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Water Sector Resilience in the United Kingdom and Ireland: the COVID-19 Challenge

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Abstract

The outbreak of COVID-19 led to restrictions on movements and activities, which presented a serious challenge to the resilience of the water sector. It is essential to understand how successfully water companies responded to this unprecedented event so effective plans can be built for future disruptive events. This study aimed to evaluate how the water sectors in the UK and Ireland were affected from a holistic sustainability and resilience-based perspective. Using pre-COVID data for 18 indicators of company performance and comparing them to the first year of the pandemic, the direction and magnitudes of change varied across companies. Financial indicators were significantly negatively affected, with *interest cover ratio*, *post-tax return on regulated equity*, and *operating profit*, exhibiting the greatest average declines of 21%, 21%, and 18%, respectively, a trend that would be dangerous to provisions and company operations if continued. Despite this, service and environmental indicators improved during the first year of the pandemic, exemplified by *unplanned outage*, *risk of sewer storm flooding*, and *water quality compliance risk* decreasing by a mean average of 37%, 32%, and 27%, respectively. Analysis using the Hicks-Moorsteen Productivity Index concluded that average productivity increased by 35%. The results suggest that the water sector was relatively resilient to the COVID-19 pandemic in terms of services, but adverse effects may have manifested in a deteriorated financial position that could exacerbate future challenges arising from exogenous pressures such as climate change. Specific advice for the UK water sector is to scrutinize non-critical spending, such as shareholder payments, during periods of economic downturn to ensure essential capital projects can be carried out. Although results are temporal and indicator selection sensitive, we recommend that policy, regulation, and corporate culture embrace frameworks that support long-term resilience to since the relative success in response to COVID-19 does not guarantee future success against differing challenges. This study generates a timely yet tentative insight into the diverse performance of the water sector during the pandemic, pertinent to the water industry, regulators, academia, and the public.

Keywords: Water efficiency, sustainability, SARS-CoV-2, regulation, water industry

1. Introduction

The outbreak of SARS-CoV-2 (COVID-19) led to global restrictions on intra- and international movements to try and slow the spread of the virus (Ní Ghráinne, 2020). In the UK and Ireland, national restrictions were imposed in March 2020 and continued to varying extents until all restrictions were lifted in February and April 2022, respectively (Tumelty et al., 2022). The unprecedented scale of change required organisations to adapt almost all aspects of their operations (Zhu et al., 2020), and the water and wastewater services were no exception since there was a crucial requirement to ensure reliable and safe water and wastewater services for safeguarding high levels of hygiene to help mollify the spread of the virus (Howard et al., 2020).

The water sector should be sufficiently prepared for obstructive events such as COVID-19 because operational, financial, and corporate resilience affects water and wastewater services for current and future consumers. Resilience at the company level is a process where operational procedures and responses are actively reviewed against the threat of potential risk and hazards (Linnenluecke, 2017), the success of which depends on the capacity to mitigate, adapt, and learn from a crisis (Butler et al., 2017). The UK water regulator has actively and explicitly documented its focus on resilience, making it one of the four themes of the 2019 price review, which sets price regulation for 2020-2025 (Ofwat, 2019a). The sector has been attempting to build a resilient system, with the most significant known threat being climate change, where changing and more unpredictable precipitation, temperature, and extreme weather events are likely to affect demand, drought, flooding, distribution, and treatment (Ofwat, 2022). Furthermore, preparations were made across the sector to be resilient upon the UK leaving Europe Union to secure supply chains (Mukhtarov et al., 2022; Lawson et al., 2022). In addition to the sector, broader disruptions to services affecting customers, communities, the economy, and the environment can be significant (Sowby, 2020). Antwi et al. (2021) further emphasise the need for sectoral resilience via water governance and management for post-COVID-19 recovery and climate threats. They highlight a lack of governmental oversight evident in the preliminary responses to the COVID-19 outbreak in European countries, where only 11 of 27 European countries (40%) implemented at least one policy intervention, such as cost absorption or deferment of bills, that considered the water sector, and these were typically short-term measures.

COVID-19 presented a significant challenge to the water sector's resilience. Understanding how companies responded to this unexpected and unprecedented world event is integral so effective plans can be built for future disruptive events, whether expected or unexpected. Studies have been emerging on the impact of COVID-19 on the UK and Ireland water sectors, primarily based on water quality and qualitative assessments. Some have shown the value the sector can have in understanding and tracking the virus through wastewater (Bivins et al., 2020; Fitzgerald et al., 2021; Kevill et al., 2022;

Poch et al., 2020) and ensuring a safe drinking water supply (Giacobbo et al., 2021). Others have viewed the influence of COVID-19 on water companies and the sector in differing ways. For example, Renukappa et al. (2021) analysed the impact of the virus on UK water sector projects and practices via twelve interviews with water professionals from six different organisations, highlighting how companies adapted positively to alternative working conditions. Lawson et al. (2022) also found that UK companies responded well to the pandemic through their eleven interviews, though they emphasised the importance of not being complacent and embedding new knowledge into best practices.

Additional interviews were conducted by Berglund et al. (2022) but included 27 water utilities within a global scope to study the effects of the pandemic on operation and vulnerability, concluding that staff flexibility, supply chain management, and finances were exposed. Atkins and Frontier Economics (2020) produced the first and rare glimpse at quantifying the impact of COVID-19 on the UK water sector, with early indications pointing towards an industry-wide reduction in return on regulated equity between 0.35%-0.97% over the current five-year asset management plan period (AMP7). What is clear is that the COVID-19 outbreak exerted additional pressure on the global water sector, which was already facing challenges due to ageing infrastructure, ill-planned urbanisation, and climate change (Mukhtarov et al., 2022). Neal (2020) notes that the pandemic acted as a "threat multiplier" to the sector's existing pressures, drivers, and threats to the path to sustainability.

