, again, when it can be provided at a reasonable cost. What is considered a reasonable cost is to be determined in accordance with The Provision of Water and Sewerage Services (Reasonable Cost) (Scotland) Regulations 2015.

DWQR, set up by the Water Industry (Scotland) Act 2002, works to ensure that Scottish Water complies with its legal duties in relation to the quality of centralised water supplies. The Water Services etc. (Scotland) Act 2005 established the Water Industry Commission for Scotland (WICS), which, among other things, promotes the interests of Scottish Water customers, reports on Scottish Water's performance, and ensures that customers are charged the lowest reasonable overall amount (Water Industry Commission for Scotland, 2023). The majority of households on centralised systems in Scotland pay for their water and wastewater services together with their council tax, and the charges are collected by local authorities on behalf of Scottish Water. Scottish Water does not have any responsibility for DWWTS.

The primary responsibility for DWWTS lies with their users and owners, but as a legacy of historic governance arrangements, local authorities have a remaining regulatory role. The DWQR also oversees local authorities in relation to PWS. Local authorities are responsible for maintaining a register of all PWS. Beyond registration, a distinction is made between regulated and exempt supplies. Regulated supplies are those that supply 50 people or more, or more than 10 m^3 of water a day, or form part of a commercial or public activity, such as a campsite. Exempt supplies are smaller domestic supplies. Local authorities are required to test regulated supplies regularly under The Water Intended for Human Consumption (Private Supplies) (Scotland) Regulations 2017. Local authorities are also required to sample and carry out risk assessments for regulated supplies every 5 years. The required risk assessments address supply vulnerability to pollution and public health risks, but not water availability and drought (Rivington *et al*., 2020).

Surprisingly, local authorities do not have a duty to test or carry out risk assessments on exempt supplies, which comprise over 80% of all PWS (DWQR, 2022). However, users can request testing from the environmental health department of their local authority. Local authorities must collect a sample within 28 days of being requested by the owner or user of the supply. Although risk assessments are not legally required for exempt supplies, local authorities must provide advice and assistance on risk assessments to those responsible (The PWS (Scotland) Regulations 2006). Those who use PWS do not pay for water charges with their council tax, but they have to pay for any risk assessments and testing carried out by the local authority, as well as the installation and maintenance of any water treatment processes. Small grants of up to £800 per property are available from local authorities for improvements to PWS (Scottish Government, 2022d).

In relation to domestic septic tanks, these are governed by the Water Environment (Controlled Activities) (Scotland) Regulations 2011. Registration with SEPA is required by the owner of the system for discharge from small septic tanks used by fewer than 15 population equivalent from domestic properties (SEPA, 2022). If the treatment system serves more than nine domestic properties, a simple licence is required (SEPA, 2022). SEPA will impose relevant conditions on registration or on granting of a licence, and also charge a fee (SEPA, 2023). Users of domestic septic tanks are again responsible for the installation and maintenance of their wastewater treatment systems (SEPA, 2023).

This brief overview shows that centralised water and wastewater services are comprehensively regulated by legislation and relevant authorities. However, DWWTS are primarily the responsibility of the users and owners, with local authorities and SEPA playing only a minor supervisory role. Many of the current challenges with DWWTS stem from these circumstances, as users and owners struggle to bear the technical, organisational, and financial obligations of managing their own water and wastewater services. Here the impact of historic neglect and governance practices in relation to rural households remains evident. These challenges will now be summarised in the next section.

CHALLENGES WITH EXISTING DECENTRALISED TECHNOLOGIES

The previous sections have traced the history of centralised and decentralised water and wastewater systems in Scotland and provided the context for exploring the challenges of existing DWWTS. In this section, the article will firstly outline the issues with water and wastewater technologies, then go on to the problems with the existing governance of DWWTS, and finally, the impact of climate change on DWWTS is discussed.

