5G Testbeds and Trials Programme: Evaluation Scoping Study and Baseline

Final Report

2 April 2019

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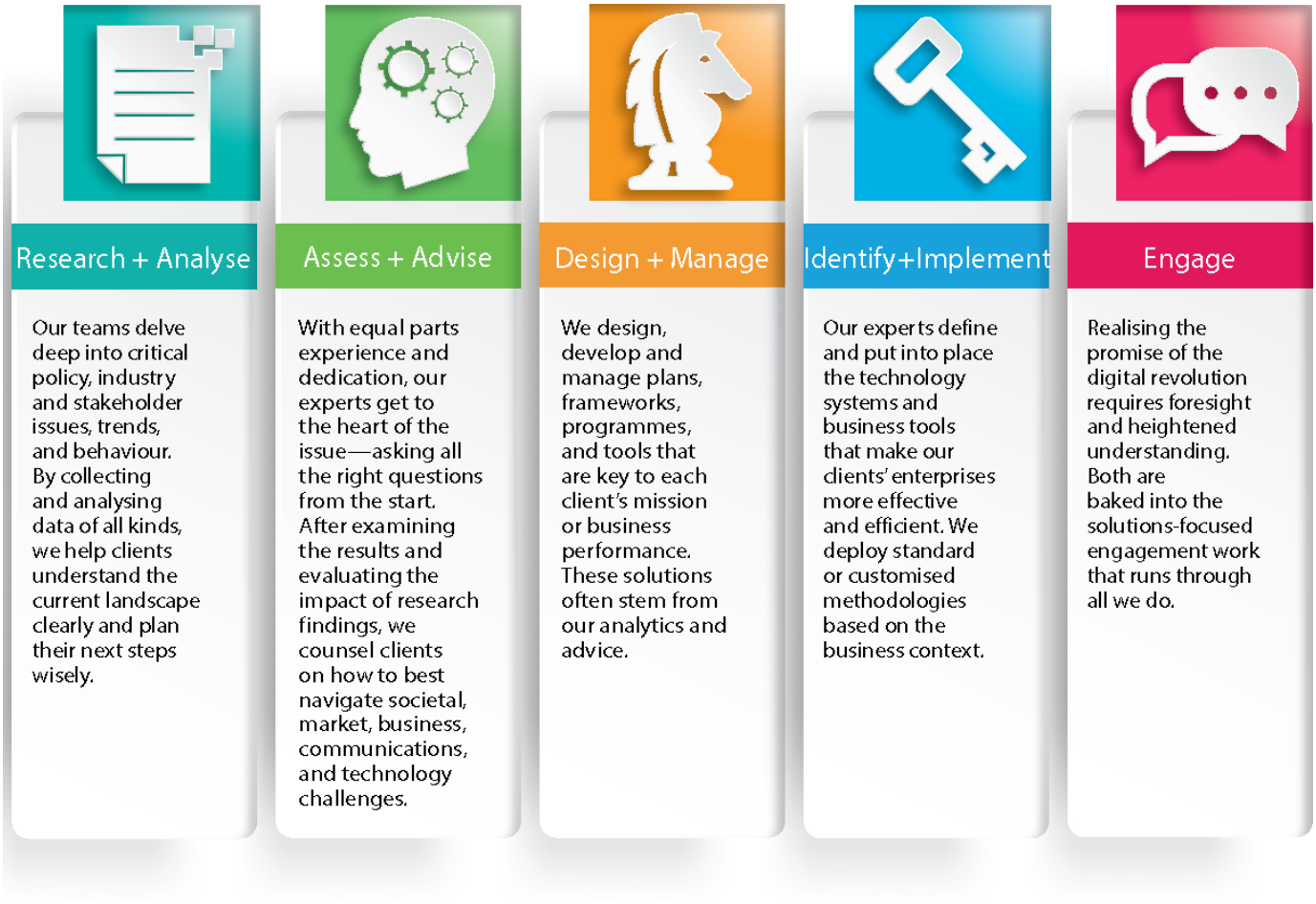

5G Testbeds and Trials Programme: Evaluation Scoping Study and Baseline

Final Report

A report submitted by ICF Consulting Services Limited
in association with

George Barrett, Plum Consulting, Avril Blamey, Susan Purdon, Stefan Sanchez, Pantelis Koutroumpis

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Joe Sunderland

ICF Consulting Services Limited
Watling House
33 Cannon Street
London
EC4M 5SB

T +44 (0)20 3096 4800
F +44 (0)20 3368 6960

www.icf.com

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Job No.	30301927
Prepared by	Jan Franke, Maria Zhitkov, Martina Rigoni, Arthur Hannah
Checked by	Joe Sunderland, George Barrett
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Contents

Glossary

Term	Definition
4G RAN	4G generation of a radio access network (RAN). RAN is part of a mobile telecommunication system. It implements a radio access technology. Conceptually, it resides between a device such as a mobile phone, a computer, or any remotely controlled machine and provides connection with its core network (CN).
5G RAN	5G generation of a radio access network (RAN)
Contribution analysis	Contribution analysis is an approach for assessing causal questions and inferring causality in real-life program evaluations. It offers a step-by-step approach designed to help managers, researchers, and policymakers arrive at conclusions about the contribution their program has made (or is currently making) to particular outcomes [1].
Cost benefit analysis (CBA)	Cost-benefit analysis (CBA) is a technique used to compare the total costs of a programme/project with its benefits, using a common metric (most commonly monetary units). This enables the calculation of the net cost or benefit associated with the programme. CBA adds up the total costs of a programme or activity and compares it against its total benefits. Decisions are made through CBA by comparing the net present value (NPV) of the programme or project's costs with the net present value of its benefits. Decisions are based on whether there is a net benefit or cost to the approach, i.e. total benefits less total costs. Costs and benefits that occur in the future have less weight attached to them in a cost-benefit analysis. To account for this, it is necessary to 'discount' or reduce the value of future costs or benefits to place them on a par with costs and benefits incurred today[2].
Fixed wireless links	Fixed wireless is the operation of wireless communication devices or systems used to connect two fixed locations (e.g., building to building or tower to building) with a radio or other wireless link, such as laser bridge[3].
Integration with other networks	System integration is defined in engineering as the process of bringing together the component sub-systems into one system (an aggregation of subsystems cooperating so that the system is able to deliver the overarching functionality) and ensuring that the subsystems function together as a system[4]
Machine to machine communication	A broad label that can be used to describe any technology that enables networked devices to exchange information and perform actions without the manual assistance of humans[5]
Network convergence	Network convergence is the efficient coexistence of telephone, video and data communication within a single network. The use of multiple communication modes on a single network offers convenience and flexibility that are not possible with separate infrastructures. Network convergence is also called media convergence.
Network sharing	Network sharing is a feature that allows resources to be shared over a network, be they files, documents, folders, media, etc. These are made accessible to other users/computers over a network[6].

[1] https://www.betterevaluation.org/en/plan/approach/contribution_analysis

[2] https://www.betterevaluation.org/en/evaluation-options/CostBenefitAnalysis

[3] www.networkcomputing.com.

[4] Gilkey, Herbert T (1960), "New Air Heating Methods", New methods of heating buildings: a research correlation conference conducted by the Building Research Institute, Division of Engineering and Industrial Research, as one of the programs of the BRI fall conferences

[5] https://internetofthingsagenda.techtarget.com/definition/machine-to-machine-M2M

[6] https://www.techopedia.com/definition/27109/network-sharing

Term	Definition
Neutral host infrastructure	Neutral host infrastructure comprises a single, shared network solution provided on an open access basis to all mobile network operators (MNOs) and is used to resolve poor wireless coverage and capacity inside large venues or other busy locations. They are usually deployed, maintained and operated by a third-party provider and they are designed to support the full range of MNO technologies[7].
Small cells deployment	Small cells are portable miniature base stations that require minimal power to operate and can be placed every 250 meters or so throughout cities. Global mobile operators will be using small cells to expand the indoor coverage and improve network capacity, improving the quality of telecommunication. Small cells can divert 80 per cent of data traffic in crowded areas. [8]
Spatial diversity	One of several wireless diversity schemes that uses two or more antennas to improve the quality and reliability of a wireless link.

[7] https://www.techuk.org/insights/opinions/item/13533-is-neutral-host-infrastructure-the-way-forward

[8] http://techblog.comsoc.org/2018/03/14/trendforce-small-cell-deployment-to-reach-2-838m-units-in-2018-4-329m-units-in-2019-for-cag-of-52-5/

Executive summary

Introduction

ICF Consulting Services Limited (ICF) was commissioned by the Department for Digital, Culture, Media and Sport (DCMS) to undertake a scoping and baseline study to inform the programme-level evaluation of the 5G Testbeds and Trials Programme (5GTT). The Programme was established in 2017 with the aim to maximise the prospective benefits that 5G could bring to the UK economy through timely deployment and effective utilisation of 5G technology. It is encouraging and funding the creation of a series of Testbeds and Trials in a range of market segments.

The study provides a combination of:

- process, impact and economic evaluation frameworks for the Programme, along with plans to take forward early, interim and final evaluations; and
- a baseline assessment against which future progress towards the achievement of the Programme's intended outcomes can be assessed.

It is recommended that the evaluation framework addresses the following five key evaluation questions.

Table ES1.1 Key evaluation questions

Evaluation type	Evaluation questions
Process	i) How effective and efficient has the delivery of the Programme been?
	ii) What is the wider learning from the evaluation for DCMS?
Impact	iii) What impact has the Programme had?
Hybrid	iv) How has the Programme achieved these impacts?
Economic	v) What is the overall value for money of the Programme?

Proposed evaluation approach

The programme-level evaluation should be conducted in three stages:

- An initial assessment, focussing on process elements and early impacts of the activities conducted to date, to take place in early 2019 – early 2020.
- An interim assessment, focussing on a refresh of the process elements, an interim impact evaluation and an interim economic evaluation, to take place shortly after the completion of the Programme.
- A final assessment, including a final impact and economic evaluation, to take place in the first half of 2025, although these timescales are indicative only at this stage.

Some of the future projects funded through the Programme – e.g. the Urban Connected Communities and the Rural Connected Communities – may involve substantial evaluation work at project level both to assess their contribution to the Programme's objectives and the extent to which they have met their specific objectives. Work on the Programme evaluation will need to be coordinated with these project-level evaluation activities.

Whilst the programme-level evaluation will take place after the completion of the Programme, monitoring of projects will be done on a continuous basis and will be used to assess how the Programme is progressing during its lifetime. More specifically, monitoring data, combined with other sources, will inform a range of evaluation metrics.

Process evaluation

This will comprise a major element of the initial assessment designed to enable emerging lessons to be applied to additional future projects. It is recommended that the process evaluation give attention to: engagement with the market and the wider ecosystem which are crucial to the likely effectiveness of the Programme; the processes for selecting and monitoring projects which are crucial to maximising its value for money; and the mechanisms to promote collaborative working which are important to the achievement of the potential for synergies and spill over benefits from the activities involved. It is recommended that a mixed set of research methods be deployed: stakeholder consultations, analysis of monitoring data and project documentation, case studies, and surveys of participating and non-participating organisations. The detailed approach to process evaluation is outlined in section 3.3.

