5G Wales Unlocked Observatory Final report – Final

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Executive summary

Cardiff University's Business School and Geography and Planning departments have worked alongside the DCMS-funded 5G Wales Unlocked (5GWU) project to assess the progress, challenges and outcomes achieved. This included research to examine the implementation and benefits of use cases in Monmouthshire (Tourism) and Blaenau Gwent (Education and Transport). The results of this research include a model to value the demand and benefits associated with 5G deployment in a rural area. All research was undertaken between June 2021 and the end of March 2022.

A review of the literature suggests that 5G represents a substantial evolution of earlier telecoms networks (e.g. 4G), offering the potential for greater download speeds, but also greater robustness and reduced latency, as well as potential for industry to innovate. Key developments associated with 5G include the growing role of the cloud in hosting elements of the network, but also neutral host technologies that allow multiple vendors to provide infrastructure services. These technologies offer the potential for cost reductions in network deployment, which may help to support the case for greater levels of rural deployment. The growth of 5G is also predicated on the greater ability to 'slice' networks, allowing public and private actors to isolate part of the network.

An examination of the evidence for economic effects of 5G networks finds that new applications and services associated with 5G are likely to boost productivity by reducing operational costs. This may be achieved through greater operational efficiencies, through factors such as automation and the enablement of working from home. It may also support climate change objectives by efficient management of traffic and energy use. Such potential impacts are, however, tempered by a potential for the reduction in employment opportunities. Achieving these outcomes will require a number of challenges to be addressed, particularly if 5G connectivity in rural areas is to achieve parity with that of urban areas. This includes potential barriers such as the distance to fibre backhaul networks, access to land and electricity, plus comparatively lower demand bases – all of which are likely to be present in rural areas.

In Wales the findings show 5G deployment is currently in its infancy, with Ofcom (2021) estimating that some 3% of 5G base stations are present in Wales. It does show, however, that initiatives such as the Shared Rural Network are helping to ensure greater 4G coverage across rural areas of Wales. While there are no universal plans to upgrade masts to 5G in Wales' rural areas, the research shows that there are already a number of 5G masts present in rural areas of Wales. These developments are understood to respond to local user demand (e.g. tourism), research and innovation activities. Plans were also noted in the Swansea Bay City Deal and North Wales Ambition Board regions to explore opportunities for 5G.

Planning has been identified as a cross cutting issue for the delivery of digital infrastructure in rural areas. The research examined the extent to which the planning system was shaping the roll out of such infrastructure. Based on planning applications the findings suggest that the majority of telecommunications infrastructure proposals in rural (and urban) areas that require consent receive it. The most challenging areas are likely to be the most scenic parts of designated landscapes, where the impact of masts are most significant. While planning procedures can take time and create uncertainly for stakeholders they can also aid facility siting and impact management, contributing to lowering public controversy surrounding network development. Indeed other factors such as network economics are likely to be more important in shaping MNO decisions over investment.

The review of progress of the use cases shows that 5GWU has largely succeeded in achieving its objectives to support 5G deployment and use in different rural areas of Wales (Monmouthshire and Blaenau Gwent) and sectors (farming, education, tourism). This has enabled new network and associated technologies to be tested. Delays in establishing the project (due to Covid-related factors) have meant that much of the use case implementation was undertaken towards the end of the funding period. While this limited the potential to fully capture impacts from the project activity the findings suggest that the use cases were able to reveal lessons that will be valuable to subsequent deployment of 5G in Wales' rural areas.

In assessing cost-benefits of the 5GWU project the research finds difficulties in valuing the benefits of the use cases at such an early stage. It does, however, point to the potential areas of new service opportunities, efficiencies and supply models, with direct benefits to business, citizens and public sector bodies in rural areas of Wales. Based on a demand and impact discussion model (using Monmouthshire as a reference case) it finds that 5G adoption in rural Wales could produce an uplift in GVA of 1% across all sectors. This model is illustrative and will need to be subject to further development before wider use – particularly around the productivity and employment effects of 5G deployment in rural areas. It is noted that other measurement approaches that focus on tangible and intangible benefits including the Themes, Outputs and Measures (TOMS) framework, this may help to value other aspects of 5G deployment.

Analysis of business models suggests that there is no current commercial MNO model for deploying 5G in rural areas. MNOs are currently focused on ensuring they maximise use and profitability of their 4G networks and services. The current examples of 5G in rural areas of Wales are outliers in the sense that they are responding to localised demand factors (or public intervention) that are not present in all rural areas. The rationale for new approaches to supporting faster 5G deployment in rural areas is therefore potentially strong (with the Tourism and Use cases strongest amongst those studied in the 5GWU project). A number of organisational models for public sector intervention are revealed in the findings, some of which may not require a major role for MNOs. In particular they allude to the importance of public-led models based on social and environmental outcomes, alongside economic outcomes. It also highlights emerging neutral host technologies and the potential for public organisations to act in an anchor role for new network developments.

The research concludes by considering policy options that could support both public and private deployment of 5G in rural areas. These findings suggest that demand-led interventions are best placed to maximise the availability of 5G in rural areas, alongside strategic support for other public bodies seeking to deploy 5G, plus actions to address barriers and raise awareness. It is unlikely, however, that 5G will be needed in all rural areas. Indeed the findings highlight the importance of demand and value assessment (such as the discussion model presented in this report) in any future public case for 5G network development.

1. Introduction

This report sets out findings from Cardiff University research on the Welsh Government 5G Wales Unlocked (5GWU) project. This was funded by the UK Department for Media, Culture, Digital and Sport (DCMS). The research aims to test the potential for 5G in rural areas through a series of use cases focused on two local authority areas of Wales – Monmouthshire and Blaenau Gwent, with the support of project partners (see Annex). The project operated between June 2021 and March 2022.

The report draws on the work of the 5GWU Observatory, led by Cardiff Business School and the Cardiff University School of Geography and Planning. Included in its programme of research were a series of project case studies, mapping of 5G activity and plans, analysis of planning and cost-benefit impact analysis.

The background to the project and the work of the Observatory is one of persistent socio-economic differences between more rural parts of Wales and the core. This is most conspicuous in productivity differentials. 5G technologies might have a role in levelling access to economic opportunities, but also facilitating innovation in existing rural industries.

The report draws on evidence from documentary review and a series of consultations with stakeholders associated with the four use cases: Tourism, Farming, Transport and Education, and wider planning and sectoral stakeholders.

It provides evidence and analysis of:

- The deployment and achievements of the use cases
- The planning considerations associated with 5G deployment in rural areas
- The expected economic costs and benefits of 5G roll out in rural areas of Wales
- How far the roll out of 5G in more rural parts of Wales might grow new business and public sector demands
- A demand and value discussion model to capture the economic impacts of 5G investment in a rural areas

The structure of the report is as follows: review of the literature on 5G and economic impacts (2), planning and its implications for 5G in rural areas (3), 5G and mobile connectivity in Wales (4), the use case synthesis (5) cost-benefits analysis (6), and conclusions (7).

2. Literature review: 5G in rural areas

The delivery of fast and reliable internet connectivity is a significant issue for all countries and regions. With most parts of developed economies, such as the UK, now able to access superfast broadband and 4G network coverage, attention has shifted to the latest generation of mobile networks, i.e. fifth generation (5G) (DCMS, 2020). Concerns, here, have also focused on the future position of rural areas in the deployment of 5G and whether they will continue to lag behind their urban counterparts in access to such technologies.

5G technology is said to constitute a breakthrough in the way that firms and individuals use telecommunication services (Schneir et al., 2018). 5G marks the next step in the transition of mobile services based on cellular technology that was begun in the 1980s (Oughton et al., 2018). The 5G network is characterised by novel trends such as network densification, spectrum expansion, and network efficiency increases (Zhang et al., 2015; Lehr et al., 2021). This rapid technological evolution has been based on the growing importance of mobile broadband as a necessary service for residents and organisations, and has seen industry concentration amongst mobile network operators (MNOs) (Queder et al., 2020).

It is believed that the introduction of 5G will help to improve the quality of telecommunications through higher-speed wireless broadband, improved strength of the signal from sensors and reduced latency (Moqaddamerad et al., 2017). On the one hand, 5G could create new services, with important social, economic and environmental benefits. These new services and the subsequent benefits relate to 'vertical sectors', such as energy, healthcare and logistics (Schneir et al., 2018). It is expected that the introduction of 5G will contribute towards a dramatic increase in data generated and processed through such networks, which in turn, may help to improve productivity and stimulate entrepreneurial activity (Lehr et al., 2021).

Given these potential benefits, 5G technology has attracted the interest of policymakers in most developed countries. Although 5G networks remain under development in most countries (Oughton and Frias, 2018), concerns have been raised that the management of these networks may bring digital divides between people or places (Schneir et al., 2018). This fact raises the issue of the geographically uneven implications of 5G deployment - a topic that has only recently been given attention in the academic literature (Oughton and Frias, 2018).

5G innovations

Cell and mobile connectivity are at the forefront of innovation in the telecommunications sector and the wider digitalisation of the global economy (DCMS, 2020). While being the outcome of continuous technological evolution, 5G networks differ significantly from earlier generations of cell connectivity in a number of areas (Oughton et al., 2018; Queder et al., 2020):

First, from the supply side, the design of 5G technology has encompassed a wider range of stakeholders than in earlier network generations (Lehr et al., 2021). This has seen private 5G networks deployed independently of MNOs, offering the potential for a greater bottom-up approach to 5G deployment than has been seen in other digital network developments. It also points to the potential for MNOs to play a comparatively smaller role in 5G deployment and services (than in earlier rounds of telecommunications development), with other service providers emerging, for example in different industry sectors (Curwen and Whalley, 2021).

Second, unlike 4G, 5G technology offers extended virtualization technologies, known as 'network slicing'. This creates new business opportunities to allow users to isolate part of the network (Afolabi et al., 2018). This has the potential for cost advantages, the provision of specialist services to industry sectors (Curwen and Whalley, 2021). Utilising 5G technologies slicing with neutral host networks, also known as multi-tenancy, for both small and macro cells could further reduce costs for deploying 5G network in rural regions (Kumar et al., 2021).

Third, to facilitate all these capacities, 5G technology requires a much greater network densification, with a greater number of cells than 4G (Oughton and Frias, 2018). This includes the development of smaller cells (microcells, picocells, or femtocells), splitting existing ones or creating small new cells, in order to take advantage of a high frequency spectrum that enables mobile edge computing (Bhushan et al., 2014). The latter could bring access points closer to mobile users and networks closer to storage and computation resources, resulting in network capacity increase and latency reduction (Zhang et al., 2015; Lehr et al., 2021). The introduction of self-driving vehicles in the future may represent further impetus for the introduction of small cells in street furniture (Curwen and Whalley, 2021).

Fourth, 5G technology can address and create market opportunities for IoT, such as the installation of sensors on street furniture and other forms of infrastructure (ITU, 2015). Such IoT applications will allow data to be collected from a range of different sources, helping to improve predictability and productivity (Tang et al., 2021). Such developments represent an integral component of the Smart City concept and its offer of positive economic outcomes (Almobaideen et al., 2017; Bresciani et al., 2017). These advances depend on the availability of sensors, services and devices such as smartphones and other telecommunications devices (Hong et al., 2016).

Such innovations introduce a greater "toolbox of capabilities" to firms than offered by previous generations of mobile connectivity (Lehr et al., 2021: 2). It is noted, however, that the driver of new network technology in recent years has largely been the desire of users to download video much faster[1]. Indeed it has been suggested that 'what operators need most of all is to use their existing…networks more intensively…to increase their ability to

[1] Curwen and Whalley (2021) estimate that by the end of 2019 approximately 60% of all cellular traffic took the form of video (p. 40).

generate revenues and to achieve an improved rate of return on investment' (Curwen and Whalley, 2021: 200).