Water technologies

The technologies available for the treatment of drinking water differ widely, both through the type of technology used, as well as capital and operational costs involved. These range from basic screening and simple filtration to advanced nanofiltration and electrocoagulation (Blackwood *et al*., 2016). Teedon *et al*. (2020) identify seven different forms of treatment technologies currently in use for non-domestic decentralised water supplies in Scotland. These include simple filtration, bone char, pH correction system, filter cartridge, UV filters and lights, sand filter, and iron reducing unit. The type of system selected by DWWTS users may depend on the type of source water, availability of technology and cost of purchase, installation, and maintenance. The availability of information on the types of technology used across Scotland for small domestic supplies is limited. However, it is likely that, if any treatment processes are used at all, it will involve a particle filter and UV filter (Teedon *et al*., 2020).

It is challenging for individuals to manage and maintain water treatment technologies themselves, and there is a lack of knowledge and understanding by users about how the technologies function and how to operate the systems (CAS, 2020; Lawson & Robbie, 2023). Local authorities have also reported that there is a lack of minimum standards in relation to technologies and systems, as well as the contractors who install and maintain these systems, which can mean inappropriate systems are installed, or installed incorrectly. Finally, local authorities have noted a minority of people are resistant to water treatment because they have 'always drunk the water, and they are fine' or they do not appreciate the risks associated with untreated water (Teedon *et al*., 2020; Ash, 2021).

The result is that many PWS are contaminated with pathogens. Data show that out of the regulated PWS that were sampled in 2021, 12.1% of samples contained *E. coli* and 23.1% contained coliform bacteria (DWQR, 2022). With regards to exempt supplies which were tested, the numbers were even higher. In 2021, 16.2% of samples taken contained *E. coli* and 33.3% contained coliforms (DWQR, 2022). The safety and quality of untested exempt supplies, which forms the majority of PWS, is simply unknown. Results from both regulated and exempt supplies continue to raise concerns around the microbiological quality of PWS and the associated public health implications (DWQR, 2021, 2022).

Wastewater technologies

With regard to the treatment of domestic wastewater in Scotland, those not on centralised supply are most likely to have a private septic tank. Septic tanks work by using gravity to settle and separate solids from liquids. Solids that have built up over time require removal (de-sludging) by a specialist contractor, whilst liquids drain away via a soakaway (Dee Catchment Partnership, 2013). How effective the treatment of waste by a septic tank is depends on the management and maintenance of the infrastructure, as well as external factors such as temperature. Failure to effectively manage septic tanks can negatively impact public health, the local environment, and drinking water quality (Borchardt *et al*., 2011; Withers *et al*., 2014). Malfunctioning septic systems can often be attributed to sagging inlet drains, or undersized, inadequately designed tanks and drainage fields (Devitt *et al*., 2016). The most common reason for malfunction or lack of performance is due to failure to regularly de-sludge the tank (Moelants *et al*., 2008). Devitt *et al*. (2016) state that although domestic septic systems are less likely to cause

events such as algal blooms in comparison with point source pollution from centralised public sewerage systems and diffuse pollution from agriculture, they are more highly correlated with the risk of waterborne diseases.

De-sludging of private septic tanks is often carried out by private contractors in Scotland, with users bearing the costs of maintenance. Scottish Water offers a private de-sludging service which for 2022/2023 is priced at £210.90 for a scheduled visit, £297.40 for an unscheduled visit or £428.60 for an urgent response (Scottish Water, 2023a). Due to the typically rural location of domestic septic tanks, the arrangement of private companies to complete the de-sludging of tanks further complicates the management of such infrastructure. Reasons for poor householder management of septic tanks include a lack of risk perception, inability to recognise when a system is failing and householder concerns related to the financial costs of system management (Akoumianaki & Ibiyemi, 2022).

Governance of decentralised technologies

Some of the issues discussed above relate to the governance of DWWTS because regular management and maintenance of these technologies is required in order for them to provide safe drinking water and adequate sanitation. However, the maintenance practices and associated regulations, as outlined above, are complex, meeting the required standards is expensive, and users are provided with limited guidance and support. Placing the main responsibility for water and wastewater services with individuals without additional institutional support means that the health of people in rural communities using these services is at risk (Teedon *et al*., 2017; Ash, 2021).