Impact evaluation

The initial assessment will be mainly limited to an assessment of how far projects are delivering their intended outputs and the results of the activities involved. The primary focus of the interim and final impact evaluations will be on the extent to which the intermediate and final outcomes expected from the Programme are being realised and its role in bringing these about. A theory-based technique (contribution analysis) is proposed to assess the latter. It is recommended that a mixed set of research methods be deployed: stakeholder consultations, analysis of monitoring and secondary, case studies, surveys of Programme and non-participating organisations. Contribution analysis is proposed to assess the cause and effect of the programme for both the interim and final evaluations. The proposed approach to impact evaluation is discussed in section 3.4.

Economic evaluation

The requirements of the HMT 'Green Book' indicate that the economic evaluation will need to be based upon a cost benefit analysis approach involving both a wide and a long-term assessment of these aspects. The analysis will need to build upon the findings of the impact assessment, attaching monetary valuations to the observed and projected effects which are identified. The recommended approach to economic evaluation is outlined in section 3.5.

Establishing an evaluation baseline

The baseline seeks to establish a point of reference from which to identify and, as far as possible, measure the change which occurs following the implementation of the Programme. The baseline work supporting this study consisted of a literature and data review covering research on 5G in the UK and elsewhere, eighteen interviews with key stakeholders from industry, academia and the public sector to gather perspectives on the current context, and a survey of programme beneficiaries to date to explore aspects of organisational motivations and expectations, especially on the part of non-lead partners. Findings are summarised in Section 4 and outlined in detail in Annex 3. Key points are presented below.

Technological development

Development of 5G technology and products – both user devices and network elements – is underpinned by development of the 3rd Generation Partnership Project (3GPP) technical standards and related chipsets and product components. Typically, the commercial availability of products follows completion of standards by some 12 to 18 months.

Regulatory environment

At present, the regulatory environment continues to evolve. Ofcom has made some progress with a focus on duct and pole access, allowing alternative network providers to utilise the Openreach passive infrastructure. A consultation for unrestricted duct and pole access led by Ofcom is currently ongoing and a final decision statement will be made in spring 2019. There is also progress with development of an integrated approach to regulatory market reviews.

Risks and enablers for 5G roll-out

The main risks and enablers for 5G roll-out include: (a) the investment case, which remains challenging for mobile operators and investors because the level of incremental cost efficiency offered by 5G (over 4G) technology is unclear (though expected to be positive); (b) the availability of radio spectrum and access to fibre networks to support connections to core networks; and (c) access to commercial partnerships across other sectors to ensure that novel services are developed and that these meet the needs of varied consumers/business users.

Industry plans and expectations

Indoor environment

In cases where full fibre to the premises is provided, ICF expects that Wi-Fi technology will remain significant, even as 5G solutions develop. In cases where no fibre and poor fixed line broadband exists, 5G technology could provide some benefits – for example via fixed wireless access, or via use of modified 5G mobile solutions for home access. Traditional wide area (macrocell) solutions, as with 3G and 4G, are expected to evolve with 5G. In such cases, spatial diversity in the technology deployments may be relatively limited and, consequently, benefits from 5G over previous cellular generations may be reduced. If 5G is seen as a network system (rather than a radio access technology), as it may do, it may be that 5G core networks will embrace many different radio technologies at the access level. In such cases, 'true' convergence may develop – with converged services across both fixed and wireless networks.

Finally, 5G small cells have the potential to improve coverage in commercial premises (such as offices, shopping centres and railway stations).

Outdoor in dense urban areas

5G technology may bring early benefits and is expected to be deployed in urban centres initially due to high market take-up levels and high traffic capacity demands. In such cases, 5G technology is likely to be deployed to provide capacity augmentation on 3G and 4G existing sites, thus conserving investment levels. A key issue will be the development of 5G services which offer incremental value over 3G and 4G based services and minimising the cost of these network upgrades.

Outdoor in non-urban areas

Beyond urban centres, demand becomes sparse and the investment case for cellular technologies becomes more challenging. Investment cases thus demand lower capex density levels, but sparse deployment of radio sites weakens the case for cost-efficient deployment of high capacity services – one of the key differentiators envisaged for 5G. If new innovative forms of network and spectrum sharing are developed and supported by Ofcom, it may be that costs can be reduced and competition is opened up for new players across the country, and this may drive increased deployment of 5G solutions across the country as a whole, as opposed to urban centres only.

The international context

Internationally, those countries with a relatively high proportion of total population based in urban areas are expected to see a commensurate high level of 5G service coverage during initial years of 5G systems roll-out.

1 Introduction

1.1 Background

Digital infrastructure is increasingly crucial to delivering a strong and growing economy and the demand for data is increasing rapidly. 5G presents the next step in the evolution of the mobile telecommunications ecosystem. Although challenging to define at this stage, it is anticipated to deliver a step change of ultrafast, low latency (i.e. quicker reaction times), reliable, mobile connectivity, that is able to support ever larger data requirements, as well as wide-ranging new applications (or use cases).

Potential applications of the technology are likely to include connected and autonomous vehicles, advanced manufacturing and robotics, smart agriculture, and smart cities, as well as media-related developments. Therefore, 5G has the potential to lead to an increase in economic output, act as an enabler for new markets within vertical industry sectors[9], bring societal benefits, and support increased productivity and efficiency more generally, including in the delivery of public services.

Recognising the potential benefits of 5G in the Autumn Statement 2016[10], the Government announced its intention to invest in a nationally-coordinated programme of 5G testbed facilities and trials as part of over £1bn of funding[11] intended to boost the UK's digital infrastructure. The DCMS 5G Testbeds and Trials Programme (5GTT) was established in 2017 with the aim to maximise the prospective benefits that 5G could bring to the UK economy through timely deployment and effective utilisation of 5G technology. The Programme is encouraging and funding the creation of a series of Testbeds and Trials in a range of market segments.

Testbeds will help industry understand the challenges of deploying new technologies according to the developing international standards for future 5G networks. Testing 5G applications will help prove different use cases, bringing ideas closer to commercial viability for future markets.

The Programme aims to explore the benefits and challenges of deploying 5G technologies in line with the following key objectives:

- help to establish the conditions under which 5G can be deployed in a timely way to drive efficiency and productivity, and maximise the chances of the UK being amongst the leading 5G countries;
- foster the development of a diverse and varied set of 5G use cases and applications to ensure that the UK and UK businesses are well-placed to maximise the benefits of 5G; and
- support the implementation of the Government's Future Telecoms Infrastructure Review[12].

[9] Products or services oriented to a particular market opportunity as opposed to those meeting a wider range of potential needs: for example, equipment used only for the purposes of monitoring a particular aspect of human health.

[10] https://www.gov.uk/government/publications/autumn-statement-2016-documents

[11] https://www.gov.uk/government/publications/autumn-statement-2016-documents/autumn-statement-2016#digital-communications

[12] https://www.gov.uk/government/publications/future-telecoms-infrastructure-review

A total of £200 million of capital funding has been allocated to the Programme. Early projects that have been successfully delivered include a £16 million investment in creating the 5GUK Test Network[13], and the establishment of UK5G – the national innovation network for the sector[14].

In March 2018, the six winners[15] of the first Phase of the 5G Testbeds and Trials Programme were announced. These six projects, led by small and medium-sized enterprises (SMEs), universities and local authorities, will test 5G across a range of applications. Each testbed will receive between £2 million and £5 million in Government grants as part of a total investment of £41 million in private sector and public sector funding. The projects will run from 2018 to 2019.[16] Public investment has also already been committed to projects looking at roads[17], rail and 5G security[18], alongside investment from the (related) Local Full Fibre Networks (LFFN) programme.

In March 2018, the Government also announced plans for a 5G Urban Connected Communities (UCC) project[19] which is expected to run from 2018 until 2022. The project will provide the opportunity to use developing technologies in the innovative delivery of both public and commercial services to individuals and businesses, and to improve the quality of urban living and working. It will support economic development by stimulating the 5G ecosystem, encompassing multiple industry sectors. Up to £50 million is currently available for the project, subject to further development and approval of the business plan. This includes £25 million from DCMS and a further £25 million in match funding from regional partners. An additional £25 million may be made available at a later stage, subject to the eventual project design and business plan justification.

Another project in the pipeline of the Government is the 5G centric Rural Connected Communities (RCC) project, which will "promote demand for services from consumers, enterprises and the public sector in rural areas and will also explore how "neutral host" infrastructure sharing and spectrum sharing can be used to improve the incentives to invest.

DCMS will also be considering projects that will have a primary focus on specific vertical industry sectors.

A number of additional future projects are expected to be funded through the 5GTT Programme. The recently published Programme Update[20] provides more information.

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[13] https://www.gov.uk/government/case-studies/5guk-test-network

[14] https://www.gov.uk/government/case-studies/uk5g-innovation-network

[15] https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy

[16] For more details about all of these projects, please visit https://uk5g.org/discover/testbeds-and-trials/

[17] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/677598/Next_Generation_Mobile_Technologies__An_Update_to_the_5G_Strategy_for_the_UK_Final_Version_with_Citation.pdf#page=13

[18] https://www.gov.uk/government/publications/autumn-budget-2017-documents/autumn-budget-2017#digital-communications

[19] https://www.gov.uk/government/news/west-midlands-to-become-uks-first-large-scale-5g-test bed

[20] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739430/5GTT_Programme_Update.pdf

1.2 Objectives of this study

In April 2018, ICF was commissioned by DCMS to undertake a scoping and baseline study to inform the programme-level evaluation of the 5G Testbeds and Trials Programme. The study provides:

- proposed approaches and plans for the process, impact and economic evaluations of the Programme; and
- a baseline assessment against which progress towards the achievement of its overall objectives can be assessed.

The aim of the 5G Testbeds and Trials Programme is to stimulate market development and deployment of 5G technology and infrastructure in the UK. The Programme is also aimed at creating new opportunities for businesses, developing capability and skills, and encouraging inward investment[21].

At the time this scoping study was conducted, information on the scope and expected timescales of 5GTT projects was only available for completed and ongoing projects started before July 2018. Whilst this report presents a proposed evaluation framework for the Programme overall and for the known projects, this general framework will need to be developed in light of future projects to ensure that their contributions to the Programme's objectives – and the extent to which they have met their own specific objectives – can be identified.

1.3 Approach

The approach to this study included:

- An inception meeting with DCMS to discuss and clarify the scope of the study.
- A desk-based review of relevant documentation, including the Programme business case, existing and proposed metrics and project specific documentation, as well as monitoring and other information on progress in implementation.
- Stakeholder consultations with 18 representatives of DCMS, Ofcom and project beneficiaries, as well as stakeholders from network providers, operators, equipment manufacturers and academia.
- Development of a Programme Logic Model building upon the draft produced by DCMS, with sub-models for the 5GUK Test Network, UK5G and the phase 1 projects.
- Pilot case studies on some of the underlying assumptions and risks of the Logic Model.
- Initial development of proposed evaluation frameworks and plans, along with proposals for further 'metrics' relating to the overall Programme and the major constituent projects, again building upon initial work by DCMS.
- A literature and industry data review – including GSMA projections on expected take-up of the technology – which in conjunction with the stakeholder consultations and a survey of Programme beneficiaries to date has been used to establish a baseline from which to identify, and as far as possible, measure the change which occurs following the implementation of the Programme.

[21] https://www.gov.uk/government/collections/5g-testbeds-and-trials-programme

- Two workshops with DCMS and external experts to discuss emerging findings and inform the subsequent refinement of the outline proposals for the evaluation programme.

1.4 Structure of this report

This report presents the results of the study. The main sections of the report present:

- A Logic Model for the overall Programme (Section 2).
- The proposed evaluation approach and plan (Section 3).
- The evaluation baseline (Section 4).

The report is supported by a number of annexes.