Other potential developments in 5G may be driven by 'outsider' businesses such as the cloud providers, for example Facebook's Telecoms Infrastructure project. This aims to work with telecommunications partners to innovate in network infrastructure and develop flexible, low cost solutions in particular locations. This is currently in its early stages, but points towards a future in which MNOs are not the sole actors associated with 5G network and service development (Curwen and Whalley, 2021).

5G benefits

The technical benefits of 5G technology include its high capacity and connection density, wide coverage, reduced latency, seamless connectivity and improved spectral and network energy efficiency (Tang et al., 2021). It is recognised, however, that 5G is currently an urban phenomenon in most countries, where deployment costs are comparatively lower, and dense populations and subscriber bases enable greater profitability for MNOs (Chiaraviglio et al., 2017).

The positive economic impacts of technological advances in telecommunications have, however, been widely acknowledged (Matinmikko et al., 2018; Lehr et al., 2021). Innovative applications and services could significantly boost economic growth (Kraft, 2010; Hong, 2017). Telecommunication innovations are likely to improve productivity in a regional economy by reducing the operational cost, although having potential negative implications for employment growth (Oughton et al., 2018). The UK Government estimate that the regional economic impact of 5G, if accompanied by full-fibre deployment, over a 15 year period would be a benefit ratio of £11:1, £3.5:1 with universal service obligation in the rural areas, and 1.5:1 when both 5G and IoT benefits are accounted (Reported in Cardiff Capital Region, 2020).

While high speed connectivity is frequently linked to full-fibre broadband, 5G technology is also expected to deliver speeds up to 1 Gbps for mobile users and 10 Gbps for stationary users (Oughton and Frias, 2018). The high speed of 5G connections, alongside rapid response times could entail a higher number of users accessing large data amounts simultaneously, thereby supporting several applications (DCMS, 2020). Indeed, a survey in the UK indicated that around 85% of respondents believed that 5G technology could help their firms generate a higher level of revenues, enabling remote working locations (RootMetrics, 2020).

In rural areas 5G offers a range of potential benefits. In the agriculture sector, for example, 5G technology may provide the basis for improving quality and yields of crops, reducing labour and overall cost, and thus improving productivity in farming (Tang et al., 2021). IoT services may also enable the automated operation of smart farming applications such as automated tractors. Tang et al. (2021) summarise the potential application benefits of 5G in agriculture as real-time monitoring, virtual consultation, predictive maintenance, artificial intelligence robots, data analytics and repository, use of UAVs, as well as augmented and virtual reality.

The impacts associated with 5G are also mediated by the version that is available. At the time of writing the 5G network in the UK is based on the existing 4G (4.5G) network. The eventual transition towards an independent, standalone 5G network is expected to offer much greater opportunities for machine-to-machine communication (Curwen and Whalley, 2021).

Besides, during the current climate change crisis, 5G deployment could be valuable in efforts to mitigate and cut emissions in different economic sectors. According to a recent report by Mobile UK (2021), 5G technologies could reduce the total carbon emissions of the combined G7 manufacturing sectors by 1% by the end of the 2020s, thus supporting the UK Government's target of reaching "net zero" greenhouse gas emissions by 2050. In particular, they may be able to cut annual carbon emissions in manufacturing by 2.6 $MtCO_2e$ by 2025. Moreover, smart transport solutions powered by 5G could help to control and streamline traffic, thereby reducing energy used by 13-44%. Specifically, 5G networks also provide the potential to reduce annual transport emissions by 6.6–9.3 $MtCO_2e$. Finally, drones and sensors employing 5G technologies could cut emissions in agriculture by 1 $MtCO_2e$, thus improving process efficiency.

5G challenges

While acknowledging the potential benefits of 5G a number of authors recognise the challenges of ensuring these are realised in rural areas (Oughton and Frias, 2018), and the potential for uneven deployment to produce socioeconomic divides (Koutroumpis and Leiponen, 2016). These concerns are reflected in policy action to address 'not spots' and to ensure widespread coverage of 5G (Webb, 2016).

Identified challenges to deployment are similar to fixed line broadband, and relate to the distance from existing telecommunications infrastructure, topography, access to land, and availability of electricity infrastructure (Chiaraviglio et al., 2017). In densely populated areas, the comparative access to networks, population are that much greater than in rural areas. It is therefore expected that 5G networks will be initially deployed in urban areas, where revenues from subscribers are higher than capital and operational expenditure costs. This can be seen in the deployment of 4G, where some 83% of premises in urban areas in Wales have access to 4G, in comparison to 40% in its rural regions, (DCMS, 2020). In the UK, the 5G network is largely available in the major cities. Oughton and Frias (2018) estimate that while 90% of the population in UK rural areas could be covered with 5G by 2030[2], coverage is highly unlikely to reach 100% due to exponentially increasing costs.

Another challenge relates to the importance of fibre backhaul for 5G (Curwen and Whalley, 2021; Cardiff Capital Region, 2020). This, however, is not available in all regions, with

[2] Oughton and Frias (2018) argue that London accounts for over 6 million of the 16 million users covered in the first year of 5G deployment, whereas Wales only accounts for less than 200,000 users. The annual spatial rollout across Britain using Ofcom's standard statistical geography, visualised geographically, emphasises that England (98%) receives near-ubiquitous coverage by 2030, whereas Wales (90%) and Scotland (86%) have areas that are still poorly served by the market at the end of the study period.

pockets of older copper connectivity still evident. Deployment of 5G will therefore need to be viewed alongside rolling out fibre in many rural areas.

In light of these challenges, government intervention may be necessary to ensure full coverage of 5G in rural areas (Chiaraviglio et al., 2017). To this end such intervention is evident with respect to the UK Government's funding of 5G Testbeds and Trials [3]. This support is focusing on early stage development of technological solutions to deployment, recognising that more evidence of the social and economic benefits of particular uses is necessary to encourage further MNO roll out. Additional public funding, however, is likely to be required to ensure harder to reach areas are connected to 5G (Chiaraviglio et al., 2017).

5G business models

Different business models of 5G deployment have been suggested by scholars and policymakers (Moqaddamerad et al., 2018; Oughton et al., 2018; Lehr et al., 2021). It is expected that MNOs will be the main providers of 5G networks, particularly in the urban areas, emerging as the dominant players of wireless connections in the short term future (Chiaraviglio et al., 2017). All 5G deployments in rural areas, however, are likely to require partnership between operators and local/regional organisations in order to fund and support the roll out of such an infrastructure (Oughton et al., 2018).

Public intervention to support the deployment of 5G networks in rural areas is evident in the recent UK Public Sector Spectrum Release programme to deliver bands of 750 MHz of sub10 GHz spectrum (DCMS, 2020). It can also be seen in the Shared Rural Network programme supported by MNOs and the UK Government. Although targeting 4G connectivity in rural areas the funding model for this programme (based on supporting the operating costs of MNOs for a time limited period) is an example of how 5G could be supported. This sharing of networks (active and passive elements) has been identified in the literature as helping to ensure the viability of 5G coverage (Curwen and Whalley, 2021; Oughton et al., 2018), and may offer potential for rural areas.

Private networks represent an alternative model and offer the potential for local communities to collaborate in securing 5G access (Ahokangas et al., 2021; Curwen and Whalley, 2021). This model has been introduced in securing fixed line mobile deployment (via grant funding) and could help support private network models of 5G deployment (although it is noted that MNO models may be more appropriate in demand intensive settings). Such models have been explored in the UK Test Bed and Trials project where the Liverpool 5G project has developed a publicly owned network[4] capable of delivering voice, text, data and video services in a local area. This model might have wider applicability. More broadly such networks are expected to provide significant opportunities for private firms that wish to connect machines wirelessly without the need for human supervision,

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https://www.gov.uk/guidance/5g-programme-findings#:~:text=The%20UK%20is%20considered%20by,even%20once%20they%20have%20concluded.

[4] https://liverpool5g.org.uk/

and to provide services to their own customers. This may enable them to take advantage of the flexibility offered by a private network to restructure activities and prioritise functions through services such as network slicing (Curwen and Whalley, 2021: 193).

A further option discussed in the literature is making use of UAVs to boost connectivity to 5G nodes, powered by batteries and solar panels (Chiaraviglio et al., 2017). This would require several UAVs to achieve connectivity in most rural areas. Chiaraviglio et al. (2017)'s analysis suggests that such models could provide adequate service to the population in rural areas, taking advantage of renewable energy, while also keeping the monthly subscription fee relatively low.

3. 5G and its implications for planning

This section sets out the main findings from our review of the role of the planning system in shaping the economics and efficacy of delivering digital infrastructure networks in rural areas. Planning has been identified by DCMS as an 'cross-cutting strategic issue' for its 'Rural Connected Communities' programme, filing it under the label 'barriers to deployment' (DCMS 2019, p.6). However, systematic analyses of the extent to which planning is actually a barrier to digital network development are limited (Yardley et al. 2017), raising questions as to whether further liberalisation of planning – the common policy solution - will yield positive system development outcomes, or create risks. The case study uses the 5G – Wales Unlocked project as an opportunity to dive deeper into the effects of planning, vis-a-vis other factors affecting digital infrastructure supply, and identify prospective issues for 5G.

The aim of this section is to analyse the extent to which the planning system is shaping the roll out of digital infrastructure in rural Wales, identify the implications for 5G deployment, recommend possible solutions and identify where further research may be helpful.

The spatial policy context

Although telecommunications policy is reserved to the UK level, devolution has given the Welsh Government important powers in a number of areas, notably planning. Planning regulation for telecommunications infrastructure in Wales is structurally similar to that in the rest of the UK in that there is a three-tier consenting system (Hutton 2021):

- Permitted development rights (PDR): giving operators rights to build certain categories of infrastructure without needing planning permission from the local authority.
- Prior notification: for certain categories of development that fall within PDR, operators must seek prior approval from the local planning authority, which is required to respond within 56 days, and only allowed to consider the siting and appearance of the development.
- Planning permission: where infrastructure proposals fall outside the criteria for permitted development, then full planning permission needs to be sought from the local planning authority, which entails wider consultation and enables other issues to be raised.

Physical scale is the main factor that defines the parameters for each of these tiers, for example the height of masts. The boundaries between these different tiers has shifted incrementally over time, in response to changing public and environmental concerns about telecommunications and digital infrastructure balanced against government desires to facilitate infrastructure deployment. Since 2010 in particular, the trend has been to progressively extend permitted development rights to larger facilities (e.g. higher masts), reflecting the belief that reducing planning control helps expedite system development. Permitted development rights have usually not been extended to the same extent in sensitive areas (such as National Parks). In planning terms, devolution has meant that

Welsh Government has set these parameters at slightly different times and levels to the other devolved nations and the UK Government (for England).

Planning and the roll-out of telecommunications infrastructure

The effects of planning on societal outcomes, be it digital infrastructure or anything else, is always difficult and complex to evidence (RTPI, 2020). Nor is it judgement-free. Planning is designed to balance multiple goals and not simply expedite development. Different actors take different views on how delivery should be balanced against other goals, such as landscape protection; and few straightforward, unambiguous outcome measures exist.

Our own analysis of planning applications gives similar results to previous research - the effects of planning on the role out of digital infrastructures is mixed, nuanced and contested. The majority of telecommunications infrastructure proposals that require consent receive it (see Arcadis, 2017). Levels of outright refusal are low (see Table 3-1), and in line with outcome patterns for planning applications in general.

Table 3-1 Outcomes of telecommunications applications in selected Welsh Local Planning Authorities

LPA	No. of applications	Accepted	Rejected	Withdrawn	Prior app. required but refused
Monmouthshire	12	12			
Brecon Beacons NP	17	13		4	
Cardiff	59	51	3	4	1
Newport	56	50	3	3	
Powys	11	11			
Blaenau Gwent	13	12	1		
Torfaen	11	8	2		1
TOTAL	**179**	**157**	**9**	**11**	**2**

Note: includes only applications that have been determined, for period 01.01.2010 to present; includes full planning applications and prior notification applications.