Although PWS users are able to access a fee-based testing regime, research conducted by Teedon *et al*. (2017) emphasises a reluctance by users to engage. The reasons for such views include the opinion that the results reflect the weather conditions at the time of the test rather than water quality, logistical issues regarding getting samples from remote communities to a laboratory in time for analysis, and the considerable cost and inconvenience that a negative result can have (Teedon *et al*., 2017). Such examples further isolate PWS users and reduce their access to safe and affordable water supplies. Environmental health teams within local authorities can provide advice to users but the level of advice provided is dependent on the knowledge and capacity of the environmental health team in the local authority in question.

Generally, local authorities have limited capacity to carry out their responsibilities in relation to PWS. Recent data show that more than half of local authorities have risk assessed less than 50% of their regulated supplies, with six councils assessing less than 10% (DWQR, 2022). In 2021, only 53% of regulated supplies were sampled (DWQR, 2022). However, this low percentage may be partly explained by the Covid-19 pandemic which restricted the possibility of testing and the increase in the number of supplies which required testing because privately rented properties are now deemed to be regulated supplies (DWQR, 2022).

Across the UK, water companies, whether privately or publicly owned, have customer care or priority service registers (Northern Ireland Water, 2022; Ofwat, 2023; Scottish Water, 2023e). Such registers ensure companies are aware of any additional needs that customers may have to help aid effective communication. In addition, in the event of a major incident which interrupts supply, the registers allow companies to share details with emergency services and local authorities to ensure everyone receives the appropriate level of support. At the time of writing, there is no equivalent to a 'priority services register' for PWS users in Scotland, which again contributes to the vulnerability of DWWTS populations.

PWS have impacts on Scotland's rural populations beyond individual users' health. Teedon *et al*. (2020) highlight the connections between PWS and rural economic development. Tourism, forestry, and dairy farming were all identified as sectors of the economy that have a particular pertinence to PWS issues. Testing, liability, and reliability of supply were all found to be of concern to business owners reliant on such supplies. Other issues

such as intermittent electricity, which greatly impacts the performance of UV treatment for disinfection of water supplies, were also considered to have a negative impact on local economies.

In relation to septic tanks, in 2012, it was estimated that 40% of all septic tanks in Scotland remained unregistered (Scottish Government, 2012). Such a high proportion of unregistered tanks means it is difficult for SEPA to not only govern such systems but also identify the source of any associated pollution events. Further, it is unknown what percentage of septic tanks are actually functioning in Scotland, or whether such tanks are merely used but not appropriately de-sludged, therefore, are continually polluting the local environment.

At present, the management of DWWTS is usually conducted on a single property basis, with few options for community wide schemes or integration of services. Research conducted by Holstead *et al.* (2018) outlines that in the UK, the engagement of communities with water is seen more as an amalgamation of individuals, without an acknowledgement that when together, people form collectives and take part in socially shared practices that influence water demand and use. Any community-scale organisation with regard to the management of decentralised technologies is dependent on individual community capacity, with little support available from central or local government. In comparison to countries such as the Republic of Ireland and the National Federation of Group Water Schemes (NFGWS, 2023), currently, there is no public body that represents the DWWTS community within Scotland at the local and national policy level.

Climate change

Existing challenges in relation to DWWTS will be exacerbated by climate change. In their 2021 report, the Intergovernmental Panel on Climate Change state that 'human-induced climate change is already affecting many weather and climate extremes in every region across the globe' (IPCC, 2021, p. 8). Such changes are expected to negatively impact the quality and quantity of water supply around the world, including in countries such as Scotland, that have been previously considered 'water rich' (Boca *et al.*, 2022). This is because changing weather patterns are resulting in a change in quantity, frequency, and distribution of precipitation (Rivington *et al.*, 2020). Rivington *et al.* (2020) state that the practical implications of such change will be wide-scale water shortages occurring in summer months due to large precipitation deficits.