Although the research published thus far regarding the effect of COVID-19 on the UK water sector has provided value in a multitude of ways, as highlighted in these studies, there is a need to fully understand how the water sector responded to the pandemic, particularly in a sustainability-focused manner, representing a more holistic view of companies and the sector. The anticipated results are that the sector will have declined fiscally, and subsequently, some services may have declined too; however, to capture a complete picture and possible unexpected results, many indicators crossing economic, service, and environmental considerations are required, where data availability allows. By interpreting the appropriate data and grasping how well companies were prepared, it is possible to identify which processes will help improve resilience to future disruptive events. This study thus had several objectives: 1) to explore how water companies within the UK and Ireland were affected by the COVID-19 outbreak using metrics encompassing a holistic sustainability perspective; 2) to use the Hicks-Moorsteen Productivity Index (HMPI) to investigate the extent of change inflicted by the pandemic and the optimal values of selected inputs and outputs at the scale of companies and the sector; and 3) to evaluate the resilience of the water sector and lay the foundations for informing future resilience, using the results and outcomes illuminated from objectives 1 and 2. These objectives provide novel insight for the water industry, regulators, and benchmarking academic literature by generating rare quantitative results regarding the water sector and COVID-19, using seldom applied sustainability metrics within a customised emerging methodology.

The paper unfolds from here with the data selection and justification, followed by the breakdown of the HMPI in the Methodology. Then in the Results and Discussion section, the whole water sector sample is evaluated together using the selected indicators to highlight the best and worst performers before moving on to the indicators by economic, environmental, and service groupings. The Results and Discussion then move on to the productivity analysis, starting on the sector as a whole, before analysing company-level productivity. Conclusions then round off the study, drawing from the key findings.

2. Methodology

2.1. Data description

The sample included 19 companies from the UK and Ireland water sectors: six water-only companies and 13 water and sewage companies. The data collected were annual financial year entries (April-April) from 2018 to 2021, covering four years. Data for 18 indicators were collected and spanned economic, environmental, and service-based metrics. Indicators were chosen to represent water companies and the sector as well as possible based on the availability of quality data (Walker et al., 2021a). Some audited and independent data (e.g., credit rating) are included, but most of the data are self-reported by companies, which should be considered when making inferences, as discussed further in the Results section. Indicators were analysed with all companies where possible; however, where data were limited, fewer indicators were used for years or companies (see Supplementary Information). A limited selection of indicators from this total pool was used for productivity analysis, which is discussed and justified further in Sections 2.2 and 3.2. All the data were acquired from publicly available company annual reports and regulatory reports, summarised in Table 1; the complete dataset is available in Supplementary Information.

For clarification on the lesser-known indicators, they are elaborated on further here and supplied by Ofwat (2019b). Return on regulatory equity is a measure of profitability in terms of returns after tax and interest that companies have earned by reference to the notional regulated equity, calculated from the regulatory capital value (RCV) and notional net debt. Adjusted gearing is the percentage of the net debt to the RCV. Interest cover ratios are a measure of a company's profitability compared with its annual interest expense, in the adjusted metric, the numerator is adjusted to subtract depreciation. Operating profit refers to total earnings from core business functions, excluding the deduction of interest and taxes.

The GHG emissions include all scopes, which are defined thus: Scope 1 regards all emissions from processes which are the organisation’s direct responsibility, Scope 2 is emissions associated with grid electricity use, and Scope 3 regards all other (upstream) emissions from relevant supply chains, which may come from sources that the company does not own or control but are strongly influenced by company activities. Unplanned outage refers to the inability of companies to supply water due to unforeseen deterioration or failure of assets. Lastly, customer satisfaction was devised from company surveys, namely C-mex and D-mex surveys. The C-mex scores are comprised of data from a customer service survey to residential customers who recently contacted their company and a customer experience survey of random members of the public about their experience of their water company. D-mex scores are from a survey of developer services customers who have recently completed a transaction with their water company, which measures performance against a set of Water UK service metrics.

Table 1. Summary statistics of eighteen variables from nineteen UK and Irish water and sewage companies (2018-2021)

	Average	**St. dev**	**Minimum**	**Maximum**
Post-tax return on regulated equity (%)	5.79	5.63	-9.21	15.56
Adjusted Gearing (%)	68.47	8.26	47.90	83.17
Interest Cover Ratio	1.93	0.66	0.22	3.31
Credit rating*	8.37	0.77	6.00	10.00
Operational expenditure (£m)	401.33	325.93	26.11	1667.70
Capital expenditure (£m)	354.68	298.70	7.97	1223.00
Operating profit (£m)	187.18	180.73	0.60	610.58
Leakage (Ml/day)	203.04	176.06	23.55	695.00
Consumption per capita (Ml/d)	144.96	9.85	126.55	163.30
Volume delivered (ml/d)	926.08	581.61	146.97	2170.98
Water quality compliance**	3.17	2.95	0.01	16.71
Treatment works compliance (%)	98.98	0.76	97.06	99.85
GHG emissions*** (kgCO_2e/Ml)	310.80	170.30	40.00	787.00
Pollution incidents (per 10,000 km)	40.03	31.09	12.00	130.87
Supply interruptions (mins/properties)	13.23	12.24	0.07	73.70
Risk of sewer storm flooding (%)	15.55	9.83	0.37	41.81
Unplanned outage (%)	2.87	3.78	0.02	18.59
Customer satisfaction****	80.51	5.18	69.59	87.78

* Credit rating based on Fitch and Moody’s rating scales and converted to numbers for ease of comparison
** Based on compliance risk index figures (lower values = less risk and more compliance)
*** Location-based carbon calculations for water production and wastewater treatment (scopes 1, 2 and 3)
**** From C-mex (customer surveys) and D-mex (company metrics) scores by OFWAT

2.2. Hicks-Moorsteen Productivity Index

2.2.1. Method description and justification

Many non-parametric frontier methods are used to compute Total-Factor Productivity (TFP) in the water sector, such as the Fare-Primont productivity index (Molinos-Senante et al., 2017a), Malmquist