Taking planning applications through the relevant procedures takes time, and can inject uncertainty, yet many categories of digital infrastructure development are permitted development and most applications get consent eventually. Industry respondents in particular strongly contend that achieving planning compliance can disincentivise infrastructural configurations that would achieve coverage more economically and effectively (such as taller masts), but it is hard to evidence the scale of any such effect. On the other hand, planning and environmental checks may aid facility siting and impact management, and this may in turn contribute to the generally low level of public controversy that rural network development in Wales attracts.

Importantly, rural areas do not, in general, experience more network infrastructure planning problems than urban areas. However, rural areas are themselves differentiated. In many rural areas, greater digital connectivity is welcomed but there are other areas which are challenging because of their particular landscape or heritage qualities. Promoting digital network development in such sensitive areas may require careful planning, but it is hard to say that the planning system causes these situations.

Many respondents mentioned the importance of digital champions in helping to foster a supportive local political and policy environmental for network development. Digital champions not only provided a clear 'front door' for digital network companies looking to work in a local authority area, but their informational role also ensured that planning decisions on infrastructure were undertaken with cognisance of wider system development agendas.

Will 5G bring more of the same?

In certain respects, the planning implications for 5G in rural areas, for backhaul connections, are likely to replicate or slightly intensify problems experienced by earlier rounds of technology. How far this is so, depends on the extent to which 5G rural networks rely on mast-based system architecture. Where masts are utilised, the performance of the Shared Rural Network (SRN) programme will be important in both setting the context for and providing an important learning opportunity for prospective 5G extension. The process of delivering new, shareable but often bulkier masts in previously unserved rural areas through SRN will indicate the social acceptability, and available siting solutions, for such facilities. Once in place, the new facilities may well form the basis of future 5G (non standalone) systems.

However, 5G is emerging within a diversifying ecology of provision, both in terms of technologies, providers and business models, such that it is not clear how far future network development will rely on conventional mast-based backhaul. On the one side, much depends on the extent to which fibre networks reach into rural areas, or on how satellite-based connectivity evolves, as both may increase coverage and capacity without the types of infrastructure (masts) most likely to encounter public and environmental concerns. In addition, there is a profusion of smaller delivery companies already active in providing fixed and mobile broadband connectivity that are increasingly confident in their capacity to get network coverage into areas left aside by dominant modes of provision. Similar confidence is expressed by actors involved in innovative 5G projects from the DCMS Connecting Rural Communities Programme, notably 5G Rural Dorset and West Mercia Rural 5G. In many instances, solutions are formed by utilising existing assets as network element hosts, based on local knowledge, and prove compatible with sensitive landscapes. Such operators do not characterise planning as a problem.

Insofar as rural 5G is likely to emerge through a much more mixed economy of provision, then planning problems might be expected to reduce in scale. However, it is possible that the networks of sensors and devices required to operationalise more innovative 5G-dependent uses cases could create new planning issues and public concerns. In many instances, such issues concern the siting and design of sensors on facilities and buildings owned by the organisation benefiting from the 5G use case (e.g. the Raglan Castle example). The small scale of such devices, and the lack of ownership problems, means that *public* planning issues are likely to be minimal. The use of 5G to enable novel immersive audio-visual experiences at heritage sites requires that sensors are located and attached to the buildings or ground in ways that do not damage the heritage value; the same applies to environmental management uses in sensitive landscapes and wildlife sites. However, the agency seeking to deploy 5G is also the main agency with the skills and responsibility to make sure that appropriate siting and design choices are made.

The main element of 5G-enabled use cases that could be perceived as a 'new, intrusive feature' in the landscape is the use of drones, tethered or otherwise, to enable farm-scale applications. The agricultural use case did not utilise a tethered drone, as was proposed, so the potential for public concern and potential 'planning issues' to arise is unknown.

Summary

The main findings are that digital network development encounters as many problems in the planning process in urban areas as in rural areas, and that the rural experience is itself highly spatially differentiated. Those rural areas that have been more challenging for network development tend to be the most scenic parts of designated landscapes; in effect, those locations where the impacts of masts are most significant. As elsewhere in digital network policy, there is a need to ensue that broad remarks about the effects of planning on network development and potential 'solutions' are actually applicable to rural areas.

Steps to liberalise planning might facilitate the workflow of telecommunications development companies and, possibly, assist with infrastructural architecture that could serve some rural areas at lower cost. However, the extent of such technological and economic benefits are hard to gauge. There could be some risk to environmental impacts and, possibly, public support though this, too, cannot be specified. Moreover, any potential workflow, economic and system development improvements would probably not dramatically re-shape the dynamics of rural network development – these are strongly conditioned by the weak economics of developing networks in rural areas.

Whether 5G faces the same experience in rural areas depends on wider technological developments and choices (e.g. around fibre and satellite), and the balance between different modes of provision, though some need to redevelop existing base stations with taller and bulkier masts is likely to arise.

What does seem likely is that rolling out 5G networks in rural areas will be slower and more costly than in urban areas, for reasons that have little to do with planning. Nevertheless, there is scope to front-load learning from some of the planning issues encountered with 4G, i.e:

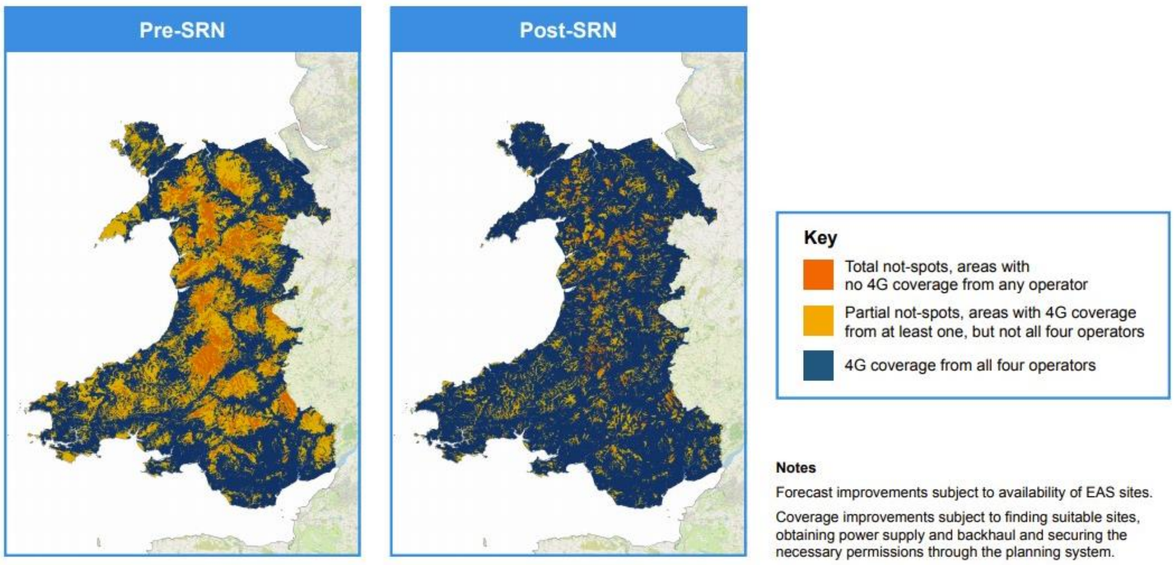
- Rural areas that have encountered planning-related challenges to network development for topographic and/or landscape protection reasons could be the focus of strategic discussions now about future network options. Relevant lessons could be taken from the 'reference case' of SRN.

- There is merit in examining the planning and regulatory issues around alternative technological pathways, notably extending fibre backhaul networks along telegraph poles and the road network, and wind-powered base stations.
- To continue to support and develop the role of digital champions in local planning authorities, and their interface with other statutory bodies.
- Whether planning or indeed any other factor can be considered a ‘barrier’ to rural digital networks depends on how one frames the problem and the goal. Even with the ambitious coverage goals of SRN, there will be premises in Wales and areas of landmass without adequate connectivity. This should spark wider deliberation around targets, i.e. what form of ‘universal provision’ is in the public interest, and do higher targets for landmass coverage make sense? 5G should feature in these deliberations from the start, including how far 5G is necessary across all parts of rural Wales.

4. 5G and mobile connectivity in Wales

5G coverage in the UK is currently being deployed by a number of MNOs. This has seen the number of 5G enabled base stations doubling across the UK, with Ofcom estimating that 3% of such base stations are present in Wales (Ofcom 2021). The deployment of 5G in Wales, to date, has primarily been an urban phenomena, with access available across a number of networks in major towns and cities. Correspondingly little coverage is present in rural areas, where 4G is not yet universally available. The Shared Rural Network programme is, however, expected to make substantial inroads into the availability of 4G (Wilkinson, 2021). This initiative is led by the MNOs with financial support from the UK Government. Such intervention reflects the ongoing challenges of the MNOs to deploy both fixed and mobile broadband in harder to reach areas of Wales, with the attendant barriers associated with the dispersed nature of the population and the topography of rural areas. It is anticipated, however, that 4G availability will become much improved over the course of the Shared Rural Network programme (see Figure 4-1). Our interview with Mobile UK – the representative body of the UK MNOs, suggests that their main focus in the coming years will be to maximise the usage and profitability of the 4G network. Outside of the core, subscriber-rich areas this is unlikely to see significant 5G deployment, without further government intervention.

Figure 4-1 Shared Rural Network coverage forecast improvements in Wales



Source: https://srn.org.uk/forecast-coverage-improvements/

Current 5G deployment in rural Wales

A summary of current 5G deployment across rural areas of Wales includes selected examples, typically associated with a single base station, including (as of March 2022):

- Abergavenny (Three), South East Wales
- Anglesey (EE), North Wales. Location of leading 5G research centre[5]
- Built Wells (EE and Vodafone)[6], Mid Wales. The Royal Welsh Showground
- Aberdyfi (EE), West Wales
- Abergele (EE), North Wales
- Ebbw Vale (EE), South East Wales, 5GWU use case
- Merthyr Tydfil and Abertillery (EE and Three), South East Wales
- Llanharry (Three), South East Wales
- Ogmore (Three), South East Wales
- Raglan (EE), South East Wales, 5GWU use case

Such deployments respond to local sources of user density and do not reflect a more generalised deployment intention across rural areas. They do, however, show examples of network sharing and joint ventures agreements (EE-Three and Telefoniaca-O2 highlighting the potential for collaboration in the sector to bring further benefits). Other semi-rural 5G coverage areas can be found in areas immediately adjacent to urban areas. These, however, are likely to reflect local circumstances e.g. mast coverage.

A number of local authorities and city-regions do, however, have plans to establish further 5G use case activity. The Swansea Bay City Deal region, for example, are keen to explore the potential for 5G to aid their strategic development sites in rural areas. The North Wales Economic Ambition Board also has a number of plans that are likely to see 5G (amongst other technologies) used to connect to research (Bangor University's DSP Centre) and other strategic sites across the region (e.g. business parks, industrial estates, transport hubs). While city region activity around the 5G agenda is largely early stage the experience of the use cases in Raglan and Ebbw Vale illustrates the potential for Welsh Government to ensure that the good practices associated with deploying 5G in rural areas are disseminated. Indeed while the nascent development of 5G in selected rural areas offers users (residents and organisations) in these areas the opportunity to connect to 5G, the presence also offers the capability for 5G trials and tests to be undertaken[7].