2 Programme Logic Model

2.1 Overview

Logic models provide a simplified representation of an intervention's inputs, activities, outputs, expected outcomes, impacts, timeframes for delivery and the linkages between these elements. Such models are used to help structure the intervention planning and evaluation processes, providing a framework through which stakeholders can identify priorities, inform the design and methods for monitoring and evaluation and identify success criteria and associated indicators.

This section presents the proposed overall Logic Model for the 5GTT Programme. The Logic Model should be treated as a 'living' representation to be updated on an ongoing basis as evidence becomes available about emerging outcomes and issues, the contributions of particular activities to outcomes, and about the key linkages and the validity of the assumptions which underpin the model.

2.2 Rationale for government intervention

To place the Logic Model in context, it is important to consider why Government intervention is needed and the outcomes 5GTT is expected to lead to.

5G has the potential to generate significant economic benefits from the digital transformation of many sectors, through enhanced consumer mobile broadband as well as enabling new use cases where, to date, the provision of connectivity has not been a part of the business model. However, the size and nature of innovation and technological challenges for the development and adoption of 5G are too large for the private sector to address on its own. These challenges, combined with the uncertainty over market structure and the revenue opportunities from 5G, and the high infrastructure costs, mean that investment levels and 5G deployment would likely be sub-optimal in the absence of Government intervention. Targeted publicly-funded intervention can help address these issues, leading to more efficient market outcomes. Additionally, regulatory changes running alongside other Government interventions to reduce deployment barriers, may form an important component of an overarching 5G strategy.

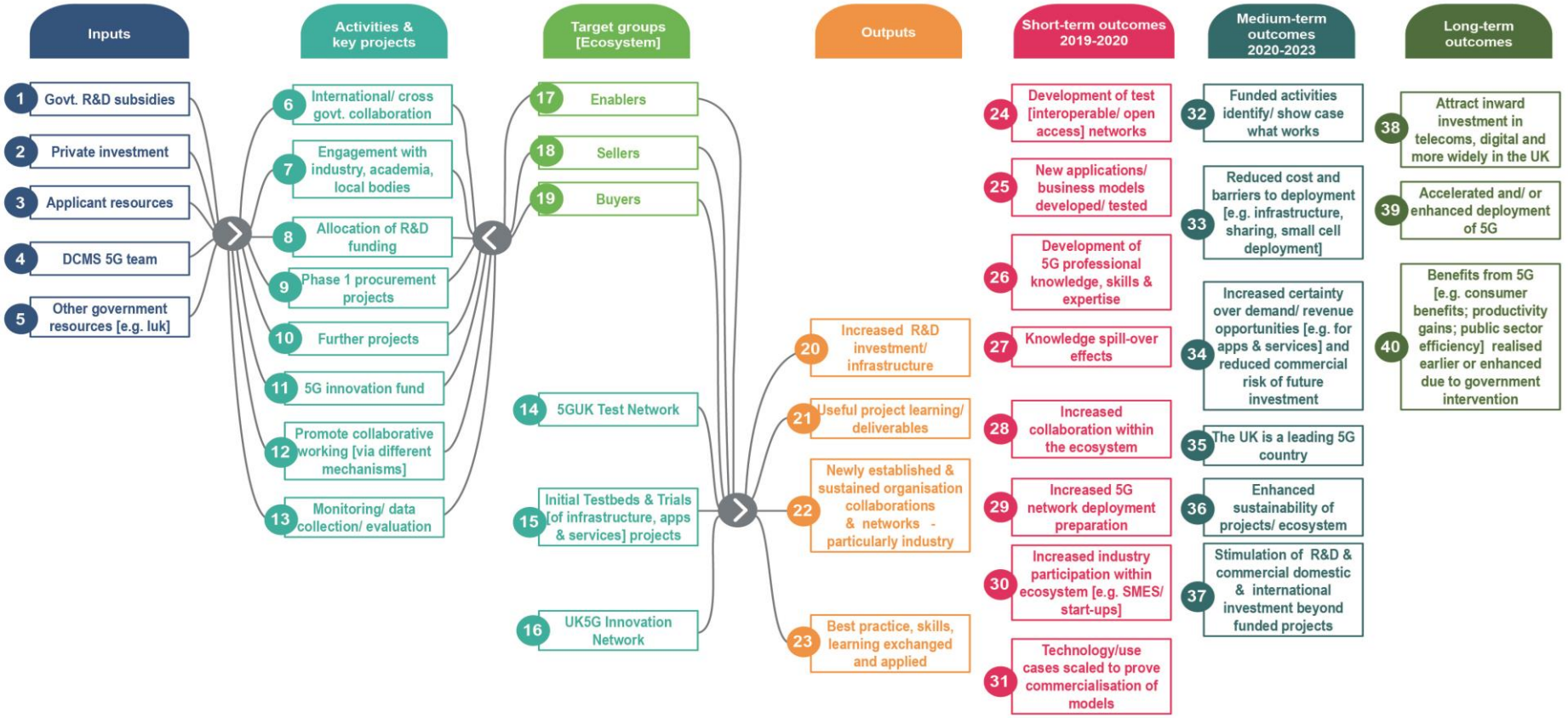
2.3 The Logic Model

The Logic Model for the overall 5GTT Programme is presented in Figure 2.1 below. It has been informed by the study team's review of programme documentation and refined through stakeholder consultations.

The key inputs of the Programme (boxes 1-5) are linked to the case for Government intervention described above. The Government is allocating public funding whilst leveraging private investment to fund a range of research and development (R&D) projects. There are also management, monitoring and governance inputs from the programme sponsors: DCMS and Innovate UK thus far.

The 5GTT Programme key activities (boxes 6-16) relate directly to the Government's investment, and include the funded projects, as well as any engagement activities with the wider 5G ecosystem, both in and outside of the UK.

Figure 2.1 5G Testbeds and Trials – overall programme logic model



Enablers = Investors, UK5G; Regulators; Standards organisations; Industry Forums, Analysts; Media; DCMS 5GTT programme
Sellers = Network operators; service providers, hard/ software vendors; &, researchers
Buyers = Citizens/ consumers; public sector; private enterprise; international]

At programme level, the key intended outputs (boxes 20-23) are the direct increase in R&D investment, the successful establishment and completion of all funded projects, and the establishment of networks where best practices and lessons learned can be shared).

These outputs are intended to lead to a number of important short-term outcomes (boxes 24-31): the new knowledge generated through the completion of projects, and the resulting spill over effects through e.g. dissemination of research outputs; the development of test networks as well as new 5G applications, products and services; scaling-up of 5G activity by programme participants; scaling up results from projects to prove commercialisation; increased participation and collaboration within the 5G ecosystem (including from SMEs).

In the medium term (boxes 32-37), the overall Programme is expected to showcase what works, reduce the deployment costs and barriers, increase certainty about revenue streams from 5G, enhance the international reputation and attractiveness of the UK for 5G investment and activity.

If these outcomes are successfully achieved over time, it is envisaged that the long-term outcomes (boxes 38-40) from the Programme will include: improved economic competitiveness of UK businesses in 5G markets leading to increased inward investment in telecoms, the digital sector and more widely in the UK; accelerated and enhanced development and deployment of 5G; and the resulting acceleration and enhancement of the benefits from 5G.

The Logic Model also presents the key target groups (boxes 18-20), whose behaviour the activities aim to influence. These groups are the key actors within the 5G ecosystem who will design, deliver and use 5G infrastructure, technology and products and who it is anticipated will benefit from the 5G outcomes.

The model timeframes are approximate. Some projects will not be delivered until around 2022 and so will contribute to later outcomes, whilst the expected long-term outcomes (boxes 38-40) are expected to fully materialise from 2023 onwards, although it is possible that some impacts will appear earlier.

It is recommended that the logic model and its associated timeframes are reviewed on a regular basis, and amended if need be, to take account of the latest evidence on impacts.

2.4 Programme success criteria

This section presents the key success criteria for the 5GTT Programme. These are based on what is expected to be achieved as a direct result of the funded activities and align with the short- and medium-term outcomes presented in the above logic model that best match the Programme's strategic objectives. The top 5 success criteria for the 5GTT are as follows:

1. 75% of the projects have seen Technological Readiness Levels (TRLs) increase;
2. The Programme has attracted more than a 1:1 ratio in match funding;
3. 50% of Programme participants have engaged in 5G-related activities beyond funded projects;
4. 60% of the projects have contributed to viable business propositions across a range of vertical sectors; and
5. Enhanced perception of the UK as a centre for the development and application of 5G.

Management Information against these criteria will be collected as the Programme progresses, and will inform its evaluation. The latter, however, will seek to cover a wider suite of outcomes, and associated indicators, which include, but are not limited to, the Programme success criteria (see section 3.4 and Annex 2 for more details on the evaluation approach and the indicators used, respectively).

2.5 Context, key risks and assumptions

Contextual factors, as well as underlying assumptions and risks, are expected to influence how far the Programme delivers its expected outcomes.

The nature and speed of competing overseas activities may shorten the window of opportunity to deliver some key outcomes within the UK. The commercial situations and motivations of the organisations delivering the Programme, as well as regulatory policy, will also drive the extent to which the anticipated outcomes are likely to materialise.

The Logic Model assumes that projects are selected so that they do not duplicate or replace market activity and are delivered effectively. It also assumes that the Programme provides a critical amount of investment to test relevant use cases, and that there was indeed a lack of 5G testbeds and trials activity before the Programme launch.

These factors can be divided into those which are inherent to the successful delivery of the Programme (internal factors) and others which the Programme has limited or no direct control over (external factors). These are summarised below

Table 2.1 Contextual factors that may influence the success of 5GTT

Internal factors	External factors
The procurement process ensures effective funding allocation	The nature and speed of overseas activities – this might shorten the window of opportunity to create some key outcomes within the UK
Projects are selected so that they do not duplicate or replace market activity	Commercial viability of Programme beneficiaries and their ability to deliver the projects
The projects selected deliver effectively (i.e. do not fail and/or provide learning from failure)	Key external factors that might impede or prevent the programme from achieving its desired outcomes – these include the regulatory environment, in particular access to spectrum and impediments to network sharing, as well as the current lack of sufficient backhaul capacity[22] and the potential for consumer take-up to be slower than assumed, for instance if 4G is found to provide a sufficient level of service for a longer period of time
Trial and testbed infrastructure supported by the Programme is fit for purpose	

[22] In wireless network technology, to transmit voice and data traffic from a cell site to a switch, i.e., from a remote site to a central site.

https://www.webopedia.com/TERM/B/backhaul.html

Internal factors	External factors
The Programme provides a critical amount of investment to test relevant use cases	
There was indeed a lack of 5G testbeds and trials before the Programme launch	

3 Proposed evaluation approach and methodology

3.1 Overview

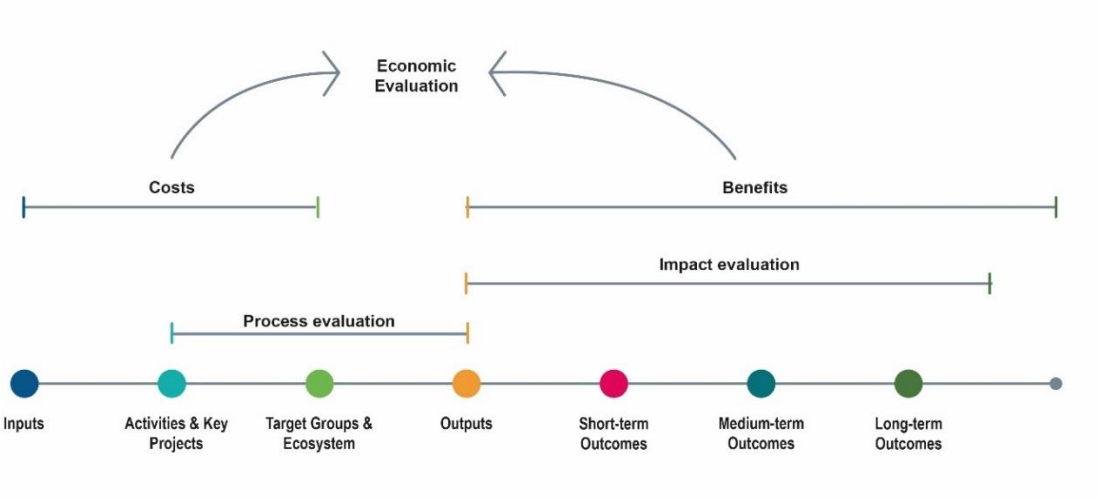
This section presents the proposed evaluation approach and methods for the three distinct elements of the programme-level evaluation planned by DCMS:

- A process evaluation, providing a review of how the Programme has been implemented, and what support mechanisms have worked (and why) and to identify possible opportunities for improvement (3.3).
- An impact evaluation, to understand whether the Programme has resulted in the desired outcomes and whether it has had any unintended (positive or negative) consequences (Section 3.4).
- An economic evaluation, to measure and monetise the programme impacts relative to its costs to assess the extent to which it represents value for money (Section 3.5).