Productivity Index (MPI) (Molinos-Sennante et al., 2017b), Luenberger Productivity Index (Sala-Garrido et al., 2018), Malmquist-Luenberger productivity indicator (Sala-Garrido et al., 2019), and the Hicks-Moorsteen Productivity Index (HMPI) (Molinos-Senante et al., 2016; Walker et al., 2021b). The essential advantage of these non-parametric frontier methods over parametric methods is that they do not require *a priori* assumptions about the functional relationship between the variables, which can cause specification and estimation problems (Silva et al., 2017; Moutinho et al., 2020). The MPI is the method most applied to analyse changes in TFP (Chen et al., 2022). Its popularity is because it can be computed without price data and can be broken down into measures of technical and efficiency changes (Shao and Lin, 2016). Despite the numerous positives of MPI, it does have some decisive limitations. O'Donnell (2014) comments that some distance functions within the index may be undefined, and infeasibility problems might ensue, meaning results may not accurately express TFP change from scale effects. Furthermore, MPI requires a choice of input or output orientation and is deemed inappropriate when the sample operates under variable returns to scale (VRS), O'Donnell (2012) demonstrated.

The HMPI largely overcomes the limitations that MPI encompasses. Defined as a ratio of the Malmquist input and output indices while using the Shephard input and output distance functions, respectively (Simões and Marques, 2012), the HMPI does not require price data and satisfies all other index conditions, including multiplicative completeness and transitivity tests (O'Donnell, 2012). The HMPI thus functions within a simultaneous input and output orientation and can be computed under both constant returns to scale and VRS technologies, giving it a distinct advantage over similar TFP methods like MPI. Furthermore, HMPI makes no assumptions about behavioural aims such as maximising profit or market settings like regulation and competition (Ondrej & Jiri, 2012). Briec and Kersten (2011) highlighted further advantages of HMPI, commenting that under substantial input and output disposability, the determinateness axiom is satisfied so that infeasibility problems are avoided, meaning that the index is well defined even when one or more of its arguments becomes zero or infinity.

The HMPI specifies optimal input and output levels for individual operating units (Mohammadian & Rezaee, 2020) as a ratio of aggregate output quantity over aggregate input quantity index (Bjurek et al., 1998). Under the assumption of each water company using a vector of *M* inputs $x = (x_1, x_2, \ldots, x_M)$ to produce a vector of *S* outputs $y = (y_1, y_2, \ldots, y_S)$, the output and input distance functions are defined thus (Shephard, 1953):

$$D_t^o\,(x, y) = \min_{\delta} \{\delta > 0 : \left(x, {}^{y}/_{\delta}\right) \varepsilon T^t\} \quad (1)$$

$$D_t^i\,(x, y) = \min_{\rho}\{\rho > 0 : (x/\rho, y)\varepsilon T^t\} \quad (2)$$

Where T^t denotes production possibilities set at period-t. $D_t^o\,(x,\,y)$ symbolises the output distance function and evaluates the inverse of the largest radial expansion of the output vector, which is achievable, given the input vector. Conversely, $D_t^i\,(x,\,y)$ denotes the input distance function and evaluates the largest radial contraction of the input vector attainable while fixing the output vector (Epure et al., 2011).

For a base period t, Bjurek et al. (1998) defined HMPI as:

$$HMPI_{T\,(t)}(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{[D^o_{T(t)}(x^t, y^t)/D^o_{T(t)}(x^t, y^{t+1})]}{[D^i_{T(t)}(x^t, y^t)/D^i_{T(t)}(x^{t+1}, y^t)]} \quad (3)$$

For a base period $t+1$, HMPI is defined as:

$$HMPI_{T\,(t+1)}(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{[D^o_{T(t+1)}(x^{t+1}, y^t)/D^o_{T(t+1)}(x^{t+1}, y^{t+1})]}{[D^i_{T(t+1)}(x^t, y^{t+1})/D^i_{T(t+1)}(x^{t+1}, y^{t+1})]} \quad (4)$$

A geometric mean of the HMPI for base period t and $t+1$ yields:

$$HMPI_{T(t),\;T(t+1)}\,(x^{t+1}, y^{t+1}, x^t, y^t) =$$
$$[HMPI_{T(t)}(x^{t+1}, y^{t+1}, x^t, y^t)\;\times\;[HMPI_{T(t+1)}(x^{t+1}, y^{t+1}, x^t, y^t)]^{1/2} \quad (5)$$

A HMPI >1 indicates an increase in TFP, <1 illustrates a decline in TFP, and a result of 1 demonstrates no change in TFP. An asset of HMPI is its classification into technical potential and relative efficiency change, along with a breakdown of efficiency change into sub-indices; however, within the scope of this study and the nature of the assortment of indicators, this was deemed unnecessary and inappropriate.

2.2.2. Sample selection

Productivity analysis was conducted on 16 water companies across the UK, omitting three companies from the total sample within Sections 2.1 and 3.1 due to a lack of data completeness in the panel data for all four years. A limited core of six indicators was chosen to measure the productivity of the water sector, namely *total expenditure* (*TOTEX*) (calculated by summing *operating expenditure* and *capital expenditure*), *volume of water delivered*, *customer satisfaction*, *water supply interruptions*, and *GHG emissions*. These indicators were chosen to represent the primary functions of water companies, from spending on operations, to producing water, to delivering good service with minimal adverse environmental impact (Walker et al., 2022).

The configuration of the indicators into inputs and outputs logically would be to have *TOTEX* as the input and the rest as outputs since they are a result of water company expenditure. However, two conventional outputs, *GHG emissions* and *water supply interruptions,* had to be handled differently since they are undesirable outputs. If they were to remain as conventional outputs within the HMPI or similar models, as their values got relatively higher, it would appear as though the sector or company within question was more efficient for performing worse. Halkos & Petrou (2019) reviewed the various methods used to treat undesirable outputs when employing DEA. Direct approaches, such as parametric outputs and input distance functions, treat an undesirable output in its original form (Ho et al., 2017).