Technology developments for rural mobile connectivity

Other technology developments in Wales might provide additional support to rural 5G deployments. This includes Vodafone's testing (with Crossflow Energy and Cornerstone)[8]

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[5] http://www.m-sparc.com/news-and-events/launch-of-a-faster-age-at-m-sparc

[6] https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.cornerstone.network%2Froyal-welsh-show-case-study&data=04%7C01%7CHendersonD3%40cardiff.ac.uk%7Cc55bc23702cb4ac0bbbc08d9efca92b4%7Cbdb74b3095684856bdbf06759778fcbc%7C1%7C0%7C637804477089793260%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000&sdata=QjuhCMFR0wcnNqrKaW4Tv49wVP5qMAKSaYuxLH3%2FksI%3D&reserved=0

[7] An example of this has been the testing of a 5G driverless Westfield POD at the Royal Welsh Showground (https://www.highwaysmagazine.co.uk/bt-brings-5g-to-wales-for-100th-royal-welsh-show/7903).

[8] https://newscentre.vodafone.co.uk/press-release/vodafone-building-self-powered-eco-tower-mobile-phone-masts/

of a wind/solar-powered mast in South West Wales. Such technologies have the potential to respond to the challenges of securing appropriate power to rural masts (a challenge experienced in the Raglan Castle use case). It further highlights how a greater net zero focus can be brought to the 5G agenda. This is a topic that is receiving increasing focus and policy commitments in Wales and beyond, and one in which internet connectivity has more generally been identified as an enabler of solutions that will reduce the dependency on fossil fuels, but also one acting as a growing contributor to electricity use[9].

The movement towards neutral host solutions to mobile deployment represents a further technology development that may support future rural 5G roll-out. Here it is noted that such solutions offer the potential to significantly reduce the amount of infrastructure required in base stations, with the potential for this to reduce both set-up and maintenance costs in rural 5G deployment, such that this potentially 'frees the telco from having to construct the infrastructure underlying the network, providing a mechanism for reducing deployment risks'[10] . Technologies such as OpenRAN provide the possibility for MNOs to make use of multiple parties to service their needs (e.g. large technology companies), to enable processing in the cloud. Such developments may be particularly significant for rural areas as it may enable MNO business models that rely on comparatively fewer users.

[9] https://www.connexionfrance.com/French-news/French-study-finds-5G-increases-risk-to-climate#:~:text=The%20HCC%20report%20found%20that,equivalents%20per%20year%20by%202030.

[10] STL Partners, https://stlpartners.com/articles/telco-cloud/neutral-host-how-open-ran-and-neutral-host-paves-way-5g/

5. Use case synthesis

The 5GWU use cases were developed by Welsh Government and partners to address key sectors of the rural economy in Wales. In each use case a number of 5G enabled digital technologies were introduced, alongside IoT devices to enable monitoring. A number of these technologies were being introduced in rural settings for the first time, allowing the potential for lessons to be drawn. The full findings from the use cases (available on request), where rationale, activities and outcomes are considered. Summary details can be found below, alongside a synthesis of outcomes.

Summary of the use cases

Farming

Overview

The use case aimed to support farmer well-being, mental health improvements, combatting isolation, and upgrading workplace health and safety on farms, through security and video analytics. It was being implemented on a single farm in Monmouthshire.

Use case

The first use case (farmer wellbeing) addressed mental wellbeing and isolation issues faced by farmers through the provision of 5G enabled digital technologies, observation and activity data.

The second use case (farms security & safety) sought to prevent the theft of machinery and livestock on farms through an integrated network of artificial intelligence (AI) enabled sensors and video surveillance technologies.

Education

Overview

The use case sought to enhance the teaching and learning experience through 5G enabled technologies, providing opportunities for live and interactive teaching access to resources from across the world. This responded to the need to foster high quality, technology engagement in the education curriculum, to enrich the teaching and learning experience of pupils. The immersive educational classroom was located in Ebbw Vale.

Use cases

The use case comprised a single use case (a 5G enabled Education Immersive Classroom), incorporating 360° video camera coverage allowing teachers to create bespoke immersive content. Webex boards were provided to four schools in Ebbw Vale and Raglan, to enable live, interactive lessons featuring the immersive classroom content (shared in real time).

The classroom also acts as an e-meeting space, allowing businesses, NHS, fire service to conduct video calls with a large number of participants and for immersive training. Opportunities for the classroom to act as an immersive art gallery space may also be possible.

Transport

Overview

The transport use case responded to the growing focus on reducing the impact of car use, including efforts to reduce single occupant car journeys. By introducing 5G enabled digital technologies the use case has the potential to aid both transport and environmental concerns in Wales, as well as addressing aspects such as anti-social behaviour at rural and valleys bus stops and offering more integrated on-demand mobility services for residents both within and travelling to Blaenau Gwent.

Use cases

The first case (Smart Buses & Smart Stops) sought to improve transport networks, by establishing on-demand passenger mobility services, such as journey planning apps, and by facilitating Internet of Things (IoT) data collection and live transmission of key data insights from moving buses.

The second case (Smart Car Parks) focuses on the promotion of public transport use and sharing culture. It included the development of Smart Car Park solutions at two car parks in Blaenau Gwent (The General Offices - Ebbw Vale and Ebbw Vale Rail Station), with the aim of encouraging drivers to carry more passengers in return for priority reserved parking benefits, such as duration of stay, guaranteed space and discounts.

Tourism

Overview

The use case addressed a need to increase tourism visits to Monmouthshire, through the creation of an immersive AR experience. It was anticipated that this would provide a more engaging experience for visitors to Raglan Castle, and act as a marketing tool to attract more visitors. The use case further focuses on identifying installation challenges for 5G networks in rural areas and heritage sites by ensuring local network equipment installations blend into sensitive environments and preserves visual amenity.

Use cases

The first use case (Preservation & Security) focused on improving security and preservation of heritage and tourist attractions, by monitoring building fatigue and detecting intruders. This included installation of Internet of Things (IoT) sensors and CCTV cameras to enable video analysis, including object detection for security, health and safety (detecting of challenge climbing). The cameras also enabled analysis of visitor flow through the castle to inform operational intelligence (e.g. engagement, dwell time) and support preventative maintenance (understanding the well trafficked parts of the attraction).

The second case (Scalable Augmented Reality for a Sensitive Site) sought to deliver a fully functional Augmented Reality (AR) experience at Raglan Castle. This offered the potential for engage visitors in immersive education, content-sharing and story-telling capabilities, and improvement of the wider offer of a key visitor attraction in Monmouthshire.

Use case outcomes

The outcomes of the 5GWU use cases have been drawn from the Observatory's longitudinal monitoring. This has highlighted a range of technical outcomes achieved by each of the use cases. These achievements, as noted earlier, are aligned to both a rural and sectoral setting, with a focus on development and feasibility testing. The technical outcomes were identified in February 2022, with the 5GWU project due to complete by the end of March. There is a likelihood of much of the equipment and infrastructure remaining at the use case sites (and the 5G masts) suggest that further use of the technologies may occur after the life of the project with associated social and economic outcomes (discussed in Section 6). These are considered by geographical region of each use case below:

The Monmouthshire use cases comprised Raglan Castle and the farm, both served by the same 5G mast. The dual use of much of the 5G enabled technologies has seen 4G for much of the project, with the 5G mast becoming operational towards the end of the use case, allowing the introduction of the VR experience at Raglan during the February half term 2022. The initial feedback from the users of the VR experience was positive, highlighting the potential for Raglan and other heritage sites to add to their existing offer. The Raglan camera system and sensors were also fully implemented, with data from the sensors captured in the Utterbery dashboard (accessible to CADW). The initial assessment of this data by CADW suggests potential for both efficiency and security to be improved both at Raglan, but also at wider heritage sites. This may be particularly relevant to sites where there are concerns about the condition and status of heritage infrastructure, but also in remote unmanned sites.

The farm use case has also been able to connect to 5G in the latter part of the project. This has seen the introduction of camera video analytics by Cardiff University, including uses such as sheep counting to be undertaken, with the potential for this to provide important regulatory data for the farm and the wider sector. Alongside the video data the farm has also benefited from the introduction of sensors monitoring key areas of the farm such as gates, and access to the Utterberry dashboard. The farmer was also equipped with an application to monitor his activity, allowing for an alarm to raised automatically if there was an accident. These technologies have the potential to improve security at the site (and those of the wider sector). It was noted that the drone had not been able to be introduced in the period of the project.

The Blaenau Gwent use cases were based on the deployment of 5G in Ebbw Vale. This had enabled two use case activities to be launched. The immersive classroom was deployed in February 2022, and in the first month it had seen 80 plus visiting teachers, and a substantial level of interest generated from the education sector, alongside potential interest from the commercial sector. This highlights the possibility of social outcomes to be derived in both Ebbw Vale and other rural sites that are able to introduce such classrooms (particularly those where fixed line broadband is not available).

The transport use case was also largely implemented in the project period. This resulted in the car parking sensors and the 5G camera being deployed, alongside the formal launch of the Appyway parking app service (in March 2022). The introduction of the 5G camera on the bus service was also, after regulatory issues were addressed, analysed by Cardiff University. This use case highlights the potential for both social (e.g. education and behavioural benefits), environmental (fewer and more efficient journeys) and economic benefit to service providers.

While a number of the planned activities were not implemented in the course of the project (e.g. the drone plan and farmer wellbeing package, smart bus stops) the overall outcomes achieved by the 5GWU use cases highlight their success as a proof of concept. The key themes from the use cases are examined both in terms of the deployment of the use cases, but also the lessons from the outcomes achieved. This analysis should be read in conjunction with the full case studies.

What can be learnt from the use case deployment?

The results of the use case suggest that they were established as broad based partnerships comprising technology suppliers, institutional partners and users. This was supported by the appointment of BT to provide 5G connectivity in each of the use case areas. Engagement of an MNO and other partners with assets and links to their respective localities was important for the delivery of the use cases but also the potential deployment in other rural areas of Wales.

The use cases further benefited from the coordination and administrative support of Welsh Government, including regular technical and partner meetings, alongside monitoring of progress and outputs throughout the life of the project. These activities are supported by a strong rationale to not only provide next generation mobile connectivity, but to do so by addressing wider social and economic and environmental objectives. The location of the selected use cases in rural areas further points to the potential to contribute towards rural development in other parts of Wales.

A range of novel technology solutions have been developed and deployed during the life of the project. This R&D activity has helped to advance technologies and identify other issues that are likely to be present in the deployment of 5G in other rural areas. Examples here include:

- Deployment of power to rural areas and ensuring the ground and mast structures are suitable for the additional weight of 5G equipment.
- Installing a bespoke immersive classroom on a semi rural site, including the importance of a suitable base and access to utilities.
- Navigating regulatory issues associated with the analysis of camera data.
- Monitoring and the importance of siting cameras to enable analysis.

Learning from the sustained use of 5G technologies has, however, not been possible in the life of the 5GWU project. This presents challenges to calculating impacts as the use-related social, economic and environmental benefits have yet to emerge fully. The costs of the use cases are also unclear in a number of areas, not least in the costs associated with 5G base stations, such as access to power.

Furthermore it is noted that the ownership of the technologies being developed within the 5GWU project, are primarily held by entities outside of Wales. In this respect it is known that the commercial value of new innovations primarily rests with the home location of the owners of an innovation (Breznitz, 2021). Wales, however, may benefit from the eventual commercial diffusion of new 5G technologies (e.g. through purchasing advanced equipment) in any future deployment plans.

What implications has the deployment had for the project outcomes?

The delays associated with the deployment of the project have impacted on the outcomes achieved. In particular the cumulative nature of the delays has meant that the ability to make full use of the data provided by the 5G enabled technologies, and capturing lessons and project outcomes has been curtailed. This included the comparatively short period by which the Observatory and partners have been able to assess both the ways in which the project activities have been used, and their potential benefits to end users.

The difficulties in capturing lessons from the project may also prevent partners from making scale-up decisions. It is unclear, for example, whether the MNO will be prepared to speed up its deployment of 5G in rural areas of Wales, given its priorities of deploying the Shared Rural Network (4G) and ensuring that it achieves a positive financial return from its existing network infrastructure.