The evaluation process is intended to be both *summative* – reporting on what has been achieved – and *formative*, contributing to future policy and programme design.

Figure 3.1 below presents a conceptual overview of how these three evaluation elements dovetail with the different stages of the Programme implementation process and the expected realisation of the Programme outcomes.

Figure 3.1 Relationship of the evaluation elements to the implementation and expected outcomes of the Programme



3.2 Evaluation questions

The proposed evaluation approach described herein is designed to answer the following high-level evaluation questions as agreed with DCMS.

Table 3.1 Evaluation questions

Evaluation type	Evaluation questions
Process	i) How effective and efficient has the delivery of the Programme been?

Evaluation type	Evaluation questions
	ii) What is the wider learning from the evaluation for future phases of the 5GTT Programme and DCMS?
Impact	iii) What impact has the Programme had (for consumers, supply chain, market, system and state)?
Hybrid	iv) How has the Programme achieved these impacts?
Economic	v) What is the overall value for money of the Programme?

The following subsections describe each evaluation element and how they address the evaluation questions above.

3.3 Process evaluation

3.3.1 Overview

The process evaluation will assess the efficiency and effectiveness of the delivery of the Programme and the potential lessons to be learned for future implementation. It will encompass *external process* issues of how the Programme has influenced outcomes through its effects on the behaviour and decisions of external actors and the effects on this influence of the implementation context. These latter aspects require consideration of what has worked, how, why and in what context.

Particular attention will need to be given to the issues of:

- Engagement with the 5G market and the wider ecosystem – this is important for developing an approach which can respond appropriately to the challenges and opportunities involved and in establishing the profile of the Programme within the target sectors.
- Selection (including the competition process, where applicable), delivery and monitoring of funded projects – aspects which are clearly central to the achievement of value for money from the investments involved.
- Mechanisms to promote collaborative working amongst funding recipients – important if potential Programme synergies/spill overs are to be maximised.

The proposed evaluation framework focuses at this stage on the phase 1 projects for which details of processes/implementation arrangements were known at the time of this study. As noted, the framework will need to be reviewed over time to consider potential changes to the processes for identifying and selecting future projects.

3.3.2 The process map

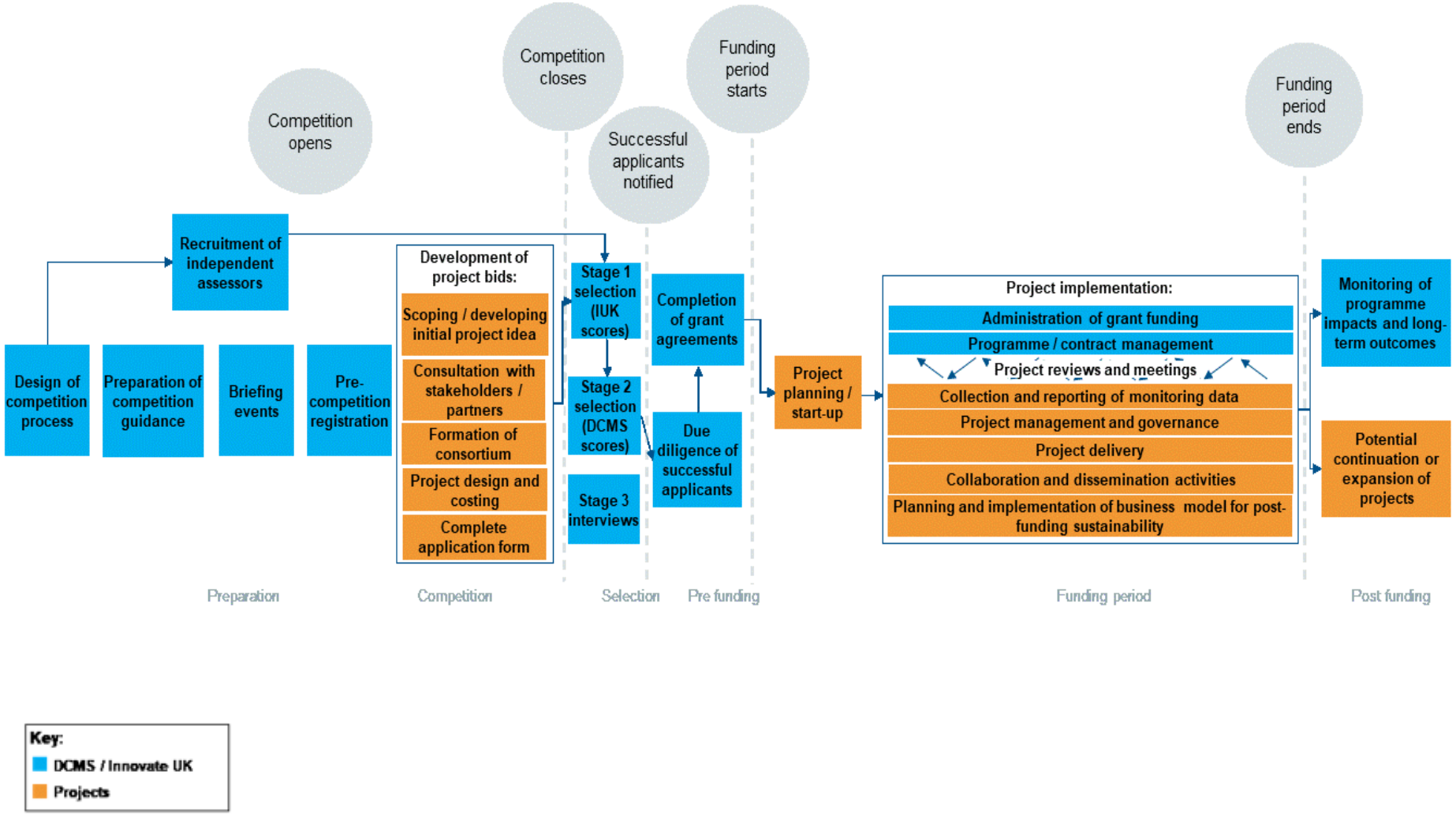
Figure 3.2 presents a process map focused on the phase 1 project competition from the design stage of the intervention through project selection – highlighting the roles of both DCMS and Innovate UK (IUK) – to implementation and monitoring.

The 5GUK Test Network project locations were selected through a non-competitive process. The three leading universities active in the 5G space were engaged, each of which had been working with one of the three major international telecoms equipment vendors (Huawei, Ericsson and Nokia).

Regarding UK5G, DCMS launched a separate competition in autumn 2017 to award grant aid to a consortium of organisations to run the UK5G, launching in early 2018.

The process aspects of the 5GUK Test Network and UK5G, as well as future projects, will therefore need separate consideration as part of the proposed case studies, as discussed below.

Figure 3.2 The Process Map for Phase 1 projects



3.3.3 Approach

It is proposed that the process evaluation be undertaken through the following tasks:

- Process team consultations and DCMS consultations. A programme of stakeholder interviews with the DCMS teams responsible for the overall design and management of the Programme as a whole and for each stage of the process, including IUK appraisal team lead(s) where relevant. Interviews would explore interviewees' experiences and perceptions of the Programme as a whole and of the particular stages of the process in which they have been involved, as well as the associated public sector costs for each stage of the process based upon the standard cost model. It is proposed that two waves of interviews be undertaken to fit with the initial and interim process evaluation timings as proposed above.

  It is suggested that within the initial assessment there should be early discussions with the officers responsible for monitoring all projects, with further discussions on the close out of projects or when issues arise which warrant specific exploration. It is assumed that a similar pattern of discussions on each project would apply in relation to possible subsequent stages of the Programme

- Analysis of project documentation and Management Information (MI). This will cover financial aspects such as levels of demand for resources relative to budget allocations, the progress of spend relative to plan, progress in delivery relative to project milestones and the achievement of outputs relative to target, any outcome/impact measures gathered by the projects, profiles of the Programme participants, as well as aspects such as assessor scores and the evolution of project status ratings (Red, Amber, Green) over time as available.

- Updates to the baseline survey, initial results of which are presented in Section 4 below. The baseline survey has collected views of stakeholders and Programme beneficiaries on the engagement process, the design of the Programme and the effectiveness of its processes, including aspects such as barriers to participation and success factors. Under the proposed approach, the baseline survey would be updated as part of the interim and final assessments to inform the impact and economic evaluations and the interim update can feed into the process component of the interim evaluation.

- Applicant survey. It is proposed that this involves:
  - A census telephone survey of all lead applicants to explore their experiences of the Programme's processes, the costs to the private sector of its involvement and opportunities for improvements, etc.
  - A sample survey of other partners – with provision for approximately 50 achieved responses across the phase 1 and subsequent projects.

- Case studies (covering the 5GUK Test Network, UK5G and a sample of phase 1 and subsequent projects) – the process aspects of the case studies will investigate in detail the pathways towards forming consortia and any support for this provided through the Programme, as well as the submission, approval and delivery aspects. It could include a 'customer journey' exercise providing a narrative on how project leads and other partners were led through the Programme processes, and would assess to what extent conclusions / lessons from phase 1 projects should inform the design of additional future projects.

- An online census survey of organisations/representatives who participated in the consultation events organised by DCMS as part of the process of establishing the

Programme but which have not figured so far in projects or project bids. The survey – which would be undertaken within the first phase of the process evaluation – would provide an opportunity to explore a wider range of perspectives on the engagement process, the design of the Programme and its processes and potential barriers to participation.

Table 3.2 maps the extent to which the different tasks would inform the proposed assessment criteria.