Conversely, indirect techniques manage the undesirable output as a classical input since both inputs and undesirable outputs are the values to the minimised; it can thus be appropriate to treat both in the same manner (Khan et al., 2015). Seiford & Zhu (2002) suggested that moving undesirable outputs over to the input side of the model can distort the actual production process because the relationship between inputs and outputs can be lost. In this study, the HMPI is used to simultaneously evaluate a collection of key indicators. Treating *water supply interruptions* and *GHG emissions* as undesirable outputs and moving them over to the input side of the model is an elegant solution to the problem. The HMPI was thus conducted with *TOTEX*, *water supply interruptions* and *GHG emissions* as inputs and *customer satisfaction* and *volume delivered* as outputs. The drawback to losing this relationship is that some of the features of computing HMPI, namely scale and technical change, could not be evaluated robustly.

The sample size and the balance between water companies and indicators used within the DEA model must satisfy specific criteria to bypass relative efficiency discrimination issues. Cooper et al. (2006) developed a minimum sample size threshold relative to the number of inputs and outputs, dubbed 'Cooper's rule'. The rule states that the number of units, in this instance water companies, must be ≥ max$\{m\ x\ s; 3(m+s)\}$, where m represents inputs and s represents outputs. With 16 companies, three inputs, and two outputs being used, Cooper's rule was followed. The input and output distance functions were computed in 'R', a statistical computing software with the package 'productivity' created by Dakpo et al. (2018).

3. Results and discussion

3.1. Sector-wide performance indicator investigation

3.1.1. Best and worst performers

The UK and Irish water sectors were evaluated with 19 companies and 18 indicators, broadly covering all company operations and service aspects. This approach enabled an understanding of economic, service, and environmental performance before and during the COVID-19 pandemic. Table 2 displays the change from the three years leading up to the pandemic to the first year of it, in percentages. The percentage changes highlighted in green, red, and amber represent positive, negative, and neutral and mixed implications in real-world performance for each factor.

Table 2. Average performance indicator results for the three years (2018-2020) leading up to, and the first year of, the COVID-19 pandemic (2020-2021). Red in the percentage change column implies a negative effect, green a positive effect, and amber a neutral, negligible, or mixed impact.

	2018-2020	2021	Percentage change	Trend
Post-tax return on regulated equity (%)	6.1	4.8	-20.6%	Deteriorating
Adjusted Gearing (%)	68.1	69.7	2.3%	Deteriorating
Interest Cover Ratio	2	1.6	-21.2%	Deteriorating
Credit rating*	8.3	8.5	2.7%	Deteriorating
Operational expenditure (£m)	404.1	393.2	-2.7%	Improving
Capital expenditure (£m)	357.8	345.4	-3.5%	Deteriorating
Operating profit (£m)	196.1	160.5	-18.1%	Deteriorating
Leakage (Ml/day)	205	197.1	-3.9%	Improving
Consumption per capita (Ml/d)	144.2	147.2	2.1%	Static/mixed
Volume delivered (Ml/d)	1022.4	1063.1	4%	Static/mixed
Water quality compliance**	3.5	2.5	-26.7%	Improving
Treatment works compliance (%)	99.1	99.1	0.0%	Static/mixed
GHG emissions*** (kgCO2e/Ml)	300.2	272.7	-9.2%	Improving
Pollution incidents (per 10,000km)	39.7	40.6	2.2%	Deteriorating
Supply interruptions (mins/properties)	10.8	10	-7.6%	Improving
Risk of sewer storm flooding (%)	20.3	13.8	-32.1%	Improving
Unplanned outage (%)	3.7	2.3	-36.8%	Improving
Customer satisfaction****	77.7	81.1	4.4%	Improving

* Credit rating based on Fitch and Moody's rating scales and converted to numbers for ease of comparison
** Based on compliance risk index figures (lower values = less risk and more compliance)
*** Location-based carbon calculations for water production and wastewater treatment
**** From C-mex and D-mex surveys by OFWAT

The UK and Irish water sectors had mixed results in their response to the COVID-19 pandemic, highlighted in Table 2 above, with a nearly even split of improved to declined performance over 18 indicators.

The neutral result for *treatment works compliance* is due to an established baseline of high levels of compliance across the sector; thus, there are only very minor changes in results. This finding is, however, according to the available water company data shared with Ofwat and the Environment Agency; the reality may be different. In November 2021, an ongoing investigation was launched by Ofwat and the Environment Agency into potential illegal discharging of raw sewage. Permits are granted for companies to discharge untreated sewage to waterways in extreme events where rainfall puts the network or treatment works at risk of being overwhelmed; however, Hammond et al. (2021) showed wastewater treatment plants between 2009-2020 made non-compliant discharges under the guise of precipitation overflows. Due to a quirk in the discharge permits, companies are not required to measure the continuation of the minimum amount of effluent treated, meaning the untreated sewage discharges could be magnitudes greater than what is intended under the permits. Therefore, not only are potential breaches of *treatment works compliance* likely being made, but the extent of the breaches is also unknown; thus, this neutral result may not represent actual performance and performance trends.

The other neutral results were *consumption per capita,* and *volume delivered*, which increased by 2.1% and 4%, respectively, and showed mixed implications. They were posed as mixed results because although an increase in these indicators was negative in the sense that companies and regulators did not want them to increase for efficiency purposes and to protect the sustainability of water resources, they can also be viewed as positive because increased demand for necessary hygiene and personal use could be met.