The costs of the project represent a further factor that is likely to influence additional scale up of the technologies. Here it is noted that the use cases have made use of high specification equipment (e.g. iPads in Raglan and Meraki cameras). This, however, may not be required for mainstream deployment. Further economies of scale are also likely to result from subsequent dissemination and use of the technologies.

Additionality of the 5G solution

The deployment of 5G is at the heart of 5GWU and its wider objectives for deployment. At the time of the project 5G was primarily deployed in selected urban areas of Wales. It is unlikely that 5G would have been made available in Raglan and Ebbw Vale (plus upgrades at Merthyr Tydfil and Abertillery) at the time of the project without government support. It should also be noted that the 5G non-stand alone technology employed in the use cases did not contain the full (future) features of 5G including the ability to 'slice networks'. This is expected to offer much greater possibilities for commercial user in the future (Curwen and Whalley, 2021).

Interviews with suppliers suggest that much of the technology employed in the use cases was able to function with 4G connectivity. This dual use functionality was particularly useful in the early stages of the use cases, where 5G was not available. While 4G may provide adequate functionality for some users, the interviews suggest that a growing number of users seeking to make use of the technology in future (likely once 5G handsets become more widely available and use returns to pre-Pandemic levels) suggests that 4G may not provide a good quality experience for all users. Indeed 5G is expected to offer real time and on demand services (and thus AR and VR as well as immersive experience) through increased latency and higher upload speeds, and private network possibilities (Curwen and Whalley, 2021). Many rural areas, without large subscriber bases or high commercial or public users of data, may be able to achieve adequate connectivity via other technologies such as fibre and 4G.

6. Cost-benefit and strategic assessment

In this section of the report we seek to identify the factors that might be considered in terms of the economic costs and benefits surrounding the individual use cases, and in terms of whether the cases hint at new business models. There are a series of issues that need to be made prior to this discussion.

First, it was not possible within the timeframe of the study to develop details of the costs associated with installation of the technology (beyond broad aggregates) or to place a monetary value on benefits. The overarching focus of the use cases was in terms of demonstrating whether the technology employed could work. Furthermore, several of the use cases came into operation quite late in the research programme. It is expected that stronger conclusions on costs and benefits could be made with continued development of the use cases. In this respect it is also noted that the use cases were developed during Covid-19 limitations and with this undoubtedly affecting both the time-scale of development of individual use cases and the quality and quantity of outcomes within the research period ending March 2022.

However, within the research programme it was possible to identify potential benefits emerging from the use cases, and then to come to conclusions on whether these benefits could be easily valued or not (see Section 5 for more details). So, for example, selected use cases hinted at private returns from application of the new technologies, but also revealed the likelihood of social returns, perhaps in terms of better education and training. One of the conclusions from the Observatory work is whether conventional cost-benefit analysis would be the best way to evaluate the benefits from 5G connectivity in more peripheral areas with perhaps an approach such as a social return on investment analysis giving better information about returns welfare returns to individuals.

Second, we are mindful that the use cases were developed in the context of high levels of uncertainty for commercial network operators. Developing a 5G network in more peripheral areas will be costly and with risk given the uncertainty of additional demands levered by the technology. In consequence it is expected that any future 5G roll out to more disadvantaged areas may be subject to risk sharing between public and private sectors that leads longer term to a stricter commercial model. Then in any risk sharing model involving public sector supports there is a need to factor in balances between private and social returns to users, but also to be mindful of unexpected spillovers from early use of the new technology. For example, even at the use case stage, there is the possibility that previously hidden markets will be better understood, or that network operators might on the basis of use cases seek to extend 5G infrastructure to investigate new market potentials.

The conclusions for this part of the report were derived from consultations undertaken throughout the research programme (see Appendix), visits to the use cases and existing literatures.

Research questions

In the research process we sought in each use case to consider the following economic costs and benefit questions (see) in coming to conclusions around how far the use cases reveal potential for new business models and then to understand the factors affecting the relationship between economic costs and benefits.

Table 6-1 Key research questions around the 5G use cases

How far are costs accurately available for the use case? Are budgeted costs for use cases a guide to scaled costs?	In some use cases deriving details of costs was complicated because not all elements are fully costed and with all contributions-in-kind unlikely to have been accounted.
Do outputs reveal additional value for 5G connectivity in rural spaces?	For example, how far might use cases meet aims using 4G or other mobile/fixed technologies.
Does it provide evidence that the solutions can be scaled?	Here, for example, the extent to which a specific use case could be multiplied among a defined user group.
Does it highlight/identify the risks involved in scaling?	Including here whether there are problems in scaling use cases, perhaps around planning, and other practical and/or regulatory issues.
Does it provide evidence of where general public support might be targeted?	Including here whether there is a role for the public sector to engage in risk sharing with commercial operators, and where public resources might be used to promote and inform prospective users of advantages of 5G technology, or help commercial operators to better evaluate potential markets.
Does the use case reveal social welfare benefits that could be a prior to public sector support?	For example, whether the use cases reveal that there are social welfare benefits, perhaps in terms of education, inclusion, health, development from use of the technology that are not easily internalised in commercial models.
Has the use case identified benefits that can be valued?	This reveals whether the use case, or extension of the use case can be connected easily to measurable money outcomes, for example, new tourism revenues, new industry and associated employment outcomes.

Has the use case identified benefits that cannot be valued?	Here focusing on outcomes which are not easily valued in money terms such as returns to education, savings from reduced commuting etc.
Has the use case identified any basis for new business models, or demand side attributes that can be scaled in rural environments?	How far the specific use cases hint at future public/private sector business models were they to be scaled-up.
Does the case reveal potential economic benefits for rural economies?	Identifying the extent which expanded use cases might provide solutions to persistent rural economic problems, or might create new industries, or new employment opportunities.
Does the use case reveal dependencies or point to supply side skills issues?	Whether the outcomes from the use case reveal dependencies, for example, for a new business model to occur other factors need to be in place; and/or might there need to be new education programmes put in place to help users employ the technology to its fullest extent.
Cost-benefit conclusions from case	Overall expected relationship between costs and benefits associated with 5G connectivity in the use case; ranked LOW, MEDIUM or HIGH.

In what follows we provide a series of tables revealing our understanding of how each case measures up against these research questions and then in the text focus more on the extent to which each use case suggests future new business models and then the expected relationship between costs and benefits. In this latter case it is very difficult to come to firm conclusions on the relationship between costs and benefits from a limited set of use cases. For example, it is virtually impossible here to analyse how far costs might reduce with scale of each user case; and to understand the nature of economies of scope where 5G services can be provided for very different users. In this respect it is only possible to signal the likely extent of benefits against costs and with findings here to be used with caution.

Farming use case

Table 6-2 summarises the findings from the farming use case. We make the following conclusions in respect of the case:

The additionality of 5G connectivity in developing outputs from the case was questionable, with the camera technology able to operate across a 4G platform. Notwithstanding there is a strong expectation that further development of farming use cases around more advanced agri-tech will be more dependent on quality 5G as opposed to 4G, particularly in applications involving automated vehicles and monitoring of farm operations. It was difficult within the use case to develop any robust material in respect of improved farmer well-being, crime reduction and reduced accidents. This would require a much larger (and longer duration) use trial.

The use case raised questions on how far 5G technology might be more/less valuable to farms in different parts of Wales. Then, for example, might the types of costs reduction and revenue benefits occurring on a farm in rural Monmouthshire be similar to farms in upland areas which are typically smaller scale? In consequence it is expected that the role of 5G technology in promoting productivity improvements on farms could vary by geography and type of farm, as well as other farm attributes. Moreover, farmer willingness to pay for such technology is also linked to specific factors such as farmer age, location and type of farm business. Accurately identifying productivity improvements linked to new 5G technology would be difficult because of the many factors affecting farm performance.

It is likely that policy interventions in the 5G farm use case would be more around raising awareness of the technical possibilities to farming organisations and individual farmers, but also the value of the technologies in other remote working environments including sectors such as construction and forestry.

The roll out of applications of mobile 5G to farms could have important multiplier effects in the rural economy. There would need to be an element of upskilling among farm users to better take advantage of the 5G opportunity.

While the use case was limited in scope, a number of potential new business models are identified:

- In rural areas of Wales there could be new opportunities in terms of installation of infrastructure. Moreover, the See What I See family of systems could lead to reductions in costs associated with veterinary and regulatory (environmental problems) call outs.
- Many farms have multiple income streams, particularly in respect of tourism and forestry, and with 5G applications around security equally useful to other parts of the farm business.
- There is the potential that improved security and monitoring associated with mobile 5G use cases might lead to reductions in insurance premiums for farms and associated businesses.
- There is scope for the 5G farm application to be linked to the Raglan Castle and Immersive Classroom cases as an education resource.

The economic conclusions from the 5G use case are as follows:

- Detailed cost data from the case was not available such that any estimate of a cost benefit ratio would be inappropriate.

- Noting limited information from one case, the 5G benefits to costs ratio is rated as LOW compared to the other use cases, and with this largely because selected applications could run on 4G.
- It is likely some of the gains for farm businesses associated with the devices (Meraki cameras) can also be achieved with 4G.
- A larger number of case studies of 5G technology farm use are required to pick up on a series of wider welfare benefits to farmers from adoption of the technology.
- In the future potential 5G applications that connect purchasers of agricultural outputs to farm operations could lead to a much greater raft of productivity benefits, for example, feed companies being able to relay back advice and guidance on their requirements having real time access to farm operations.

Table 6-2 Farming Case: Summary

Economic questions	Farm business case IoT and camera monitoring
How far are costs accurately available for the use case? Are budgeted costs for use case a guide to scaled costs?	Limited cost information in the use case; issues in terms power access which could be a key issue in other Welsh rural areas. Unlikely indicative costs from use case representative. Likely trial will continue to be run outside of trial period because of relatively low overheads. There may be potential to develop the farm as an agritech testbed with the support of partners such as Monmouthshire County Council
Do outputs reveal additional value for 5G in rural spaces?	Limited evidence of marginal impacts of 5G in the use case. Selected benefits are available through 4G. Appears use case farm has not had consistent access to 5G connectivity. Complex agri-tech applications require 5G connectivity.
Does it provide evidence that the solutions can be scaled?	Benefits in terms of security and drone usage (although this was not part of the use case) could be shared across different farm businesses through collaborative arrangements. Questions on technology value on smaller scale upland farms. Limited linkages to other use case cases. Potential usage of technology in other rural/remote working environments such as construction and forestry.
Does it highlight/identify the risks involved in scaling?	Welsh farms vary considerably in how far such technology promotes productivity and/or security/monitoring improvements.

Does it provide evidence of where general public support might be targeted?	Raising awareness of the opportunity in agriculture; and whether technical solutions are appropriate to other sectors featuring remote working environments such as construction, forestry. Supporting power access to remote areas.
Does the use case reveal social welfare benefits that could be a prior to public sector support?	Use case focused on whether technology worked. Use case did not provide evidence of improved farmer health (this element was not implemented during the use case); reduced rural crime, reduced cost of accidents, but these effects would need to be explored in further trials.
Has the use case identified benefits that can be valued?	Farm productivity improvements expected to be difficult to measure because of the wide variety of factors farm productivity. Productivity growth evidence not established within the use case. Camera and IoT sensors might work to bring down farm insurance costs.
Has the use case identified benefits that cannot be valued?	Expected long term benefits in terms of mental well-being improvements; health and safety issues are expected to be measurable (i.e. reductions in number and cost of accidents). These benefits could be valued indicatively through such frameworks as the Themes Outputs Measures (TOMS) system. Potential uses of the technology in reducing rural crime.
Has the use case identified any basis for new business models, or demand side attributes that can be scaled in rural environments?	Potential new business models in installation, inspection. Potential application to animal health and regulatory matters of the See What I See system, savings on specialist call outs. Potential application to environmental sensing. Potential to link the 5G to businesses co-located on farm property such as tourism. Farmer willingness to pay expected to vary by farm in Wales.
Does the case reveal potential economic benefits for rural economies?	Agricultural sector well integrated into the rural economy such that improvements/growth in sector would cause multiplier effects in other parts of the local economy.
Does the use case reveal dependencies or	Dependencies in terms of access to power.

point to supply side skills issues?	Remote areas and development of new masts / existing mast strengthening.
Cost-benefit conclusions from case	Uncertainty on the scale of benefits within the case. Productivity benefits might be quantified over time; a number of other potential benefits are more difficult to value in monetary terms. Uncertainty on underlying costs. While equipment in terms of devices and cameras can be costed individual farms might be disadvantaged by power issues around mast development. Camera costs may be reduced sharply. Potential for benefits in rural economy around wider adoption but expected some of this might be achieved in presence of 4G.