Table 3.2 Mapping of the tasks to the assessment criteria

Small extent Medium extent Large extent

Process Element	Evaluation Criteria	Process Team Consultations	DCMS Consultations	Documentation and MI	Baseline Survey and Updates	Applicant Survey	Case Studies	Survey of Event Attendees
Engagement and Communication	Whether ecosystem considers it has been sufficiently engaged in relation to the project's design.							
	Whether there is a good general knowledge and understanding of the aims, objectives and eligibility requirements of the Programme within the ecosystem and whether its processes are seen as sufficiently transparent							
	Was feedback provided to unsuccessful applicants useful (e.g. for future applications)?							
Programme Design	Whether the ecosystem considers that the final design is well suited to the achievement of the Programme's aims and objectives							
	Overall assessor scores							
Guidance and Support for Grant Applicants	Whether the eligibility requirements and guidance to applicants are/are considered to be clear and appropriate							
	Whether applicants consider they have needed support with the application process and, if so, whether this has been sufficient							
	Whether applicants needed/received support for consortium building (including re needs/requirements for consortium agreements)							

Process Element	Evaluation Criteria	Process Team Consultations	DCMS Consultations	Documentation and MI	Baseline Survey and Updates	Applicant Survey	Case Studies	Survey of Event Attendees
Application Processing and Project Selection	Demand relative to budgetary provision – whether need for 'portfolio approach'							
	Time taken relative to (any) targets							
	Costs to applicants and the private sector							
	To what extent considerations of additionality influenced selection?							
Delivery	Spread of assessor scores							
	How far projects deliver their planned outputs/results							
	Whether project issues which emerge ex-post were identified ex-ante							
	Number, character and handling of 'change requests'							
Due diligence and contracting	Turnaround relative to (any) targets							
	Applicant and public sector costs							
	Extent of project failures associated with applicant financial problems or consortium related aspects							
Monitoring	Effectiveness of monitoring arrangements in understanding project progress and timely identification of potential/emerging issues/problems							
	Effectiveness of corrective actions taken in response (project leads' perspective as well as DCMS's)							
	Costs incurred by grant recipients in complying with monitoring arrangements							

3.4 Impact evaluation

3.4.1 Overview

Assessing the additionality of a Programme is crucial to impact evaluation as it allows one to measure the extent to which the observed outcomes would have been achieved in the absence of Government intervention. It requires the development of a counterfactual (i.e., what would have happened in the absence of the intervention).

Many research methods are available to evaluators to estimate a counterfactual. As part of the present study, the team have reviewed the feasibility of such methods, and concluded that the impact evaluation will need to draw upon both quantitative metrics and qualitative analysis utilising a theory based 'contribution analysis' approach. This approach considers how far it is plausible that the intervention, and not other factors, was essential in causing the outcomes observed/reported. It develops a 'contribution story' around the role of the intervention in bringing about the observed outcomes, set against other confounding factors that may have influenced these outcomes.

The role of contribution analysis in the impact evaluation

Contribution analysis is proposed for this impact evaluation for a number of reasons. First, it represents an established method which can practicably be applied to deal with the challenges associated with the 5GTT Programmed (discussed within Section 3.7). Second, based upon the current population of projects, it would not be practical to apply statistical methods required to meet the Scientific Maryland Scale (SMS)[23] Level 3+ benchmark for central Government evaluations (although we discuss possible opportunities which may arise for the limited application of such approaches in Annex 3) and so contribution analysis represents an alternative, established technique for informing evaluation conclusions surrounding attribution. Third, there is an established Logic Model for the 5GTT Programme and therefore contribution analysis is a useful approach for testing the relationship between observable inputs, outputs, outcomes and impacts. Finally, contribution analysis can contribute to the formative aspect of the 5GTT evaluation (by providing evidence and information surrounding the contribution of the Programme to outcomes and impacts which can then be used to inform future projects under the 5GTT Programme).

The proposed contribution analysis approach "seeks to provide evidence and a line of reasoning from which we can draw a plausible conclusion, within some level of confidence, that the program (Programme) has made an important contribution to the documented results"[24]. How far the desired outcomes have been realised does not in itself prove how far the intervention has been effective. Outcomes would need to be compared to objectives to assess the effectiveness. Contribution analysis involves a structured effort to explore and – if possible – estimate the relative contributions of the intervention and other factors to bringing about the observed changes[25]. It requires:

- The assembly and testing of evidence that the Programme has indeed helped produce the observed/desired outcomes – in this case including both wider evidence, particularly from the stakeholder consultations, and the findings from the project specific assessments.
- Consideration of alternative hypotheses about why the observed outcomes have come about and the potential role of drivers of change which are external to the Programme.

[23] http://www.whatworksgrowth.org/resources/the-scientific-maryland-scale/

[24] https://www.betterevaluation.org/en/plan/approach/contribution_analysis

[25] http://whatworks.org.nz/methods-tools-and-techniques/contribution-analysis/

The application of this approach depends heavily on the quality of the available evidence and the capacity of the evaluation team to undertake robust, independent judgements of the weight which can be attached to diverse and likely imperfect sources. Robust and independent judgements are tantamount to judgements which are free from improper influences or conflicts of interests. This can be challenging sometimes when the sources of information used have biases. We recommend that the programme evaluation be carried out by experts who have not been involved in the design and delivery of the Programme and its constituent projects. The evaluation activities could either be carried out internally by DCMS, or DCMS could appoint a suitable external provider. For a Programme of this profile, an external evaluation would normally be commissioned.

The proposed approach to the Programme-level impact evaluation involves a combination of:

- Tracking changes in high-level indicators (Annex 2 provides further details) reflecting the causal chain through which the Programme is expected to deliver its desired outcomes as set out in the Logic Model defined in Section 2. The observed changes in these metrics will then need to be attributed to the effects of the Programme and other potential drivers of change by triangulating evidence on a 'balance of probabilities' basis (given the relatively small number of Programme participants and non-participants, which prevents the evaluation from identifying a statistically robust comparison group). This means that information will be gathered from different sources and a judgement will be made after analysing the information. This is due to the fact that changes in metrics could potentially be attributed to a variety of factors, not all of them under the influence of the Programme. A judgement made on the balance of probabilities means that, based on the evidence presented, the occurrence of an event is more likely than not. For instance, changes in the indicator "extent to which key international companies in telecoms and auxiliary / vertical sectors consider UK a prime target for 5G related investment" will be attributed to the effects of the Programme depending on the substance of evidence indicating this is the case, after considering different sources of information related to this indicator. Annex 2 provides more information on indicators.
- Assessing the effectiveness of individual interventions/projects in achieving their intended outputs, outcomes and impacts as identifiable at the time of the evaluation. This information will feed into the triangulation process as practicable. Bibliometric and patents analysis will be a particularly important potential source of evidence on how far the projects funded through the Programme have been responsible for driving overall knowledge development in relation to 5G technology and its applications. However, there is a temporal challenge associated with such analytical techniques which means they are likely to be best suited to the final evaluation. Specifically, bibliometric analysis is reliant upon the publication, peer review and citation of articles, which can take some years to occur. Similarly, patent analysis is reliant upon the creation of patents which can typically involve a long period from the time at which a patent application is made to the point at which a product/service is invented on the basis of that patent, with appropriate citations.

3.4.2 Impact evaluation questions

Overall, and as agreed with DCMS, the impact evaluation is intended to explore the extent to which the programme has driven the intended and wider changes in 5G related activity, as well as to identify unintended (positive/negative) changes. It will also look at how the Programme achieved these impacts and how its influence has

been affected by the implementation context or circumstance, some aspects of which are matters for the process evaluation, as noted above.

3.4.3 Approach

It is proposed that the early and interim impact evaluations be undertaken through the following tasks, which will be targeted to capture Programme level impacts and those specific to each project/intervention:

- An update of the baseline survey[26] which has collected views of 5GTT project participants on the expected impacts of the Programme and for which initial results are presented in Section 4. The baseline survey would be updated as part of the initial, interim and final assessments. The updates will need to include both questions relating to the development of 5G and its applications and the role of the Programme and its constituent interventions in bringing this about.
- An updated literature review to build upon the understanding of the developing context as presented in Section 2 above.
- MI and secondary data analysis. In conjunction with the process evaluation, this needs to review the outputs delivered by the Programme as a whole and the constituent projects and the extent to which these are meeting targets.
- A programme of semi-structured face-to face interviews with key stakeholders. It is envisaged that this would cover a combination of senior DCMS personnel, industry specialists (both UK and international players), CEOs of telecommunications companies (including MNOs), and academics. The interviews will include the exploration of the pattern and pace of development of 5G-related activity and effects of the Programme in driving changes.
- Project surveys and case studies**.** As noted, it is envisaged that census surveys of lead applicants for all approved projects would be undertaken, as well as sample surveys of project partners for these projects, to feed into the process evaluation. Case studies could also include testing project results against a set of technological 'success criteria', which would classify a project as 'breakthrough' or successful.
- The case studies of the 5GUK Test Network and UK5G projects, along with a purposive sample of around 10-15 other projects. The approach to the impact evaluation will be customised in the case of the 5GUK Test Network and UK5G projects based on the specific assessment frameworks developed for these projects (included within Annex 2) and on the basis of the specific characteristics and objectives of projects in other cases. The case studies will draw upon a combination of:
  - Analysis of MI data and review of associated project documentation.
  - Face-to-face interviews with the lead partners in the case study projects, as well as the telephone interviews with other partners.
  - Telephone interviews with relevant external stakeholders.
  - Telephone interviews with member organisations in the case of UK5G. This could potentially be combined with a social network analysis to help

[26] Please see subsection 3.4.4 for more details.

understand the extent to which the partnerships and collaborations developed under UK5G.

- ‘Soft’ assessments based upon the perceptions of lead and other partners, as well as those of stakeholders and the ecosystem – as relevant - on the effectiveness/value of the project concerned and its role in bringing about wider observed 5G related outcomes.

The evaluation will also involve:

- Bibliometric and patent analysis**.** This will focus in particular on exploring the influence of the Programme based upon the extent to which the research outputs of the projects being funded are cited in the academic/technical literature and or in patents registered by firms within and beyond the 5G ecosystem.
- Comparative, Counterfactual Impact Evaluation (CIE)/econometric analyses if/as agreed to be practicable.
- Triangulating evidence and reporting based on the analyses performed.

The final impact evaluation will need to be based to a large extent on a further update of the baseline survey and stakeholder consultations, as well as project follow-up where practicable.

Table 3.3 below maps the extent to which the different tasks would inform the proposed assessment criteria. This table refers to the elements of the logic model. Specific indicators are included in Annex 2, Table A2.1.