The largest positive changes were exhibited by *unplanned outage*, which declined by 37%; this was closely followed by *risk of sewer storm flooding* with a decrease of 32%, and *water quality compliance*, which had its measurement of compliance risk decline by 27%. These are significant reductions and improvements to the service and security of water to consumers, despite an increase in total and residential water demand (Abu-Bakar et al., 2021a). It is possible that *unplanned outage and risk of sewer storm flooding* had considerable improvements due to exogenous factors such as a reduction in the frequency and intensity of meteorological events. However, with *pollution incidents* increasing by 2.2% and the Met Office (2021) noting that 2020 (the COVID-19 variable year covered April 2020-April 2021) was a year of extremes with the sunniest spring on record, a heatwave in the summer, a day in October breaking rainfall records, and mean temperature, rainfall, and sunshine increasing compared to the average across the UK by 0.8°C, 14%, and 9%, respectively, the positive results are unlikely to have been exclusively dependent on weather. Furthermore, the significant improvement in *water quality compliance* could partly be attributed to the lack of residential sampling opportunities caused by government-imposed restrictions, although alternative sampling was sought from staff homes, commercial premises, and company property, and when these options were unavailable, surrogate samples at service reservoirs (Ofwat, 2021). Since these were data from water companies from alternative sampling, the positive results should be taken cautiously. However, there has been a trend of sector-wide improvement in the compliance risk index for several years, with particular improvements in taste and odour and Iron concentration being recorded (Drinking Water Inspectorate, 2020).

Whilst there were some considerable performance improvements, some aspects of performance were substantially adversely impacted – primarily related to economic performance. COVID-19 affected the global economy, with developed and developing countries experiencing an estimated decline in output of 5.6% and 2.5% in 2020 (UN DESA, 2021). However, the economic decline appears to have disproportionately affected the water sector. For example, in the sample provided by the World Bank (World Bank, 2020), water utilities saw their income fall by 40% globally due to the suspension of water billing for low-income consumers and moratoriums on supply cut-offs, which were put in place to ensure access to hygiene and ultimately slow the spread of the virus (Butler et al., 2020). The UK and Ireland water sectors were no exception to these economic downturns, although to a lesser and more mixed extent. The analysis revealed the most negatively affected aspects of the UK and Ireland water sectors: *interest cover ratio*, which suffered the greatest negative impact of -21%, followed by *post-tax return on regulated equity* with -21%, and *operating profit* with -18%. Generally, these indicators show that revenue and income declined significantly. The economic indicators are naturally interlinked, though; for example, *operating profit* influences *interest cover ratio*, which affects *credit rating*. However, by utilising multiple and varied economic indicators, it is possible to narrow down key problem areas, and *interest cover ratio* is one of these. This indicator measures a company's ability to cover outstanding debt with incoming revenue, so the lower this ratio is, the less stable and resilient the company is. A significant negative shift is dangerous for the sector, especially if this trajectory occurs over a sustained period. The negative economic results over the COVID-19 period are not unique to the water sector in the UK, with corporate debt rising by 6% in the UK from the end of 2019 to the first quarter of 2021 (UK Parliament, 2022); fortunately, water sector credit ratings only declined modestly.

3.1.2. Economic, environmental, and service groupings

All the economic indicators used in this study show negative results in their change from pre-COVID-19 years, apart from *operational expenditure*, which marginally declined by 2.7%, possibly due to declining personnel, travel, and meter reading costs, along with some staff costs being provided by the government (Atkins and Frontier Economics, 2020), as opposed to an operational efficiency improvement; the effect would thus be expected to be temporary. Conversely, the decline in *capital expenditure* (*CAPEX*) of 3.5% was because capital programmes were delayed or reprioritised from original asset management plans. The reduction in *CAPEX* and new investments in the water sector is an international trend, which is likely to continue in the short to medium terms (Mukhtarov et al., 2022) due to allocation issues and delays in foreign investments, with low- and middle-income countries having possible *CAPEX* declines up to two-digit number percentages. A decline in capital expenditure is a dangerous trend for sector-wide resilience, with infrastructural problems likely to build up over this period.

The economic performance of the UK and Irish water sectors declined during the first year of the COVID-19 outbreak. However, a study by Hall (2022) showed that dividend pay-outs to shareholders from the private UK water and sewage companies were £1.4 billion in 2020 and approximately £0.5 billion in 2021. Furthermore, Hall (2022) proposes that there is evidence that companies likely pay out larger sums than their documented figures, with three devices used to conceal the actual level of dividends: deferring payments, claiming that they are paid to immediate shareholders and not shareholding companies, and so is somehow less significant, or by 'round-tripping', where dividends are paid out to a holding company to use the money to pay off a loan from the operating company to its immediate owner. This is not exclusive to 2021, with an average dividend pay-out per year estimated to be £1.6 billion from 2010-2021 from UK water companies. Hall (2022) and others (Armitage, 2012; Bayliss & Hall, 2017; Yearwood, 2018) argue that excessive dividend pay-outs reduce the money available for investment and have increased the cost of water for the customer, whilst company debts have continued to rise; essentially meaning that companies are financing payments for dividend pay-outs with loans, and the customers are paying more against these debts and interest payments. It appears that the COVID-19 outbreak adversely affected the economic performance of companies, yet shareholder profits were prioritised over company resilience during the disruption. Shareholder payments should be reduced at least in the short term and be flexible to do so into the future if resilience is to be achieved in the water sector, with the decline in interest cover ratio of 21% a warning for what could happen to revenue and debt payments.

Given the economic performance indicators used here, it is surprising to observe an improvement in seven service and environment indicators, with three more having negligible or mixed impacts. The expectation was that as companies' financial performance and stability decline, so does the quality of the delivery of services, particularly under the lockdown provisions imposed across the UK and Ireland, with many staff unable to fulfil their job roles. It is probable that the long history of regulation via asset management plans within the UK water sector, with the first plan dating back to 1990 and the seventh (current) plan in operation until 2025 (Mounce, 2020), has contributed to this sector-wide service resilience. Throughout the years, the specific targets of asset management plans have changed. Collectively, however, they have focussed *on leakage*, efficiency, and customer service, with an emphasis in recent years on resilience, reducing environmental impacts, and digitalisation (Kijak, 2021). These themes and past innovations are apparent in the indicator results, with *supply interruptions* and *unplanned outage* reducing by 8% and 37%, respectively, despite more drinking water entering the system than usual and *greenhouse gas emissions* and *leakage* continuing their declining trends with further reductions of 9% and 4%, respectively, in 2020. It is also possible that these indicators, excluding *greenhouse gas emissions*, were somewhat improved since COVID-19 disruptions because the lower interference of urban traffic may have made maintenance interventions easier. Furthermore, these metrics likely, at least partially, contributed to the improvement in *customer satisfaction* of 4%.