Raglan castle use case

The Raglan Castle case was particularly interesting because of the mix of sensor and camera technology employed. One of the underlying themes investigated here was how far the 5G technology solutions could be used in other remote tourism locations in Wales. Heritage sites in Wales represent an important draw for domestic and overseas tourism. However, there are many industrial/cultural heritage sites that are geographically remote, have very limited fixed communications and where, as a result, on-site interpretation is made difficult. In consequence some selected historical sites and buildings of real cultural significance get smaller number of visitors because there are no staff on-site and with interpretation limited to notice boards. Clearly Raglan Castle is not that remote a site, but the use case emphasised the use of 5G technologies to aid interpretation and in safeguarding heritage. As in the Farm use case, there is a strong expectation that useful data will continue to be generated from the site after the initial funding period (ending March 2022).

The Raglan Castle case provided evidence of the additionality of 5G connectivity in terms of improving the augmented reality experience of visitors. In the absence of 5G fewer visitors would be able to benefit from the visitor experience. However, much of the sensor technology is not dependent on 5G, yet the sensor ability to detect pollution, smoke, vibration and building movement would seem to be particularly important for more remote historical heritage sites where a physical human presence is not always practical or cost effective.

In terms of scaling-up from the use case several factors were identified as possible barriers:

- Access to power for 5G enabled and suitable strengthened masts. The use case evidenced a series of problems in operationalising a 5G mast close to the site and this is expected to be a roll out issue at more remote rural tourism-heritage locations.

- The use case reveals that the placement of camera and sensors is critical in terms of deriving services, but with a tension that optimum placement might be deemed intrusive and depreciate the aesthetic value of historical and cultural sites.
- That listings place on historical buildings and industrial sites might practically prevent installation of some devices.

The use case revealed that there could be a stream of benefits that can be valued, particularly in terms of the 5G technology being employed to maintain or create new visitation (which could be valued using tools such as the Wales Tourism Impact Planning Model), but also returns in terms of reduced inspection and engineering costs, and better developed preventative maintenance schedules. In the Raglan Castle case specifically, there were also identified benefits in terms of how monitoring of septic tanks would reduce risks associated with harmful pollution incidents. Other benefits were clear in terms of reduced vandalism and inappropriate behaviour at sites.

In terms of new business models based around the 5G application, a number of conclusions are made. There is a developing base of evidence that visitor sites able to offer an augmented reality experience gain competitive advantage over others and with increasing demand for these types of services. In consequence AR might be associated with improved tourism engagement with the site, longer visits, and changes in tourist behaviour while at sites. In terms of the AR delivery there is also evidence that visitors prefer not to download material onto mobile phones, but use discrete devices provided on site. That noted, provision of discrete devices would not be a practical option across more remote visitor sites with no employees on site, such that the opportunity would seem to be more in terms of visitors at the most remote sites downloading material onto 5G phones but then benefitting from a similar stream of services that occur when using the discrete i-PADs being employed at Raglan.

The use case also revealed opportunities to link the castle experience to the immersive classroom, and enhancing opportunities in terms of remote visitation for education and training purposes. Other potential business/economic opportunities included: local firms being able to develop content to enhance the AR visitor offer at heritage sites; the opportunity to use the technology to connect visitors to other CADW/tourism facing sites in the area; and to link the technology to new gaming/treasure hunt options and with the potential to license site specific assets to firms.

While the use case exemplified the importance of mast location and associated power access, it did hint at opportunities to scale across remote heritage sites, and to build upon the AR offer. This together with the fact that the streaming of visitor services required 5G connectivity suggested that the potential ratio of benefits to costs was MEDIUM in the Raglan Castle use case, compared to the other use cases.

Table 6-3 Raglan Castle: Summary

Economic questions	Raglan castle case
How far are costs accurately available for the use case? Are budgeted costs for use case a guide to scaled costs?	Limited costs data was available. Unlikely costs in respect of roll out representative of those at other remote CADW and National Trust sites. Expected that technology can be used outside of the trial period to gain further value insights.
Do outputs reveal additional value for 5G in rural spaces?	Technology shown to work across multiple on-site uses Much of the system can be run on the 4G network; system better with 5G particularly with multiple users of the technology.
Does it provide evidence that the solutions can be scaled?	CADW and NT sites among the most visited in rural Wales and some in very remote locations. Use case hints at potential to scale to sites with fewer visitors which are not currently staffed. Potential for remote sensing at heritage sites and reduction of damages at sites far from urban areas. Including use at sites where direct visitor interaction is limited because of health and safety issues. IOT sensors and CCTV to detect pollution, smoke, vibration. These technologies would also be relevant to other rural buildings and sites and with some potential spillovers to the farming 5G case.
Does it highlight/identify the risks involved in scaling?	Access to power for the 5G network. Technology might be intrusive and unsuitable for other Cadw or NT sites. Visitor resistance to new technology; depreciation of aesthetic value of heritage assets. Installation costs expected to vary between sites. Heritage listings prevent installation of the technology in some cases or lead to increased costs.
Does it provide evidence of where general public support might be targeted?	More in terms of encouraging improvement to underlying power infrastructure. Linking technology to other remote tourism-facing activity.

Does the use case reveal social welfare benefits that could be a prior to public sector support?	Educational benefits to schools and other visitors. Improved health and safety at remote rural sites.
Has the use case identified/suggested benefits that can be valued?	Where an outcome is maintained or additional visitation this can be valued. More likely outcomes are in terms of maintained visitation. Value of visits and associated spending can be assessed using the Tourism Impact Planning Model for Wales. Benefits in terms of reduced engineering costs, preservation in cultural value, preservation of visitor revenues, reduced inspection costs, improved health and safety for visitors (improved dangerous weather monitoring). Reduced damage and repair costs, better managed preventative maintenance schedules. Reduced incidence of pollution incidents and related penalties.
Has the use case identified benefits that cannot be valued?	Expected reduction in social misbehaviour at sites; also social returns in terms of improvements to education provided by AR.
Has the use case identified any basis for new business models, or demand side attributes that can be scaled in rural environments?	A developing evidence base that visitor sites with AR capability improve visitor experience; AR leads to more supportive visitor behaviour. AR in research revealed to support tourist engagement, new tourist behaviours, increasing visitor numbers, and scope to improve offer. Visitors may prefer not to download material onto mobile phones but prefer to use remote devices. Visitor locations with better connectivity increasingly offering AR services placing them at some advantage. Potential for remote visitation/tours for education purposes; creation of interactive content for extremely remote heritage sites with limited physical support infrastructure. Local firms could lead in terms of developing content for the AR.

	Such technology might reduce demands for more conventional firms of site interpretation i.e. information boards and video. Potential to use AR to connect visitors to other tourism-facing industries in the local area. Potential to link technology to gaming options/licensing site specific assets through the technology; treasure hunts.
Does the case reveal potential economic benefits for rural economies?	Tourism part of a relatively narrow industrial base in rural areas. Maintenance of tourism demand is important but unclear on whether the technology will lead to improved quality of employment/earnings in the sector. Visitation to heritage sites has multiplier effects in other parts of the rural economy such as accommodation and food services.
Does the use case reveal dependencies or point to supply side skills issues?	Potential issues with consents on changes to historic buildings. GDPR issues. Poor power supplies to more remote heritage sites, and potential mast strengthening requirements
Cost-benefit conclusions from case	Depending on resolution of power issues expected to be positive ratio of benefits to costs where new technology helps maintain tourism revenues longer term. Some potential for new business models at heritage sites. Potential reduction in costs associated with site interpretation.

Education immersive classroom use case

Table 6-4 reveals a summary of the economic costs and benefits points in terms of the immersive classroom. While some costs were available for the use case this excluded the cost of network provision. Moreover, relatively few such classrooms have been developed in the UK. While the immersive classroom has worked well it is currently located in a more urban setting, and with the strength of the future business case resting in part on how far such classrooms can be moved to more remote areas to provide services where there is very limited fixed connectivity. Key to the business case is that the 5G connectivity provides some flexibility in terms of locating the immersive classrooms and then with limited fixed groundworks required.

The use case provided evidence of sustainable demand for the immersive classroom from varied education and training providers, and this beyond primary and secondary education. To strengthen the business case there would need to be a more thorough long-term evaluation of the value of the additional learning outcomes associated with the immersive classroom infrastructure. Also in this use case the fixed capital and operational costs are greater than those in other use cases, and there are uncertainties on how far these costs would reduce as the number of classrooms used increases, and with associated issues of who precisely would pay for such facilities. In consequence it is unlikely the immersive 5G classroom concept could be scaled without public support through local authorities and Welsh Government. There is a challenge here of exploring the strength of demand from both public and private sector uses for training and education purposes, and the extent to which capacity would be fully used and how it would be fully used were the classroom to be moved around. There is also a need to identify whether different types of teaching skills are needed in the immersive environment.

The immersive classroom could be linked to reductions in costs for training providers, but the main benefits would be in terms of social returns to users, and the potential to innovate in terms of classroom provision. Teaching visitors to the classroom highlight that such a facility could have a role in curriculum development. The immersive classroom also offers an opportunity to link to other use cases; for example, outputs from the 5G-facing technology employed at Raglan Castle and in the Farming case can be embraced within the classroom infrastructure. However, of more interest is how far such classrooms might be placed in very remote rural locations, perhaps adjacent to heritage sites, to improve interpretation and visitor value. In terms of future business models there might also be opportunities in terms of new content development, including adding more sensory elements to the user experience.

In summary here the use case evidenced demand but this was in a fairly easy access urban location. The longer-term cost benefit conclusions around 5G-connectivity relate to how far this type of classroom can be used in more rural parts of Wales, and then whether there would be the strength of demand away from more urban areas. In terms of the marginal benefits associated with 5G connectivity the ratio of benefits to costs is rated as LOW.