The impact of water shortages on PWS in Scotland was seen during the summer of 2018. The record high temperatures and low river flows (Fennell *et al.*, 2020) resulted in an increased number of emergency assistance requests from PWS users (Rivington *et al.*, 2020). DWQR, (2019) reported requests for assistance from at least 500 PWS users. In response to the emergency, the Scottish Government provided additional funding to the value of £475,432 to local authorities, which enabled emergency assistance to be provided in the form of bottled water and tankers (Rivington *et al.*, 2020). In their 2019 report, the DWQR state that the event highlighted the vulnerability of PWS users across Scotland to a changing climate (DWQR, 2019). As many PWS are dependent on small-scale surface water sources rather than groundwater, supplies are less resilient to such predicted changes in climatic conditions.

More frequent periods of heavy rainfall and storms are also likely to impact water quality and quantity in Scotland. Higher ambient temperatures are expected to result in warmer surface waters (Lloyd Owen, 2020). Research conducted by May *et al.* (2022) found that 88% of Scottish lochs and reservoirs experienced warming between 0.25 and 1.0 °C per year from 2015 to 2019, with 9% increasing by 1.0–1.3 °C per year. Consequences associated with the warming of standing waters include a potential increase in algal blooms and cyanobacteria, both of which will negatively impact water quality targets for water supply and safe recreational use (May *et al.*, 2022). Additionally, increases in rainfall and high rainfall events were found to increase the rate at which pollutants are delivered to standing waters, which will in turn result in further problems with eutrophication (May *et al.*, 2022).

With regard to septic tanks, the impacts of climate change are thought to be two-fold. Nnaji & Utsev (2011) state that rising temperatures will lead to an exponential increase in bacterial activity, that will result in increased treatment efficiency, with most septic tanks also having minimal energy input requirements. This may, however, also result in the production of more greenhouse gasses. Due to the accumulation of organic matter under anaerobic conditions, septic-based systems are producers of greenhouse gases (Huynh *et al*., 2021). Methane, carbon dioxide, and nitrous oxide emissions are known to occur from conventional septic tanks, but there is a dearth of information with regard to more exact quantities (Diaz-Valbuena *et al*., 2011). The reason for such limited data, especially with regard to methane emissions, is that the two major mechanisms of methane formation (breakdown of acetic acid and reduction of carbon dioxide), are heavily influenced by local operating conditions (temperature, organic loading, and biosolid residence time) (Diaz-Valbuena *et al*., 2011). Such issues coincide with the fact that SEPA remain unaware of the exact number and location of septic tanks across Scotland, and therefore the emissions produced by septic tanks. The extent to which this will increase with climate change is unknown.

Opportunities for decentralised water and wastewater technologies

The previous sections have identified multiple challenges with decentralised water and wastewater technologies in Scotland, but opportunities for such systems also exist. It is not feasible to implement centralised infrastructure to all those using existing DWWTS. However, the standard of living of those using DWWTS must be improved. The following sections, therefore, provide an overview of the opportunities and potential policy pathways for DWWTS in Scotland, and these pathways are necessary to explore when considering the development and implementation of new or improved decentralised technologies.

Universal access to safe water and adequate sanitation

Goal 6 of the United Nations Sustainable Development Goals (SDGs) is to ensure the availability and sustainable management of water and sanitation for all (United Nations, 2023). Scotland's National Performance Framework and National Outcomes have been designed to align with the SDGs (Scottish Government, 2023d). From the analysis above, it is clear that Goal 6 is not being met for those currently on DWWTS in Scotland. Work by Consumer Scotland has also highlighted the need for action in relation to people using PWS to ensure their access to safe drinking water and fulfil the SDGs (Ash, 2021).