The positive environmental and service results are juxtaposed against the negative economic outlook; however, it is likely that the deteriorating financial position during, and possibly because of, the COVID-19 pandemic, could be felt in the future if continued. The most obvious example is *capital expenditure*, where integral capital projects may have been delayed. In a shorter-term analysis, spending appears to have declined, but the negatives of underspending are not yet shown within available indicators and data (Walker et al., 2020). Leakage management often suffers when companies fall behind on their asset management plans due to less ability to assess, repair, and update infrastructure (Speight, 2015). A similar effect may be expected for *customer satisfaction* since there will likely be increased bills to make up for lower operating profits and a weaker financial position, as well as the increased cost of energy, with UK water prices already rising by 1.7% on average in 2022 (Water UK, 2022). Currently, these are only hypothetical scenarios because the changes are being evaluated one year into the change induced by COVID-19, and it is unlikely that one year of reduced spending would severely affect other areas of water services. However, an extended period of underspending due to either poorer financial positions, misaligned shareholder payments, or restrictions could be significant.

Results can vary from year to year due to the nature of intertwined performance indicators (Walker et al., 2019), and the trends presented here would probably change if the years of the sample were extended, both into the past and future. Broadening the sample further into the past, for example, would change the average or baseline years compared to the COVID-19 variable year, although that would generate questions of validity and representativeness of those years to current market and operating conditions. In this study, a three-year control period was deemed appropriate to capture variances within indicators without using data from an extraneous period (e.g., a different asset management plan and regulation cycle). The time series from the COVID-19 variable year onwards is limited; however, this can only be addressed with future studies applying a comparative approach. Equally, results could differ if alternative or additional indicators were used, but indicators were carefully selected to represent the vital aspects of company performance and regulatory requirements – informed by recent studies (Walker et al., 2020). This study generates a timely yet tentative insight into how the pandemic impacted key performance indicators pertinent to the water sector's short- and long-term resilience.

3.2. Water sector productivity analysis

3.2.1. Whole sector productivity

For 16 UK water companies, productivity analysis was conducted utilising the HMPI to evaluate the efficiency change between the three years leading up to the COVID-19 pandemic (2018-2020) and the pandemic's first year (ending April 2021). To represent the primary operations of water companies, the choice of inputs and outputs is pivotal, which is why *TOTEX*, *water supply interruptions*, and *GHG emissions* were selected as inputs and *volume of water delivered* and *customer satisfaction* were chosen as outputs to cover all aspects of a water company. The methodology's nature and sample size meant that no more indicators could be incorporated into this part of the analysis.

Company scores were generated relative to their peers over time, and productivity change was deemed to increase when TFP was >1 and to decrease when estimates were <1. The average TFP change was positive, with a value of 1.35 from the average of the three years pre-COVID-19 to the first year of the pandemic, as shown in Figure 1, which indicates an average increase in productivity of 35%. This finding signifies that the outputs have significantly grown compared to the levels of inputs across the sector, which is supported by the results in Table 2, showing the outputs of *volume of water delivered* and *customer satisfaction* increasing, but with inputs such as *GHG emissions, water supply interruptions*, and *TOTEX* decreasing. Interestingly, the COVID-19-induced temporary reduction in *OPEX* positively affects TFP results since it appears that outputs are being performed more efficiently. Nevertheless, this substantial improvement is a surprise considering the extent and speed of changes imposed by COVID-19. The UK water sector has been focussing on creating a resilient industry (Rodríguez et al., 2020), where companies actively review operational procedures and responses to anticipated and unanticipated threats (Linnenluecke, 2017). The goal of this process is for firms to have a broad capacity to mitigate, adapt, cope, and learn from a crisis (Butler et al., 2017), and these initial results show that this has been delivered to an extent. There are and will be other challenges in the future, from extended alternative consumption patterns and limited capital project progress from COVID-19, along with increasing energy prices and climate change, but during the year of the pandemic, the indicators chosen showed that the sector’s preparation served it well.