Table 3.3 Mapping of the tasks to the overall assessment criteria

Small extent Medium extent Large extent

Contributions to Assessment Criteria – in terms of:	Link to Logic Model element	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Surveys and Case Studies	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Extent of Achievement of Milestones/Delivery of Outputs as Planned	20 Increased R&D investment/ infrastructure 21 Useful project learning/ deliverables 22 Newly established & sustained organisation collaborations & networks - particularly industry 23 Best practice, skills, learning exchanged and applied							
Network Development and Deployment	24 Development of test [interoperable/ open access] networks 29 Increased 5G network deployment preparation							
Development of Ecosystem and Collaborative Activities	28 Increased collaboration within the ecosystem 30 Increased industry participation within ecosystem [e.g. SMES/ start-ups] 36 Enhanced sustainability of projects/ ecosystem							

Contributions to Assessment Criteria – in terms of:	Link to Logic Model element	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Surveys and Case Studies	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Business Model and Use Case Development	25 New applications/ business models developed/ tested							
Knowledge and Skills Development and Diffusion	27 Knowledge spill-over effects 26 Development of 5G professional knowledge, skills & expertise							
Stimulation of Wider 5G Related Investment	37 Stimulation of R&D & commercial domestic & international investment beyond funded projects							
Demonstration/Showcasing Effects	31 Technology/use cases scaled to prove commercialisation of models 32 Funded activities identify/ show case what works							
Reduced Costs and Barriers to Deployment	33 Reduced cost and barriers to deployment [e.g. infrastructure, sharing, small cell deployment]							

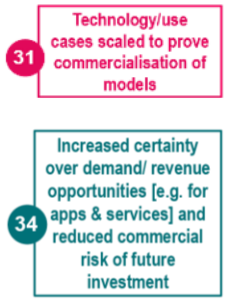
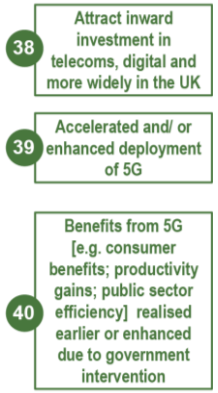
Contributions to Assessment Criteria – in terms of:	Link to Logic Model element	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Surveys and Case Studies	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Development/Establishment of Commercial Case for Development								
UK a Leading 5G Country								
Policy Learning effects								
Achievement of Longer-Term Deployment and Associated Economic Objectives								

Table 3.4 Mapping of the tasks to the 5GUK Test Network assessment criteria

Small extent Medium extent Large extent

Contributions to Assessment Criteria – in terms of:	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Survey work / Case Studies	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Extent of Achievement of Milestones/Delivery of Outputs as Planned							
Development of UK wide connectivity for hubs and spokes using JANET JISC network							
Interest/Engagement by Ecosystem and Collaborative Activities							
Extent of 'third party' and other use of networks							
Knowledge and skills development and knowledge diffusion							
Development of business models and applications – including within 'vertical sectors'							
Effects in terms of actual and planned R&D investment							
Lessons learned in relation to programme development aspects							
Development of spatial clusters of related activities							
Spill over effects							
Long-term sustainability of trial network							

Table 3.5 Mapping of the tasks to the UK5G assessment criteria

Small extent Medium extent Large extent

Contributions to Assessment Criteria – in terms of:	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Survey and Case Study	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Extent and reach/pattern of membership/participation/level of participation							
Awareness of network within ecosystem							
Perceptions of value of network within ecosystem							
Increasing awareness of 5G potentials and opportunities							
Enhancing interests in / commitment to taking actions for 5G related development							
Exploitation, including within 'vertical sectors'							
Partnership development							
Knowledge diffusion							
Technical and standards development							
Increasing the international profile of UK							
Increasing volume and effectiveness of R&D investment							
Long-term sustainability of UK5G							

Table 3.6 Mapping of the tasks to the phase 1 projects assessment criteria

Small extent Medium extent Large extent

Contributions to Assessment Criteria – in terms of:	Literature review	MI and Secondary Data Analysis	Stakeholder and other consultation	Project Surveys and Case Studies	Update of Baseline survey	Bibliometric and Patent Analysis	Counterfactual / Econometric Analysis
Extent of Achievement of Milestones/Delivery of Outputs as Planned							
Network Development and Deployment							
Development of Ecosystem and Collaborative Activities							
Business Model and Use Case Development							
Knowledge and Skills Development and Diffusion							
Stimulation of Wider 5G Related Investment							
Direct commercial and employment impacts (additional R&D investment, net additional employment etc)							
Wider programme objectives, including reduction in costs and barriers to deployment							
Spill over effects to other sectors							
Policy learning effects Long term sustainability							

3.4.4 Timescales

The extended timescales and complex paths through which the Programme is expected to achieve its impacts mean that much of the focus of the interim assessment will be on the extent to which the Programme is achieving the intermediate outcomes identified within the Logic Model (short-term outcomes – boxes 24-31 – and medium-term outcomes – boxes 32-37 – as identified in Figure 2.1).

As part of the assessment of acceleration effect for the interim evaluation, it would be useful to undertake a high-level assessment of the UK's 5G readiness against a set of previously used spectrum and infrastructure-related metrics.[27] This would be synthesised from the various research instruments proposed and would include a review of:

- the extent and timeline of 5G spectrum release;
- the 5G spectrum roadmap published/updated by Ofcom;
- Government backing and infrastructure policy; and
- the extent of industry 'proof of concept' trials of 5G networks and equipment.

The proposed methodology requires the evaluation to provide a systematic – and, as far as possible, quantified – assessment of the extent to which the intended outcomes of the Programme are realised over different timescales. It is proposed that the focus of the different phases of the impact evaluation be as follows:

- An Early Assessment will focus largely on the extent to which the activities involved are 'additional' (in terms of type, scale and/or timescale) to what would occur in the absence of public sector support, and the extent to which they are delivering their intended outputs and results. The principal challenge is likely to be the additionality assessment and identifying possibilities to supplement the self-reported evidence from beneficiaries who have incentives to stress the need for DCMS funding. Strategies to minimise such 'strategic response bias' are described below.
- An Interim Impact Evaluation will focus largely on the extent to which the desired/expected interim outcomes of the programme are being realised. The principal challenges at this stage will relate to the measurement of some of these outcomes and assessing how far the observed changes can realistically be attributed to the Programme interventions.
- The Final Impact Evaluation will need to assess the developing competitiveness and productivity and other benefits from the application of the technology. The key challenge is likely to be to assess how far these can realistically be attributed to the effects of interventions which may have been completed some years previously. If, as seems likely, there are follow-on interventions which seek to build upon the Programme, the impacts of these will almost certainly need to be considered within the evaluation.

[27] Based on Analysis Mason (2018), Global Race to 5G – Spectrum and Infrastructure Plans and Priorities.

3.4.5 Challenges and risks

The proposed approach is inevitably vulnerable to positivity bias[28] and, as noted, strategic response bias on the part of funding recipients, given it will be based to a large extent on stakeholder opinion and views. More specifically, organisations who have received funding will very likely provide very positive feedback, since they benefited directly from the Programme. This means that topic guides used for stakeholder consultations must provide flexibility for interviewers to follow up issues, test responses for consistency and even challenge answers for their consistency, both internally and with earlier statements in application forms and at interview stage. In addition, evidence from Programme non-participants could also prove useful for countering bias by providing a source of information on what might have occurred in the absence of Government funding.

The triangulation process will also need to check the consistency of evidence from interviews with both material from more objective sources and other interviews covering similar ground – for example, through reviewing the extent of the alignment of the answers from different partners in relation to the same project.

Some of the future projects funded through the Programme – e.g. the Urban Connected Communities and the Rural Connected Communities – may involve substantial evaluation work at project level both to assess their contribution to the Programme's objectives and the extent to which they have met their specific objectives. As noted, work on the Programme evaluation will need to be coordinated with these project-level evaluation activities.

3.5 Economic evaluation

3.5.1 Overview

The economic evaluation will largely seek to use a social cost benefit analysis (CBA) approach rather than cost-effectiveness analysis. The latter would require the impacts of the programme to be defined largely in terms of a specific metric which can be compared with the costs of delivering a similar outcome through other means. Such an approach is more appropriate, for example, in relation to an assessment of an intervention designed to create jobs for which there is a range of evaluation evidence in relation to interventions with a similar objective with which comparisons can be made.

CBA seeks to assess the value for money of an intervention by taking both a wide view of the costs and benefits involved, irrespective of their incidence, and a long-term view, with all costs and benefits discounted to 'present values'[29]. The application of CBA in relation to UK public sector decision making and evaluation is governed by the HM Treasury 'Green Book'[30] which also provides details of the key concepts involved.

Nevertheless, it will still be necessary to consider whether and how the cost-effectiveness of the Programme might have been improved – in the sense of whether

[28] Positivity bias means that recipients of fund are likely to provide very positive feedback on a Programme since they received funds from the Programme

[29] Values are discounted to account for the social rate of time preference for current over future consumption and the opportunity costs of the investment involved.

[30]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

similar outcomes might have been delivered at lower cost or greater outcomes delivered at the same cost. Such considerations are clearly important in relation to the process of learning lessons to enhance the value for money of this or future Government interventions.

The CBA will require the estimation of:

- The costs of the Programme and the projects involved to both the public and the private sectors – including both administrative costs, measured, as noted, using the standard cost model conventions, and project related spend. This is much the most straightforward aspect to address.
- The additional R&D, network investment and other costs to the private sector associated with the effects of the programme in stimulating the development of 5G, which can be understood as the cost of investment leveraged. Assembling estimates of the investment involved should be reasonably straightforward, although there will be a need for judgements in assessing the effects of the Programme in increasing and/or bringing forward the costs involved.
- The net benefits from the Programme in terms of:
  - bringing forward or enhancing the consumer benefits of the technology;
  - bringing forward or enhancing the supply-side benefits of the technology to the private sector, primarily through enhancing total factor productivity[31] though its application in a range of 'vertical sectors' and the private sector more generally; and
  - the productivity benefits in relation to the delivery of public services.

Estimating benefits will be the most challenging aspect for the analysis. The HMT Green Book[32] makes it clear that even 'harder' impacts such as attracting foreign direct investment and creating economic activity do not strictly represent economic benefits which can be brought directly into a benefit cost ratio.

Further detail on assessing the consumer and productivity benefits of the Programme is set out below.

3.5.1.1 Assessing consumer benefits

One measure of the consumer benefits attached to 5G is the price they pay for emerging services. Alternatively, or additionally, a willingness-to-pay (WTP) exercise could attempt to estimate the stated consumer preference, i.e. observing consumer choice between a mix of existing (fixed line broadband, 4G, LTE) and hypothetical alternatives (5G mobile), with different attributes regarding price, broadband speed, quality and capacity.[33]

WTP approaches are helpful where revealed preference cannot be inferred from existing market data. However, underlying real consumer preferences might be subject to changes in time, and WTP surveys can be complex and lengthy depending

[31] This measure takes account of the capital involved in the production process rather than the more conventional measure which considers just labour inputs

[32]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/685903/The_Green_Book.pdf

[33] For a relevant example of a wtp survey see Lu, H., Rohr, C., Burge, P., Grant, A. (2014), Estimating the value of mobile telephony in mobile network not-spots.

on the complexity of the discrete choice experiment the questionnaire is attempting to model.[34]

A possible strategy to reduce questionnaire length is to implement what is called a fractional factorial, where choice tasks are designed in a way that preferences not explicitly tested can be inferred from those that were.[35]

The outcomes of a WTP survey would have to be compared with other research and data sources, such as previous or parallel efforts to value the consumer benefits of technology changes in broadband.

However, it should be acknowledged that the feasibility and reliability of a WTP approach for valuing consumer benefits largely depends on, amongst other things:

- the timing of the interim economic evaluation relative to actual 5G roll-out in the UK;
- the extent/coverage of 5G network roll-out;
- the extent to which the results of a WTP survey reflect the preferences of early adopters or a more representative sample of future 5G users; and
- the availability of 5G enabled products and services – any estimates resulting from the interim economic evaluation might underestimate the value per subscription – although conversely later adopters may have a lower WTP for a novel technology.

Much of the realised consumer benefit will rely on any evidenced/assumed acceleration impact of the Programme, i.e. the impact assessment will need to provide supporting evidence, or sufficient grounds to make assumptions, in relation to how far the Programme has accelerated 5G deployment in the UK. The proposed research methods are discussed in section 3.5.2 below.

3.5.1.2 Assessing productivity benefits

Even though their likely scale is difficult to evidence in quantitative terms at this stage, the potential for 5G technology to generate productivity benefits in the wider economy in the longer term through reducing delivery costs or enabling the provision of a new range of value-added services arguably represents the core part of the economic case for public intervention.