In addition to the SDGs, a human right to clean water and sanitation has been recognised by the United Nations General Assembly as forming part of the right to an adequate standard of living (United Nations, 2010). A right to a healthy environment has also been recently recognised (United Nations, 2022). Within a UK context, Struthers, (2022) highlights the difference in attitudes and approaches to human rights between England and Scotland. Within Scotland, policy makers repeatedly link human rights to the lived experiences of the Scottish people (Struthers, 2022). This has created a human rights-based approach to law and policy making in which rights are placed at the heart of day-to-day decision making and debates on issues like health and the environment. The framing of Scotland as a human rights-friendly nation is in direct contrast to the current English approach (Struthers, 2022). In 2018, an Advisory Group on Human Rights Leadership was set up by the then First Minister Nicola Sturgeon to consider how to further implement human rights in Scotland. The report from that Group proposed a new Act of the Scottish Parliament which provides human rights leadership (Miller *et al*., 2018). In June this year, a consultation opened regarding a Human Rights Bill for Scotland which would incorporate a range of economic, social and cultural rights into Scots law, as well as a right to a healthy environment (Scottish Government, 2023a). The consultation discusses moving towards a duty to comply with the incorporated rights meaning relevant public bodies would have to show progressive realisation of the rights and ensure

the delivery of minimum core obligations. A right to water and sanitation is not proposed as an independent right in the consultation, but a right to safe and sufficient water is stated as part of a right to a healthy environment and an adequate standard of living. In order to fulfil a human right to safe water and adequate sanitation, the existing services and governance of DWWTS must be revised and improved.

Finally, connected to universal access to safe water is the implementation of the European Union's (EU) recast Drinking Water Directive (rDWD). Despite the UK's withdrawal from the EU, the Scottish Ministers have indicated that 'where appropriate' they would like Scots law to continue to align with EU law (McIver, 2021). The rDWD is the first water or wastewater-related directive to be transposed by the Scottish Government following Brexit. A fundamental principle behind the rDWD is to ensure access to safe drinking water for all. The 2021 Hydro Nation report (Scottish Government, 2022a) states that for consumers in Scotland, this includes ensuring that those on a PWS are equipped to effectively manage their water supply and cope with the impacts of climate change. Exactly how the rDWD is transposed, and the resulting duties, have the potential to alter how DWWTS in Scotland are governed and managed to improve the standard of living of people on these services.

Just transition to net-zero

Although centralised water and wastewater systems have undoubtedly been successful in providing adequate water and sanitation services in urban areas, centralised infrastructure is extremely energy intensive and repeatedly ranks as a significant contributor to greenhouse gas emissions (Romeiko, 2020). Within Scotland, Scottish Water is one of the largest electricity consumers with a requirement of around 442 GWh each year (Scottish Water, 2023b). Scottish Water estimated their operational carbon footprint for 2019/2020 to be 254,000 tons of carbon dioxide equivalent (tCO2e) (Scottish Water, 2023d). The use of decentralised technologies reduces the large energy and material requirements associated with centralised infrastructure. This is through a reduction in the need to pump large volumes of water and effluent over long distances and simplified treatment processes.

The concept of net-zero has been at the forefront of Scottish Government policy for more than a decade. The Climate Change (Scotland) Act 2009 set a target year of 2050 for the reduction of greenhouse gas emissions. The Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 amended the 2009 Act and set a target for Scotland to have transitioned to net-zero emissions of all greenhouse gases by 2045. Actions identified by the Scottish Government to help reach the net-zero target include, supporting decarbonisation of the public sector, engaging with business and industry on decarbonisation, supporting communities to tackle climate change and delivering a just transition (Scottish Government, 2023c). The Scottish Government state that a just transition is both 'the outcome of a fairer, greener future for all, as well as the process that must be taken in partnership with those impacted by the transition to net zero' (Scottish Government, 2022b, para. 1). A Just Transition Commission was created to scrutinise plans for a transition to net-zero as well as provide expert advice and engage with those most likely to be impacted.

The ambitious targets outlined in policy and legislation relating to net-zero require large-scale changes to the way in which current water and wastewater infrastructure is managed in Scotland. In 2020, along with Zero Waste Scotland, Scottish Water launched new net-zero transition plans that target net-zero by 2040 (Scottish Water, 2023c). The requirement for a reduction in emissions produced from water and wastewater infrastructure provides opportunities for the introduction of less carbon-intensive technologies.