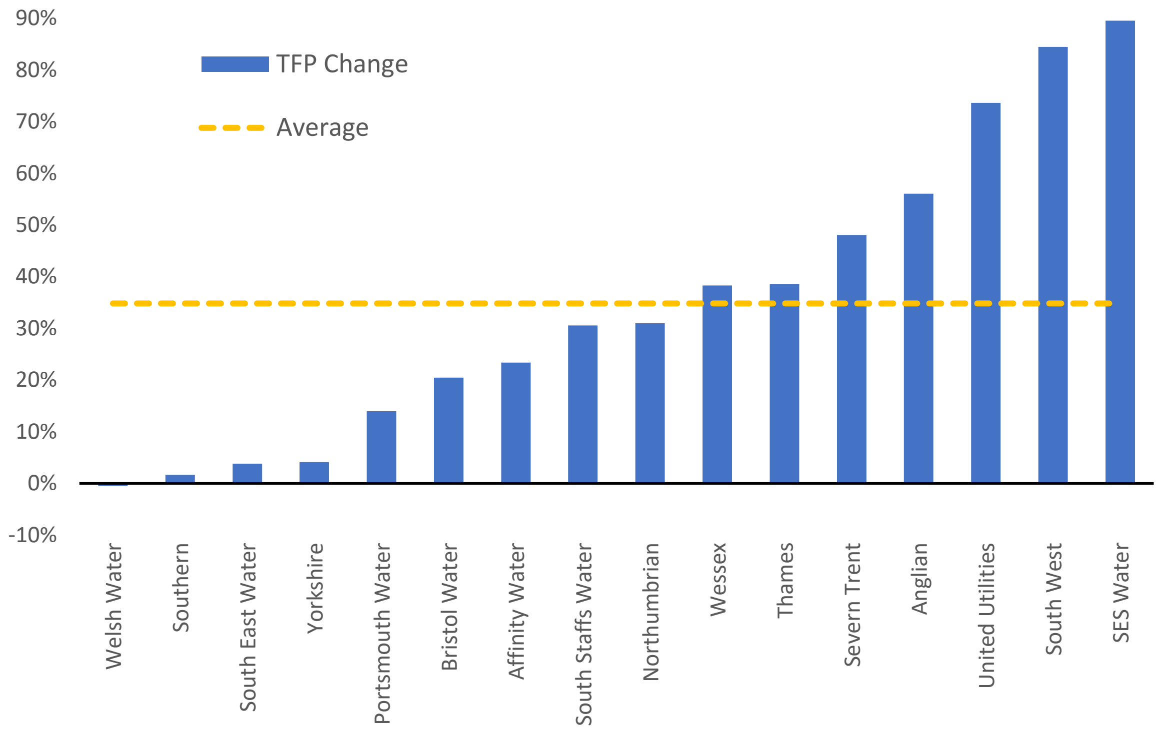

Figure 1. Total factor productivity (TFP) change for the UK sector covering the three years (2018-2020) leading up to, and the first year of, the COVID-19 pandemic (2020-2021).

The positive and resilient performance displayed in the results is echoed in other studies, too. For example, Lawson et al. (2022) conducted 11 interviews with UK water executives to evaluate organisation responses during COVID-19. They found the UK water sector's preparation to be effective, with pandemic contingency plans, past incident management experience, water network pressure management, and existing customer support, to all be contributing factors to the positive response of the sector. Furthermore, industry-wide collaboration in response to Brexit and preparing for that by securing reliable supply chains helped ensure sound strategies were deployed when the pandemic began (Cotterill et al., 2020). Despite the positives found across the studies, a concluding point from Lawson et al. (2022) was that the pandemic highlighted some pre-existing system vulnerabilities, with a realisation of risk displayed across the sector, and perhaps pre-existing pandemic plans were not prepared for the scale of the COVID-19 pandemic.

The mixed response of the UK water sector displayed across Sections 3.1 and 3.2 can still be considered resilient in core activities; however, according to a report by the Stockholm International Water Institute (SIWI) and United Nations Children's Fund (UNICEF) (2021), this appears not to have been a universal response. Outside of the UK, changes to demand patterns, supply disruptions, and government measures have posed a significant risk to the operational reliability of services, sustainability, and the financial viability of providers. The pressures have exposed inadequate and fragile services, resulting in lower levels of sanitation, which has disproportionately affected poorer communities. Furthermore, COVID-19-induced government restrictions, supply chain disruptions, and increases in chemical and fuel prices have culminated in a lack of maintenance and poorer operation of infrastructure. As noted in Section 3.1, *CAPEX* has declined in the UK, and is a trend seen elsewhere. A study by Goldin et al. (2022) showed how such underspending negatively impacted 46% of water industry projects in South Africa. The resulting global service gaps have been a major theme in the water sector alongside the threatened financial sustainability of providers (Mukhtarov et al., 2022). SIWI and UNICEF (2021) document how these shortcomings may be a springboard for reform towards resilience via digitisation, leakage reduction, increased efficiency, and stakeholder and citizen engagement, somewhat similar to how the UK has developed over the past couple of asset management planning cycles.

3.2.2. Company productivity

Average productivity results for the UK water sector were above what was anticipated; however, the range of relative company performance was vast (Figure 1). SES Water and South West lead the sector over the sample period, with +89% and +84% productivity change, respectively. SES water interestingly had slight declines in performance across *TOTEX*, *water supply interruptions* and *customer service* but had substantial improvements in *GHG emissions* of 77%. Similarly, South West did not improve in all indicators with the increase in *TOTEX*; however, it significantly improved *water supply interruptions* by reducing them by 69.5%. In a more traditional efficiency and productivity analysis of water companies (Molinos-Senante et al., 2017; Molinos-Senante & Maziotis, 2020), these companies would have performed much differently since the big improvements were in service and environmentally based indicators, which are often neglected.

In reality, companies have not improved in efficiency by an average of 35% or had individual peaks of 89% in the traditional sense, i.e., operations as a whole; however, when taking into account the specific selected key performance indicators as we have here, companies and the sector as a whole have performed surprisingly well during the pandemic. The perceived substantial increases in productivity were mainly due to the inclusion of sustainability-focused metrics, which have taken more of a priority in recent years. Due to the recent focus on such metrics compared to conventional indicators, they will naturally have more influence on perceived performance, and *GHG emissions* are a perfect example of this. There was a sector-wide change of -9% in *GHG emissions* per m^3 from the average of the three years preceding the pandemic to its occurrence. This finding is likely due in part to the continued decarbonisation of the electricity grid that supplies much of the sector's energy and not operational efficiency gains within companies' control, which has inflated the productivity results.

For example, the UK electricity grid lowered the average $kgCO_2e/kWh$ from 0.232 across 2017, 2018, and 2019 (years of the pre-COVID baseline) to 0.156 in 2020 (BEIS, 2021).