Table 6-4 Immersive Classroom: Summary

Economic Factors	Education class room
How far are costs accurately available for the use case? Are budgeted costs for use case a guide to scaled costs?	Case roll-out at £0.8m but not including shared cost of the network provision. Case evidenced strong reliability on 5G, but in an area where coverage of the 4G network is questionable. Use case costs only a guide to costs of scale up, as relatively few classrooms of this nature have been developed in the

	UK. Unclear how far it is practical to re-locate classrooms at short notice to meet education and training needs.
Do outputs reveal additional value for 5G in rural spaces?	5G connectivity important for live streaming HD footage from mobile devices, and extensive use of AR. Selected outputs not likely to be achievable with 4G. Key issue in terms of presence of 5G leads to flexibility in terms of installation with limited groundworks and cable installation.
Does it provide evidence that the solutions can be scaled?	Evidence for new demand from education and training users. Requires detailed user evaluation on additional learning outcomes from the immersive classroom infrastructure over and above other learning methods. Expected that selected elements of teaching content can be scaled and made available to other users including health sector. Content developed in Wales could be shared to other places. Technology scaling of the 5G enabled applications: providers have intrinsic interests (beyond the use case) to further develop and sell their applications.
Does it highlight/identify the risks involved in scaling?	Unclear how far classrooms can be scaled without presence of rural 5G. More research needs to be undertaken on local demand in rural areas for the services offered by an immersive classroom. In a secondary and tertiary education environment unlikely to be scaled without support from local authorities and Welsh Government, and with school budgets limited so scaling needs to work within an infrastructure sharing plan.
Does it provide evidence of where general public support might be targeted?	Technology scaling might require further R&D support, particularly for those applications that are further from market. Pump-priming to show the learning value of the classroom. Support for content creation around the immersive classroom concept.
Does the use case reveal social welfare benefits	Case evidences demands from other public/private sector users for training, and community support uses.

that could be a prior to public sector support?	
Has the use case identified benefits that can be valued?	For third party users some evidence of reductions in costs of training with other providers i.e. in situation training. New content creation for the classroom could have commercial value attached, but note limited evidence of new content creation in use case.
Has the use case identified benefits that cannot be valued?	Improvements to teaching and learning for beneficiaries; social returns to innovation in education process.
Has the use case identified any basis for new business models, or demand side attributes that can be scaled in rural environments?	Issue of capacity usage and whether classrooms can be moved with limited costs. Role in innovative curriculum development. Classroom use of content developed on other 5G use case sites; a means of bring 5G use cases together to create long term learning outcomes. New content creation in Wales with wider commercial potential. Potential to add sensory elements to the immersive experience.
Does the case reveal potential economic benefits for rural economies?	Use case not in a rural area.
Does the use case reveal dependencies or point to supply side skills issues?	Use case use case strongly dependent on 5G availability. Unclear how far different teaching skills required in immersive environment.
Cost-benefit conclusions from case	Some evidence of demand for the services that a classroom could offer. Key benefits better understood within the framework of a social return on investment in education, training etc. Cost-benefit conclusions depend in part on how far facility is mobile and can be used in genuinely rural remote locations.

Transportation and car park use case

Table 6-5 summarises the economic questions around the transport and parking use case. Once again here the use case use case was focused on showing that technology applications worked and therefore with little indication of the costs involved in scaling. In both elements of the case there was limited evidence of marginal returns to 5G connectivity, and with cameras employed not 5G enabled during the trial. The evidence on the scaling potential and economic benefits from the car parking and bus route technology is expected to be better inferred from use cases in other urban areas. The use case had to overcome a series of hurdles in terms of GDPR and this would be material in any wider scaling of the technology.

The transportation and car parking case connects well with elements of Wales' sustainable economic development strategy. Previous work in Wales has highlighted the costs and uncertainty connected with travel/commuting from more needy parts of Wales to employment opportunities across the M4 corridor. Where the technology reduces this uncertainty it could have more inclusive outcomes. Other social, economic and environmental benefits are the potential for safer travel, reduced travel time to parking (and reduced pollution), reduced incidence of illegal parking, reduced unauthorised use of car parks, and the potential to link technology solutions to the South Wales Metro system. In a strict cost-benefit framework improvements to road safety, reductions in accidents, and reduced pollution associated with travel can be valued.

The key elements of the business case would be better capacity utilisation from bus operators and lessons here might be inferred from other on-demand real time travel services available in South Wales. The car park camera technology and associated dashboard could likely be developed to cover off the presence of free electrical charging points. While much of the camera technology employed would seem to be better suited to more urban areas, the potential for such systems to point to opportunities for electric charging could be more important for rural areas with less charging infrastructure and with this cited as one reason why purchase of electrical vehicles varies across space.

The use case highlighted questions around the ability of local authority and commercial operators to actually use the data coming from the case, and with limited information available on the strength of consumer demand for this type of car parking application. The more fundamental question in terms of new business models is the extent to which the provision of the benefits really requires 5G connectivity. Then in terms of the benefit-cost ratio around 5G connectivity this is expected to be LOW relative to the other cases.

Table 6-5 Transport and Car Parking Case: Summary

Economic questions	Transport and parking case, including digital totem and bus carpark
How far are costs accurately available for the use case? Are budgeted costs for use case a guide to scaled costs?	Use case focused on testing the technology and does not provide the basis for scaled costs. No cost data available in respect of car park case. On smart bus stop case likely that a significant element of costs relates to API and licenses which could reduce with scale. Delays in implementation of the use case. Underlying cost inflation in terms of time due to data protection issues.
Do outputs reveal additional value for 5G in rural spaces?	use case might not be considered a genuinely rural setting. 5G additionality in making supply/demand interface more responsive although elements of the car parking scheme likely to be achieved with 4G; 5G better able to transmit video footage.
Does it provide evidence that the solutions can be scaled?	Evidence on scaling potential less likely to arise from the case but more likely to be derived/inferred from other related technology roll out in the wider UK i.e. electrical charging points for cars. Technology could have a wide application across car parks but may be suitable for urban areas.
Does it highlight/identify the risks involved in scaling?	Potential issue in how far data can actually be employed; GDPR issues. Some services already offered by other business models such as Liftshare
Does it provide evidence of where general public support might be targeted?	Prior research in Wales has revealed issues in terms of costs and time of travel to work for residents in more disadvantaged areas; and with issues of uncertainty in travel.
Does the use case reveal social welfare benefits that could be a prior to public sector support?	Potential benefits in terms of reduced pollution, and safer travel, that fit with sustainable economic development agenda in Wales. Roll out of the technology could link into sharing culture, and improve community networks. Also potential for improve access to employment opportunities and with evidence that costs in terms of travel to work are a serious issue in the case area. Scaled up use cases could have safety and security implications.

Has the use case identified benefits that can be valued?	Reductions in travel time and more efficient travel can be valued. Reduced pollution where car journeys are substituted to public transport. Reduced unnecessary bus movements. Approaches available to assess reduced carbon and costs of time saved in commuting etc.
Has the use case identified benefits that cannot be valued?	Difficult to identify from the use case.
Has the use case identified any basis for new business models, or demand side attributes that can be scaled in rural environments?	Some possibility that the transport uses in measuring timing, direction of travel would reduce supply side for public transport, identify underused routes at selected times. Unclear whether case provides any scope for new business models with exception of efficiencies gained in operators on poorly used routes, and minimisation of bus routes. Potential new markets for technical application providers but these may not be in Wales. Other on demand transport services are available in Wales with real time aspects; demand for services founded in 5G in rural areas could be inferred from demand for these services.
Does the case reveal potential economic benefits for rural economies?	Use case location is essentially urban not rural. Little evidence of benefits for genuinely rural economic situations.
Does the use case reveal dependencies or point to supply side skills issues?	Dependencies identified in terms of appropriate permissions and data security issues. Unclear how volumes of data produced would be actually used by stakeholder groups. How far potential users have the capacity to use the data produced.
Cost-benefit conclusions from case	Unlikely benefits exceed costs and with technology solutions more appropriate to more urban locations.

7. 5G demand and impact discussion model

A framework has been developed to better understand the cost-benefits of the use cases. Given the lack of detailed quantitative evidence of benefits the analysis is necessarily experimental, and focused on a single use case area for indicative purposes (Monmouthshire). The model is developed from analysis of the demand conditions in the County. This allows us to consider three main questions:

- What is the likely demand for 5G network services across the County?
- Where might most value occur?
- In which sectors might there be scope for network services to add to local gross value added?

Table 7-1 highlights:

- Monmouth employment by sector, share of total employment and employment growth 2016-2020. It is accepted that the time period here and associated growth rate would be impacted by Covid-19. This data is derived from the ONS *Business Register and Employment Survey* available from NOMISWEB[11].
- Estimated GVA by sector in Monmouthshire, and share of GVA by industry sector. This is derived from ONS Regional gross value added statistics at ILTS3.[12]
- An estimate of UK productivity growth in the sector based on real output per hour from the ONS.[13] This is ranked HIGH where real productivity growth 2016-2021 is over 20%, MEDIUM if 5-19%, and LOW if less than 5%.
- An estimate of the relative productivity of the sector compared to other sectors in the local economy. This is based on estimates of GVA per employment for the Welsh economy and ranked HIGH, MEDIUM and LOW.
- Two industry specific variables from the ONS UK e-commerce survey[14] showing proportion of UK businesses in these sectors that make e-commerce sales , and who purchase cloud computing services.

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[11] Nomis - Official Labour Market Statistics - Nomis - Official Labour Market Statistics (nomisweb.co.uk)
[12] Regional gross value added (balanced) by industry: all ITL regions - Office for National Statistics
[13] Real output per hour index by industry, UK, chained volume measure: for more information see https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/ukproductivityintroduction/julytoseptember2020

[14] For more information on this survey see Digital Economy Survey (formerly E-Commerce Survey) - Office for National Statistics (ons.gov.uk)

Table 7-1Monmouthshire economy by broad industry sector

	Employment 2020	% share	Growth emp 2016-20 %	GVA est 2019 £m	Share GVA%	Productivity growth	Relative Productivity	% UK firms in ind. purchasing cloud computing services 2019	% UK firms in this ind. making e-comm sales
A/B : Agriculture, forestry and fishing	2010	5.2	-33.3	27.9	1.4	Medium	Low		
C : Manufacturing	3500	9.2	0.0	288.5	14.8	High	High	35.5	20.1
D/E Utils	180	0.5	-41.7	32.9	1.7	Low	High	33.2	
F : Construction	3000	7.9	20.0	182.9	9.4	Low	Medium	23.3	4.1
G : Wholesale and retail trade;	6000	15.7	-14.3	213.9	11.0	Medium	Low	23.4-36.4	19.1-36.1
H : Transportation and storage	1750	4.6	16.7	66.9	3.4	Low	Low	10.1	
I : Accommodation and food service activities	3500	9.2	0.0	72.4	3.7	Medium	Low	12.3	
J : Information and communication	800	2.1	-20.0	76.6	3.9	Low	High	57.8	5.4
K : Financial and insurance activities	250	0.7	-16.7	15.9	0.8	Low	High	69.5	6.7
L : Real estate activities	800	2.1	14.3	285.7	14.7	Low	High	69.5	6.7
M : Professional services	2500	6.6	42.9	64.0	3.3	Low	Low	69.5	6.7
N : Administrative activities	1750	4.6	0.0	76.0	3.9	Low	Low	69.5	
O : Public administration	2000	5.2	14.3	116.8	6.0	Low	Medium		
P : Education	2500	6.6	0.0	106.0	5.4	Medium	Low		
Q : Human health and social work activities	6000	15.7	-14.3	260.7	13.4	Low	Low		
R : Arts, entertainment and recreation	1000	2.6	11.1	20.4	1.0	Low	Low		
S : Other service activities	600	1.6	20.0	42.4	2.2	Low	Low		
Total	38140	100.0	-3.4	1949.9	100.0			32.1	11.6

Taken together the Table highlights for Monmouthshire:

- Sectors where there has been recent growth in terms of employment.
- The significance of sector activity in terms of contributions to local employment and gross value added.
- The expected productivity characteristics of these sectors.
- Sectors where if network services were improved where some of the largest returns might be. So for example, in manufacturing, it contributes an estimated 15% of Monmouthshire GVA, but is also expected to have strong productivity characteristics in terms of growth, but also in terms of the sectors high productivity in comparison to other sectors in the local economy.
- On the other hand, there are sectors such as education and health/social care, which while important in terms of employment and gross value added for the local economy, tend to be associated with poorer productivity characteristics. However, in these same sectors improvements to network connectivity could lever social welfare returns to the local population.

It is next useful to think about what the technical opportunity might be in terms of 5G perhaps or better network capability. Table 7-2 below provides some examples of commonly understood benefits. Clearly these will vary within these broad sectors but much of the research literature concludes that the scope of technical opportunity does vary by industry and is one of the factors explaining variations in productivity growth. The second column of Table 7-2 hints at the technological opportunity in these broad sectors, although this is based on historical data.