The Carbon Neutral Islands project is a programme designed by the Scottish Government aimed at supporting islands to become carbon neutral by 2040. The islands included in the project are Hoy, Islay, Great Cumbrae, Raasay, Barra, and Yell (Scottish Government, 2022c). It is hoped that the project will help to demonstrate the ability of Scottish Islands to be hubs of innovation in renewable energy and climate change resilience whilst simultaneously positively impacting island economics, population retention and growth. The six islands

chosen to take part in the project were identified by the Scottish Government in August 2022 through collaboration with local authorities and island representatives (Scottish Government, 2023b), and they have recently published community-led climate action plans (Community Energy Scotland, 2023). Such projects again highlight the multiple policy opportunities for pathways of implementation for DWWTS which are less carbon intensive, but these technologies and systems must perform and be governed in a better way than is the current state of affairs.

Community empowerment

Within Scotland, the challenges with DWWTS are predominately experienced by rural communities. This is because few urban areas have any form of PWS or septic tanks. The rural versus urban divide is one that can be applied to many areas of Scottish life as 91% of the population live on just 2.3% of the land (National Records of Scotland, 2022). Many communities in Scotland are experiencing changes in population levels and demographics, with urban areas, specifically those within commutable distance of major cities increasing in population and other, notably west coast areas, facing depopulation (Scottish Government, 2021b). Patterns of migration in Scotland are heavily concentrated within younger populations resulting in a trend of ageing rural communities. Population and demographic changes are now recognised as a 'National Challenge' with Scotland's first National Population Strategy published in 2021 (Scottish Government, 2021a). The strategy focuses on achieving a 'population balance' across Scotland in which people are well-distributed across the country, with adequate access to jobs and economic opportunities, as well as access to education, infrastructure, housing, digital, and transport (Scottish Government, 2021a). The National Population Strategy outlines 36 actions many of which relate to the creation and maintenance of sustainable rural communities through increases in funding to local authorities and investment in infrastructure. The creation of sustainable rural communities across Scotland would contribute to an environment in which DWWTS can be more successfully managed and operated.

Finally, research conducted by Holstead *et al.* (2018), states that it is increasingly recognised that the success of environmental interventions relies on community awareness and action. Community empowerment is a core policy of the Scottish Government and there is a National Outcome that we 'live in communities that are inclusive, empowered, resilient and safe' (Scottish Government, 2023e, sec. 2). However, this policy does not mean that communities should be left to manage essential services without support or assistance. The key to successful implementation and management of DWWTS may be finding the balance between community management and institutional support from public bodies in relation to carefully designed technologies to ensure that the technologies are appropriately used and maintained, and fulfil the right of everyone to access to safe water and adequate sanitation.

CONCLUSION

This paper has analysed the challenges and opportunities for decentralised water and wastewater technologies and systems, through the use of a Scottish case study. In Scotland, there are multiple challenges with DWWTS, which are the result of the history of the implementation of centralised infrastructure and people in rural communities being left out of this implementation. The result of these circumstances is that existing DWWTS are currently underperforming and contribute to the vulnerability of rural communities. In relation to PWS, users struggle to manage and maintain their water supply, and many local authorities do not have the resources to fulfil all their obligations in relation to these supplies. The quality of water being consumed by users on untested exempt supplies is simply unknown. This is putting the health of rural communities at risk. In relation to septic tanks, many of these systems are underperforming due to lack of maintenance, and therefore polluting the local environment, but again the scale of the problem is unknown due to the lack of registration of

tanks and enforcement of registration or licence conditions. These challenges will be exacerbated by climate change.

There are, however, opportunities and policy pathways in Scotland for improvements to the implementation and management of DWWTS. The opportunities outlined here were universal access to safe water and sanitation, a just transition to net-zero and community empowerment. These opportunities are evident in the Scottish content, but these are also global goals which are recognised by many countries around the world. The remaining question is how to design technologies and governance arrangements for DWWTS in order to tackle the challenges outlined here. There is much research still to be done to find the balance between community management and state support in order to meet these global goals and support sustainable rural communities for generations to come.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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