Only one company, Welsh Water, exhibited a negative TFP change, albeit narrowly at -1%. This result was the outcome of the comparative nature of the methodology and having low levels of improvement, for example, being the second worst performer in *customer satisfaction* and *GHG emissions* change, with results of 0.6% and -8.2%, respectively, in conjunction with an increase in spending of 1.2%. Welsh Water note in their 2021 annual report the challenges from COVID-19, which had a 'detrimental effect' on their energy self-sufficiency, reporting self-sufficiency of 23%, falling short of their 31% target for the year (Dŵr Cymru Welsh Water, 2021). The two attributable factors documented were a hydropower system being offline for five months and an advanced anaerobic digestion plant being delayed by several months, and it is these shortcomings, amongst others, that likely caused the company's *GHG emissions* not to have declined as much as their peers. Although Welsh Water did have a negative TFP score, they were amongst a distinct group of four, additionally made up of Southern (2%), South East Water (4%), and Yorkshire (4%), who trailed behind the next company Portsmouth Water by at least 10%. It is feasible that these companies can improve further by learning from resilient structures, procedures, and practices from top performers by, for example, evaluating their approach to *GHG emissions*, both at management and technological scope, and assessing their strategies to lower *water supply interruptions*, particularly in a period of overall increased consumption and shifting consumption patterns to residential over the business.

The results presented and discussed here can have real value in informing the process of building and maintaining resilient operations; however, the study did have limitations. Foremost, productivity results are driven by indicator choice, and whilst the indicators in this study attempted to cover all aspects of a water company's operation in a manner encompassing key sustainability themes of economics, society, and the environment, alternative perspectives and objectives could significantly change results. For example, more economic indicators would likely have shown a poorer performance and response to the COVID-19 pandemic, with *operating profit* and *interest cover ratio* declining considerably (Table 1). Varying scopes across Sections 3.1 and 3.2 allows for the fullest display of response from the UK and Ireland water sectors based on data availability and quality.

Indicators and the nature of efficiency models, particularly when evaluating the water sector, have interesting quirks. As such, the way *volume delivered* is treated in the analysis is noteworthy since when company efficiency is based on minimising inputs and maximising services, delivering more water at the lowest cost is deemed positive (which it is to an extent). However, the water providers are unique as a business since attempts are made to reduce the volume of water consumed via education campaigns and water-saving devices, to manage water resources more sustainably (Abu-Bakar et al., 2021b), which is why the increase in *volume delivered* is highlighted as a mixed result in Table 2. *Volume delivered* is still treated as a typical yet imperfect output here because a company still performs more efficiently if it provides its core service for lower costs. Because COVID-19 induced increased water consumption, though, the entire sector appears more efficient. Furthermore, *Volume delivered* does not include all water put into the network and leakage, so it is possible there are inefficiencies not being captured, leading to skewed productivity results.

In addition to temporal sample coverage effects outlined in Section 3.1.2, which impact many efficiency analyses evaluating year-on-year change (Albrizio et al., 2017; Walker et al., 2022), proactive companies possibly performing well over the long term are viewed relatively unfavourably in a shorter-term study. For example, early adopters of sustainability-focused metrics may have already reduced their *GHG emissions* in the years preceding the sample period in this study. Therefore, it is possible that the significant gains that are often achieved in the early adoption stages (Forés, 2019; Sousa-Zomer & Miguel, 2018) are not captured, and companies can appear that they are performing comparatively worse than their peers who may have only started improving in recent years. This idiosyncrasy is often a risk; however, it is unavoidable under data availability constraints. However, when analysing this possible skew, the baseline performance of all companies showed a weak relationship with the percentage changes of each of the five indicators used, with a R^2 ranging from 0.001-0.29 (details can be found in the Supplementary Information), showing that the starting point for companies did not significantly impact their COVID-19 comparative performance results, i.e., lower baselines did not necessarily mean larger positive changes. Remembering the eminent words of George Box, “all models are wrong, but some are useful” (Box and Draper, 1986) provides the appropriate context for the results in Section 3.2 in light of the limitations outlined.

4. Conclusions

The objectives of this study were to evaluate how the water sectors in the UK and Ireland were affected by COVID-19 from a holistic sustainability and resilience-based perspective, using publicly available key performance indicator data and productivity analysis. When evaluating performance change with 18 indicators spanning all areas of company operation, the sector displayed mixed results, with a near even divide between declining metrics, which were predominantly economic, and improving metrics, which mainly were service based. The most improved indicators were *unplanned outage*, *risk of sewer storm flooding*, and water *quality compliance risk*, which decreased by 37%, 32%, and 27%, respectively. Despite the increase in total and residential water demand, these results represented significant improvements to the service and security of water to customers. Conversely, the worst affected indicators were *interest cover ratio*, *post-tax return on regulated equity*, and *operating profit*, which exhibited declines of 21%, 21%, and 18%, respectively.

Further conclusions were drawn following the productivity analysis, where *TOTEX*, *volume of water delivered*, *customer satisfaction*, *water supply interruptions*, and *GHG emissions* were modelled as inputs and outputs within the HMPI. The average productivity change of all companies was positive at 35%, compared to the preceding three years of COVID-19. However, the productivity model was necessarily based on a limited number of indicators, chosen to encompass the main aspects of company operations, and the balanced representation between financial and service indicators displayed the sector to be much more productive in the breakout year of the pandemic.

The results suggest that the UK and Ireland water sectors were somewhat resilient to the COVID-19 pandemic, supported by past innovations and planning. However, it is possible that many of the adverse effects arising from a poorer financial position following COVID-19, if continued, could manifest in the future, exacerbating exogenous pressures such as climate change. Although the economic downturn across the sector is likely only to be temporary, it is recommended that non-critical spending, including shareholder payments, should be scrutinized during periods of the economic downturn to support long-term resilience and that lower-performing companies learn from the best practice of their peers. Furthermore, resilience in response to COVID-19 does not necessarily mean the water sector will be resilient to all future disruptive events, such as climate change and exposure to new contaminants. Thus, it is vital to continue to build on the successful aspects that put the sector in a good position, like digitisation and the management structure that allowed a fast response. Future research could overcome the limitations of the study by expanding the sample years and indicator selection, which would capture any lag effects or slower changing indicators, significant variation in sustainability metrics, and environmental influences and generate a complete picture of the long-term impacts of the COVID-19 pandemic on the water sector. This study provides novel insight for the water industry, sector regulators, and academia by generating preliminary quantitative sustainability-focused analyses of the resilience of the UK and Ireland water sectors in response to COVID-19.

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