Table 7-2 Sector potentials from improved network connectivity/5G

A/B : Agriculture, forestry and fishing	Agriculture starting to use IoT to better processes inc. water management, fertilisation, livestock and crop monitoring; 5G allows real- and farm managers can better develop systems to up profits efficiency, and safety.
C : Manufacturing	Network connectivity and 5G improving manufacturing efficiency, 5G assists automation, IoT, and AI; powering AR overlays in workflows, HSA improvements via VR-based training, fault reduction
D/E Utilities	5G linked to new solutions in energy production, transmission, distribution, and usage, also associated with smart grid development.
F : Construction	Security on remote sites, management of processes on site.
G : Wholesale and retail trade;	Higher levels of purchases using mobile devices, and 5G may allow better consumer experience on line via VR and AR.
H : Transportation and storage	Potential for autonomous vehicles, better public transport efficiency in remote locations, improved traffic management, travel innovations.
I : Accommodation and food service activities	5G allows improvements to booking services, accommodation selection, real time updates on availability.
J: Information and communication	Development of new applications to benefit from 5G
K : Financial and insurance activities	5G may permit better quality real time services, more services dealt with by mobile devices, contactless payments, improved fraud protection and security enhancement, better understanding of real time risks for insurance industry.
L : Real estate activities	Virtual real estate tours, house price effects as 5G improvements allow more opportunity to work in remote spaces.
M : Professional services	Varies by sector
N : Administrative activities	Limited as much of activity urban based.
O : Public administration	Improved provision of public services in more rural areas, improved security and monitoring.
P : Education	More immersive education opportunities, with AR/VR, real time learning through collaboration with external users, education innov
Q : Human health and social work activities	5G might allow more use of AI, and AR/VR in direct health, welfare and care sectors, growth of telemedicine in remote areas, remo
R : Arts, entertainment and recreation	5G allows better data transfer, new opportunities for media firms, and gaming firms.

Then in terms of the value proposition for improved network connectivity one outline approach for an area such as Monmouthshire would be to consider:

- The significance of the sector to the contemporary Monmouthshire economy in terms of contribution to employment, GVA, and its productivity characteristics.

- Link this through to the likely technological opportunity from improved network services.
- Be mindful of welfare benefits that are not valued in sectors such as education and health.

This might lead to some very outline value propositions for improve connectivity as follows:

Agriculture- Low. For Monmouthshire it is a small sector of the economy in terms of GVA with limited productivity growth, although improved network solutions might be connected to improved sustainable economic outcomes. So in this sector even if improved connectivity might be associated with a 10% year on year increase in GVA this might only be worth £2-3m pa because of the size of the sector.

Manufacturing- High: around 10% of employment and 15% of Monmouthshire GVA (estimated £289m of GVA in Monmouth and stronger productivity growth/characteristics linked to better network services and 5G). But in this case were improved network connectivity to lead to just a 1% uplift in sector GVA this might be worth £2-3m pa - in other words an amount similar to what one would need in a 10% uplift in agricultural GVA, and with manufacturing potentially in a better place to use the technology to gain productivity outcomes.

Education- High while low productivity characteristics, this is an important element of the local economy in terms of employment and there are strong expected social welfare returns from improved connectivity.

Overall, were improved network services to lead to just a 1% uplift in GVA across all sectors of Monmouthshire this would be worth £20m.

Then our discussion model considers local value in terms of:

- Technological scope of the sector to benefit from improved network services
- Evidence of the past, present economic contribution of the sector to Monmouthshire
- Evidence of how far the industry as a whole reveals evidence of using network services
- The availability of welfare returns to the local population.

8. Conclusions

Ensuring the deployment of 5G mobile connectivity across remote and peripheral areas represents an important challenge for policy makers. The 5GWU project addresses this through a series of use cases in Monmouthshire and Blaenau Gwent. Over a period of nine-months the 5GWU Observatory – comprising Cardiff University's Business School and the Geography and Planning School - examined the progress, achievements and scale-up potential of these use cases. In this concluding chapter we consider the findings from the Observatory research and their implications for accelerating deployment of 5G across rural Wales.

Use case achievements

The use cases have largely succeeded in achieving their objectives to implement technologies that support the use of 5G in different sectoral contexts (farming, education, transport and tourism), despite notable challenges associated with Covid-19. They have also produced potentially valuable lessons that could inform future deployment of 5G in rural areas. Yet while the R&D objectives of the use cases have largely been achieved, there has been little time to implement services for end users.

The cost benefit analysis highlights the challenges of identifying benefits for the end users, given their early stage nature. It does, however, suggest that such benefits are likely to emerge in areas such as efficiency and new service and supply models, with both direct and indirect impacts for business, public sector and citizens in rural areas of Wales. Our discussion model reveals that were 5G adoption and use to produce an uplift in GVA of 1% across all sectors (based on analysis of the reference case Monmouthshire) it might realise a £20m pa annum gain to the local economy in terms of GVA. Our wider analysis also highlights the potential to measure both tangible and intangible benefits using methodologies such as Themes, Outputs, Measures (TOMS). Assessing such impacts, however, will only be possible once the services are fully operational and used by end users. This suggests that the focus needs to be placed on deepening the evidence base before further scale-up is considered.

Much of the activity covered in the use cases, it should be noted, links to sectors characterised by low productivity growth, and then what might be lower paid employment opportunities. It is currently unclear how far better 5G connectivity might lead to improvements in the quality of employment prospects, and how far the technology might in the future work to displace employment. In order to understand the precise impacts, however, there is strong potential to continue to collect data on the use cases for some time after the end of March 2022. In many instances costs to keep the use case infrastructure in place are relatively small in comparison to the initial set up and capital costs, and with the University in a strong position to continue to engage in research around the cases.

Strategic assessment, scaling themes and business models

The findings of this report confirm that there is currently no commercial MNO business model to deploy 5G in rural and remote areas. They show isolated examples of rural 5G in Wales, but these tend to be in areas where there is a sufficient user base. 5GWU is therefore supported by a strong rationale based on accelerating the deployment of 5G in rural areas of Wales and ensuring that businesses and residents are 'not left behind' in mobile connectivity.

The use case assessment suggests that successful scale-up is likely to be determined by a clear use case and potential market, technological solutions and supportive partners – linked to 5G. Based on our analysis the Tourism and Education use cases demonstrate the clearest markets and demonstrable need for 5G. In developing these use cases and their underlying technologies we note that many of the suppliers are likely to continue to develop their products, and build evidence and customer bases. This is likely to continue beyond the life of the use cases, but will not necessarily be spatially focused on the rural needs of Wales without further intervention, nor to the direct benefit of Wales (as most technology partners are based outside of Wales).

The use cases do, however, suggest the role for collaborative organisational approaches to support 5G deployment in rural areas. Such approaches are evident in the use cases, although fully funded by UK government. In future there is the potential for greater risk sharing between public and private partners in the 5G space. That is, the business models that support 5G deployment are most likely to be built on a social, environmental and economic case in which the public sector acts to mitigate risk, either in support of private sector deployment, or to play an anchor role in solutions such as neutral host. In this respect the use cases allude to such outcomes, particularly when activities are aligned to public service objectives. The modelling results further highlight the importance of demand in determining the case for new deployment of 5G. That is, any prospective business case needs to include both an assessment of demand as well as social and economic outcomes.

This raises relevant questions such as whether there is a need for 5G in all rural areas. At present the use case evidence is not clear, with some suggestions that 4G connectivity may address the needs of many areas. This, of course, may change as user needs develop (and MNO upgrade plans are implemented). The role for government in any future business models, as hinted at above, will require it to be agile, working alongside the MNOs to support their deployment (e.g. through barrier busting, awareness raising). The nature of emerging technologies such as neutral host offers additional business models to support 5G deployment in which MNOs do not own the infrastructure. Here the government may be able to create its own case for developing publicly owned networks in which it may act as a platform to lever public services innovation and economic growth opportunities in rural areas. This potential to generate social and economic outcomes across multiple public sector objectives suggests that cross government support may be garnered for such interventions. Here the mapping findings suggest that UK government are the main public funding source for mobile broadband infrastructure (linked to their reserved responsibility for telecommunications). The City Deals (with UK and Welsh Government funding) are also potential partners and funding sources. More widely, the use cases point to social, health and wellbeing, transportation, tourism and education as objectives that may be aligned to other areas of the public sector. This presents a comparatively rich and potentially varied funding landscape for future 5G deployment than has been present in the past.

Policy options

Policy options to accelerate rural deployment of 5G are set out in Table 8-1. These options provide a range of models by which risk sharing could be brought to bear on 5G deployment. This includes policy options for infrastructure (based on infrastructure-led development of masts and fibre) and use case focused models (bottom up demand-led approaches based on identification and aggregation of area-based use cases), plus strategic enabling (to support the activities of sub-national partners in Wales seeking to develop 5G in rural areas) and cross-cutting models such as barrier busting (cross-governmental action to remove barriers and support the deployment of 5G) and uptake support (support to encourage users to make use of available 5G services). Much, however, will depend on the availability of funding in each of these areas and the appetite of partners to engage in these models. Developing this agenda will therefore require increased levels of collaboration both within multiple levels of government (including DCMS), private and community sectors, as well as other relevant bodies engaged in 5G (e.g. Scotland 5G, Sunderland Council).

Table 8-1 Intervention options to accelerate 5G connectivity in rural areas

Policy option	Models	Actors	Cost	Potential for Welsh Government
Infrastructure-led development	Private networks, infrastructure sharing, fibre deployment (e.g. SRN)	Government MNO Community	High	Work with UK Government / MNO to explore potential to upgrade existing 4G infrastructure in rural areas
Demand-led development	Identification of demand-led interventions in association with partners	Government (national / local) Private	Medium	To target support around selected demand-led interventions, engaging with public actors, private and community actors
Strategic enabling	Collaborative support for public and private parties to	Government Private	Medium	Work with City Regions and MNOs with the objective of developing 5G

	develop 5G solutions			solutions in rural Wales
Barrier busting	Support deployment / manage trade-offs between policy agendas	Government (national / local)	Low	Support the diffusion of good practice across rural Wales
Uptake support	Awareness raising of benefits of use (e.g. SFC)	Government Private	Low-Medium	Raise awareness and promote the benefits of 5G in rural areas

These policy options include different stages of the policy development cycle, ranging from design and development (infrastructure-led development, demand-led development and barrier busting) to post implementation (uptake support). Welsh Government has the ability to take action on all but the most ambitious forms of infrastructure-led development (which is likely to require UK Government funding). The findings of our research suggest, however, that a demand-led approach would be more appropriate. This should be supported by strategic enabling actions such as diffusing good practice expertise to others in local authorities and City regions, barrier busting and uptake support.

Future forms of government intervention will, however, need to consider whether 5G is required in all rural locations. A technology agnostic approach may allow for flexibility in addressing those areas of greatest need in rural areas, where demand and value for services shapes connectivity solutions can inform a case for intervention. Adopting this approach help to move away from the narrative of ‘rural areas need 5G’ towards one in which 5G is needed in rural areas because of the presence of sources of demand such as telemedicine, networked education, mobility as a service.

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Annex

Interviewees

Organisation	Interviewee
Welsh Government	David Warrender Peter Williams Tom Allen (contractor)
DCMS	Alan Srbljanin
DCMS	Nadeem Mughal
Blaenau Gwent County Borough Council	Amy Taylor
Monmouthshire County Council	Mike Powell Adam Greenwood
CADW	David Penberthy
Cardiff University	Omer Rana
NW Ambition Board	Stuart Whitfield
Bangor University	Peter Curnow-Ford
Cardiff Capital Region	Colan Mehaffey
Mobile UK	Gareth Elliot
BT	Gavin Parsons
Appyway	John Fogelin Stephen Jones
Utterberry	Heba Bevan
CISCO	Peter Shearman
Jam Creative	Adam Martin-Jones
AWS	Wayne Phillips