The suggested starting point for the scenario analysis is an assessment of the productivity/economic benefits of relevant Phase 1 and later projects as potential exemplars. This assessment will be undertaken both at a macro level and a micro level to determine whether, for instance, a phase 1 project enhanced productivity in a particular context,

The estimate of productivity impacts will require specific capital costs to be converted into access charges and will need to take account of how far benefits could be increased and/or costs reduced through learning and applying lessons from the project concerned. The two types of consumer benefits which arise in the context of these projects are potentially additions to the WTP estimates from above if/where users do not require a 5G subscription to access the services involved.

[34] Wardman, M. (1988) A Comparison of Revealed and Stated Preference Models of Travel Behaviour. Journal of Transport Economics and Policy, 22(1), 71-91.

[35] Carson, Richard T. and Louviere, Jordan J. (2010) Experimental design and the estimation of willingness to pay in choice experiments for health policy evaluation. In Applied Methods of Cost-Benefit Analysis in Health Care eds. Philip Clarke, Emma Frew, Jordan Louviere and Emma McIntosh, Oxford.

Establishing what proportion of the potential estimated productivity benefits should be attributed to the 5GTT Programme will depend upon the estimates from the impact assessment of how far the programme has brought/is bringing forward the roll-out of the enabling 5G technology and estimates from the case study concerned of how far the project funding is likely to affect the pace and extent of development of the application involved, where this proves to be economically viable.

Ideally, the estimated impact and value of the application should also consider potential spill over benefits from the demonstration effects of the success of the application involved to the extent that this is practically possible.

Developing these estimates of productivity benefits into overall scenarios for inclusion in the economic evaluation will also require:

- Using the evidence from these use cases, the available literature on 5G – particularly within key vertical sectors to the extent that these are not the focus of the projects being funded or the case studies - and wider evidence on the impacts of connectivity advances from DCMS and other relevant evaluations. This will need to be used to develop a wider scenario for the economy wide benefits of the productivity benefits which have been – and are likely to be – generated by the Programme.
- Converting these to a present value and combining this with the estimated present value of the consumer benefits.

3.5.2 Approach

The economic evaluation will involve the following tasks, many of which will form part of the tasks already described in relation to the impact evaluation in Section 4 (for example, the stakeholder interviews and the case study research).

The outputs will be monitored on a continuous basis and the data collected will inform the evaluation. Monitoring consists of an ongoing change control and checkpoint monitoring of projects including the delivery of project milestones. Responsibility for monitoring primarily sits in the Programme delivery authority and Programme Management functions. As part of agreed terms, individual projects are required to carry out at least a basic level of their own monitoring and evaluation. Analysis of monitoring data will inform a range of evaluation metrics, together with other sources of information, therefore playing an important role in informing the evaluation.

At the interim stage, the tasks will involve:

- Extension of the literature review to identify potential monetary values for the identified impacts/benefits.
- An update of the baseline survey to review any changes in the intervention context that might be influencing the success of the Programme. This will include a review of the evolution of the underlying risks/enablers and other contextual factors subsequent to the baseline presented in Section 4 below.
- Review and collation of the MI data, project reviews and case studies as available and estimation of likely final expenditure. The task will also cover data DCMS might collect from beneficiaries on the early outcomes/benefits of trialling activities.
- Qualitative interviews with 10 programme staff to establish time spent working on the Programme and associated costs. These interviews will also provide an

opportunity to explore perspectives on the cost-effectiveness of the Programme and potential opportunities for improvement.

- Inclusion of questions within project participant interviews and case studies to: collect information on participants' costs; help assess benefits to date and how these are expected to evolve, as well as to explore issues of cost-effectiveness and possible improvements.
- Construction of scenarios of the potential future benefits of the Programme based on triangulation of findings.
- A potential WTP survey to provide detail on how this might differ across locations (urban, rural) and consumers with different broadband usage patterns.
- Estimation of indicative Benefit Cost Ratios (BCRs) of the scenarios, leading to an initial potential VFM assessment with consideration to how cost-effectiveness might have been improved/could potentially be improved in future programmes of this type.
- Triangulating evidence and reporting based on the analyses performed.

For the final evaluation, the tasks will involve:

- Update of the literature and data review, focussing on information published subsequent to 2022 to inform the update of the monetary value of the benefits estimates.
- Review of the MI data on final programme expenditure.
- Assessment of the benefits of the development of 5G-related activity to date and their likely future evolution based upon relevant secondary data and interviews with key stakeholders and the ecosystem. These interviews could also provide an opportunity to elicit views on the cost-effectiveness of the Programme in driving the observed changes.
- Analysis of all end-of-project reviews as available to establish costs, outcomes and impacts achieved, along with any assessments of VFM.
- Supplementary qualitative interviews with a selection of project leads to collect further information on benefits, including exploitation related aspects particularly within 'vertical sectors' and the public sector and how these are expected to evolve over time, as well as VFM aspects.
- Potential (further/updated) WTP survey to inform the benefits assessment and provide detail on how benefits appear to differ across locations (urban, rural) and consumers with different broadband usage patterns.
- Construction of scenarios of the overall monetary value of the benefits of the programme based on triangulation of findings.
- Estimation of updated BCRs based upon the scenarios**,** with an assessment of cost-effectiveness and how this might have been improved/could be improved in future programmes of this type.
- Triangulating evidence and reporting based on the analyses performed.

Table 3.7 summarises how the various elements will need to be brought together to inform the two phases of the economic evaluation.

Table 3.7 Economic evaluation – mapping of key elements to evaluation questions

Work programme stage	Key elements	Evaluation questions addressed
Interim evaluation	■ Built upon the interim impact assessment findings ■ Collection of information and data from literature review, baseline survey update, project reviews, etc. and evidence from interviews ■ Assessment of the public and private costs incurred up to 2022 and expected future costs ■ Development of scenarios to assess potential benefits of the Programme ■ Potential WTP survey ■ Assessment of Programme costs ■ Assessment of benefits to date and to be expected ■ BCR calculation and comparison with relevant benchmarks from other programmes.	Early indications to address the questions of: ■ What was the Benefit-Cost Ratio (BCR) of the programme? ■ Did it represent good Value for Money (VFM)? ■ How could the cost effectiveness of the policy be improved?
Final evaluation	■ Built upon final impact assessment findings ■ Updating of supporting information and data ■ Updating and extension of scenarios to assess potential benefits of the Programme ■ Potential (further) WTP survey ■ Assessment of programme costs ■ Assessment of benefits to date and to be expected ■ BCR calculation and comparison with benchmarks from other programmes.	■ What was the Benefit-Cost Ratio (BCR) of the programme? ■ Did it represent good value for money (VFM)? ■ How could the cost effectiveness of the policy be improved?

3.5.3 Challenges and risks

DCMS has indicated that it will require evidence on VFM from the interim assessment as well as the final assessment to inform the development of its programmes and future spending decisions. As noted, this creates some fundamental challenges as only limited evidence on the eventual long-term impacts of the Programme is likely to be available by 2022. There will also be some minor issues associated with the lags in publication of secondary data which will limit the extent to which definitive evidence on even the post-project economic performance of beneficiary firms will be available.

The approach to the interim assessment at this stage would therefore need to be based on a scenario-type approach in which the evidence available is used to develop a set of projections of the long-term impacts and net benefits of the Programme and, at least notionally, to assign probabilities to these to generate an expected value of the eventual outcome, albeit one subject to a high level of uncertainty.

The scenario development process will need to be based to a significant extent on the expectations of those involved in projects and the ecosystem more generally. However, quantitative evidence and novel approaches to valuing impacts should be

utilised wherever possible. Examples of using quantitative data sources in scenario building are as follows:

- In some cases it will be possible to value impacts from evidence on intellectual property valuations or the income streams from licensing agreements. In others, particularly where the technologies which have been developed are still some way from market, evidence on firm valuations in recent venture capital (VC) funding rounds or from VC fund valuations may provide useful indicators of the expected commercial value of the technologies which have been developed through the Programme.
- In other cases, it may be possible to utilise other research evidence. For example, many BEIS research studies have estimated the value added by the acquisition of Masters and PhD qualifications to the individuals involved and to society at large based upon the wage premium which people with these qualifications receive.[36]

Any CBA, particularly for the interim assessment, will be indicative given the complex and long-term nature of the intended process of change.

In the longer-term as the benefits of 5G start to become evident, the uncertainty around the future scenarios will clearly reduce, although even by 2025 any assessment will still be provisional. However, as institutional memories of the projects involved fade, it is likely to become more difficult to establish how far the emerging benefits can be ascribed to the Programme as opposed to other drivers of the changes involved. This latter issue will need to be dealt with by ensuring that the final evaluation builds upon earlier evidence from the interim evaluations rather than being implemented as a 'free standing' exercise.

3.6 Proposed timings for the evaluation

Figure 3.3 overleaf presents the detailed timings proposed for the different elements of the evaluation. Reflecting the discussions above, aspects of the detailed evaluation design may, of course, need to be adapted considering how the Programme evolves.

Whilst the programme-level evaluation will take place after the completion of the Programme (as noted below), monitoring of projects will be done on a continuous basis and will be used to assess how the Programme is progressing during its lifetime. More specifically, monitoring data, combined with other sources, will inform a range of evaluation metrics.

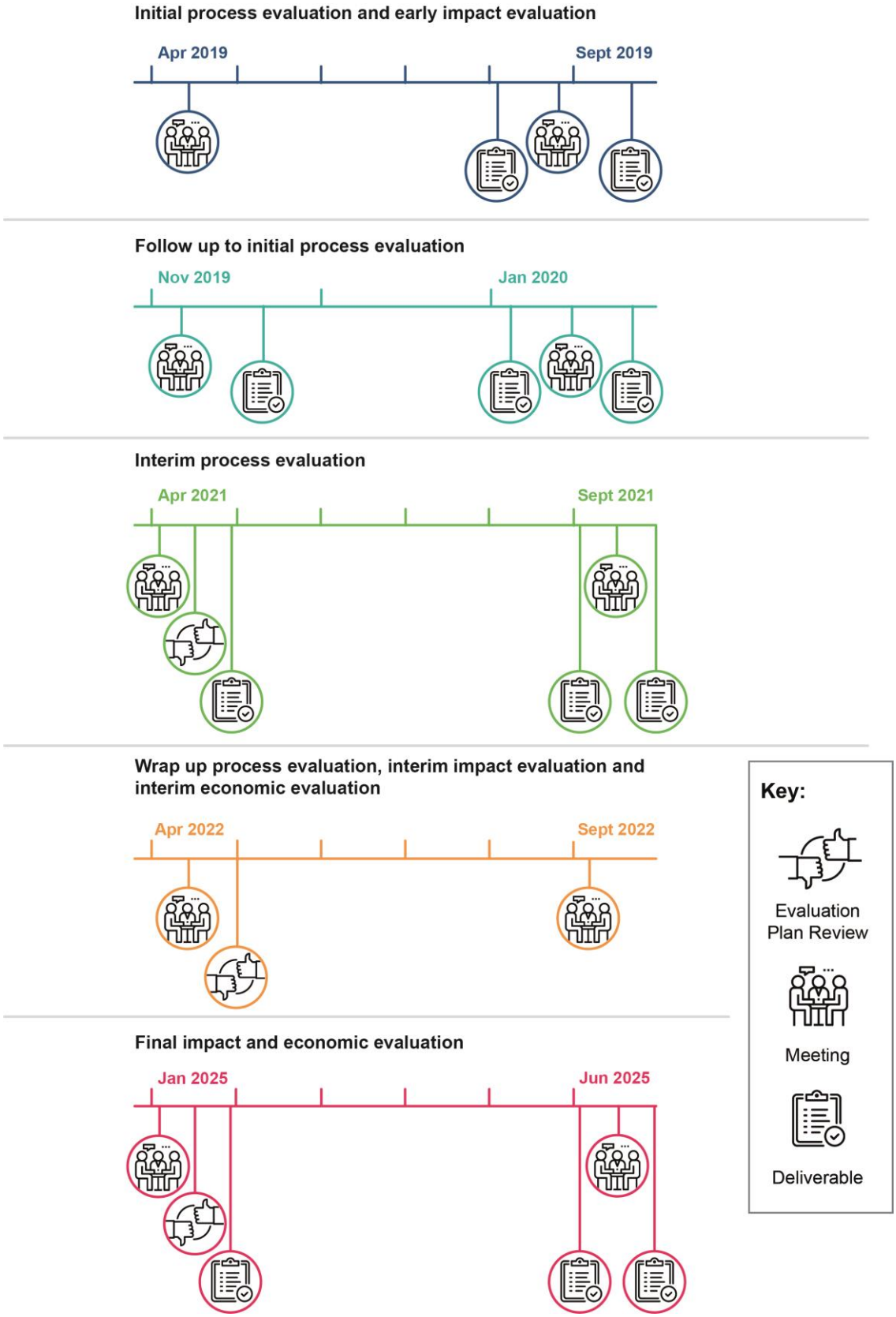
The suggested timescales for the initial, interim and final assessments are as follows:

- The initial assessment will focus on process elements to identify any suggested changes which can usefully inform the implementation of later projects, as well as to identify early impacts and associated issues to inform the case for further funding. In practical terms this points to a timing of early 2019 – early 2020.
- The interim assessment, focussing on a refresh of the process elements, an interim impact evaluation and an interim economic evaluation, is proposed to take place from early 2021 – late 2022, reflecting DCMS' requirements for this study and the expected completion of the Programme implementation phase.
- The final assessment, including a final impact and economic evaluation, is proposed to take place in the first half of 2025 by which time there should be at

[36] See for example: BIS Research Paper No 112. The impact of university degrees on the lifecycle of earnings. Some further analysis. August 2013.

least a reasonable degree of clarity about the likely nature and scale of the eventual impacts of the Programme. These timescales are indicative only at this stage and may need to be revised in future, depending on whether the expected outcomes will have materialised.

Figure 3.3 Overall programme evaluation plan



3.7 Challenges for the evaluation

3.7.1 The Programme has a range of complex characteristics

The nature and design of the Programme involves different types of project partner and a diverse range of projects with differing objectives and potential outcomes, established in different contexts and involving different vertical sectors and potential use cases. The Programme is also framed by a range of external factors which are likely to influence how far its anticipated/desired outcomes are achieved and which will need consideration (e.g. wider academic research, the nature and speed of international developments, including by producers of mobile devices and microchips, developments in/'pull' from vertical sectors in particular the media and health, disruptive technological development by SMEs, the potential need of UK mobile networks to forestall entry/cross-entry threats, etc.).

3.7.2 Some assumed Programme outcomes will only materialise in 5-10 years or more

As indicated by the Logic Model, a range of key outcomes are only likely to materialise fully in the long-term, imposing limitations on the interim impact evaluation in particular and posing major practical challenges for the interim economic evaluation. Some outcomes may not be observable within the proposed final impact evaluation and would have to be picked up by further research.

3.7.3 The design of future Programme elements has not been finalised

As noted, there is uncertainty about potential future Programme projects which creates associated uncertainty in relation to: (a) identifying the full range of potential outcomes as well as the key linkages leading to these; and (b) the likely characteristics of the direct and indirect Programme beneficiaries.

3.7.4 The numbers of direct Programme beneficiaries may be limited

The assessment of the feasibility of potential statistically based evaluation methods requires an understanding of the likely number of Programme beneficiaries of different types. The uncertainty about the scope of the future projects which may be funded means that only an indicative picture of the likely number of beneficiary organisations can be provided at this stage. Across the Programme, we estimate that there are around 90 programme beneficiaries directly funded by DCMS in 5GUK Test Network and phase 1 projects, of which there are:

- around 65 business beneficiaries (SMEs and large firms); and
- around 25 public sector and university / research organisation beneficiaries.

Future projects may support a much larger number of direct beneficiaries. Only £41 million has been committed, so more beneficiaries are expected in the future. However, it would be a risk to base the evaluation plan on an assumption that a much larger population of beneficiaries will be available for analysis, especially as many of the current beneficiaries may 'reappear' in subsequent projects. It is also understood that there is no large pool of unsuccessful bidders for funding who could serve as the source of a 'comparison group'. This is because those who might remain in such a group cannot be guaranteed and there is a limited number of 5G organisations.

A much larger number of firms and consumers should benefit from 'second order' effects, such as the availability of 5G-enabled services and business models. However, the characteristics and size of such groups of wider beneficiaries are difficult to estimate at this stage.

For some future projects under the Programme, it may be possible to define indirect beneficiaries by geography or other factors. For instance, the announced 5G Urban Connected Communities[37] project might involve a significant number of individual and business users registered in specific locations whose performance could be tracked as part of the longer-term evaluation.

Given that the number of organisations directly supported by the Programme is relatively small in a statistical sense, the complex nature of the Programme, and the lack of a substantial population of unsuccessful applicants, the statistical methods that can be employed to undertake a counterfactual impact evaluation (CIE) even at the Programme level[38] are limited. As noted too, there is also a likelihood that applicants may well appear in more than one of the consortia which will be successful and/or unsuccessful bidders for funding. Many bidders may also be recipients of funding under other Government programmes, complicating the assessment of how far observed changes in their performance can be attributed to the Testbeds and Trials Programme. Moreover, a significant amount of the benefits will accrue indirectly (i.e. to users who won't directly receive funds) and, therefore, it is harder to evaluate the end beneficiaries, judging from this perspective, too.

3.7.5 The Programme-level evaluation will need to be coordinated with the project assessments

The diversity of the activities being funded means that some projects will need to be subject to individual evaluations. The Programme-level evaluation work will therefore have to be coordinated with these evaluations to ensure that duplication is avoided where possible.

[37] https://www.gov.uk/government/publications/5g-urban-connected-communities-project

[38] In its simplest form, counterfactual impact evaluation (CIE) involves comparing the outcomes of interest in those which have benefitted from a policy or programme (the "treated group") with those of a group similar in all respects to this group (the "comparison/control group"), the only difference being that the comparison/control group has not been exposed to the policy or programme. The comparison group provides information on "what would have happened to the members subject to the intervention had they not been exposed to it", the counterfactual case.

https://ec.europa.eu/jrc/en/research-topic/counterfactual-impact-evaluation

4 Establishing an evaluation baseline

4.1 Overview

The baseline seeks to establish a point of reference from which the outcomes and impacts of the Programme can be compared and its additionality identified. The baseline touches on the challenges to 5G rollout, such as spectrum allocation and the UK planning regime. This is to provide context for Programme risks and enablers, rather than to identify broader challenges that the Programme is designed to influence. A baseline ideally details conditions prior to the implementation of an intervention. However, in this case, the supporting research was undertaken in Summer 2018, after the Programme had started. The issues this potentially creates have been mitigated where possible, but the risks of some associated 'contamination' – in particular, the possibility that the Programme may have already influenced some stakeholders' expectations – need to be recognised.

The baseline work brought together findings from:

- A literature and data review, covering research on 5G in the UK and elsewhere. Over the last few years, several relevant studies have been published, some covering aspects relevant to the baseline. GSMA industry data was also reviewed to understand the current projections of operators in the UK and elsewhere as to the pace of roll-out and take-up of the technology.
- Eighteen interviews with key stakeholders from industry, academia and the public sector to gather perspectives on the current context. These took the form of 'strategic conversations', identifying potential or likely future scenarios, the opportunities involved, potential barriers to their exploitation, and the threats and challenges involved.
- A survey of programme beneficiaries to date to explore aspects of organisational motivations and expectations, especially on the part of non-lead partners. The interviews also covered specific topics relevant to the planned process and impact evaluations.

More generally, the baseline research focused on a range of topics agreed with DCMS and chosen as important in setting out the context for the evaluation. These topics, which reflected key aspects identified within the Logic Model and pilot case studies, considered:

- the current state of development of:
  - the technology;
  - the associated regulatory framework;
- drivers and enablers of 5G deployment, take-up and application in services and use cases, as well as potential associated barriers and risks, including uncertainties around business models and issues of investment readiness;
- expectations/plans in relation to:
  - the future path of development, roll-out and adoption of 5G, including likely business models and R&D activity;
  - consumer//business take-up; and
- the international context in terms of 5G-related activity.

These topics seek to provide a baseline for some of the logic model outcomes. The current state of development of the technology and the associated regulatory framework is related to some of the short-term outcomes, such as the development of test networks or the 5G network deployment preparation. The drivers and enablers of 5G deployment, together with the barriers and risks, inform some of the assumptions and context/external factors underpinning the model, as well as the medium-term outcome "reduced cost and barriers to deployment". The expectations/plans in relation to the future path of development, roll-out and adoption of 5G inform some of the short-term outcomes (such as new applications/business models tested), as well as medium-term outcomes (such as stimulation of R&D). The international context provides information that can be used as a baseline for the medium-term outcomes of the UK becoming a leading 5G country.

The key findings of the research tasks are summarised below and are structured around the key elements of the baseline (Figure 4.1), with emerging implications for the evaluation drawn out as relevant. More detailed evidence underpinning these baseline findings is presented in Annex 3, which can be read in conjunction with the summary content presented below.

Figure 4.1 Elements of the evaluation baseline[39]

4.2 Summary of evaluation baseline findings

4.2.1 Technological development

The first area of focus for the baseline evaluation work is the current state of development of the 5G technology. Research in this area identified three key themes related to technological development:

[39] Please note that the use of colours is only for design purposes.

- standardisation and UK contributions to these standards;
- research and development (R&D) and patenting activity; and
- other 5G development needs and requirements.

4.2.1.1 Standardisation and UK contributions to these standards

Although the 5GTT Programme is not intended to impact directly[40] on standards for 5G, the development of 5G technology and products – both user devices and network elements – is underpinned by development of the 3GPP technical standards and related chipsets and product components. Typically, the commercial availability of products follows completion of standards by some 12 to 18 months, hence the 'critical path' associated with the establishment of 5G standards prior to the commercialisation of 5G products. Therefore, the evolution of the 3GPP technical standards may constitute a confounding factor in the context of this evaluation by impacting the scale, nature and speed with which 5G technology and products are developed.

In addition, it is widely considered that development of local fibre and 5G connectivity must go 'hand in hand'. Small 5G radio cells, as are expected to be deployed in urban centres, are likely to require Gigabit (per second) capacity connections (so called 'backhaul') to connect to major 'trunk' networks. At the time of this report, the UK had far less backhaul fibre available than many other countries, but Ofcom is taking steps to ease access to backhaul connectivity[41] and to the physical infrastructure of ducts and poles owned by BT[42] and DCMS funding programmes such as Local Full Fibre Networks (LFFN) are progressing which involve a number of 'models' to help industry to extend fibre to the premise connections[43]. Consequently, the development of local fibre may also constitute a relevant consideration when measuring the impact of 5GTT on the development and deployment of 5G connectivity in the UK.

4.2.1.2 R&D and patenting activity

The UK has been involved in significant research and development (R&D) activities related to 5G development. The 5GTT Programme has added to the stock of 5G knowledge and has provided £16 million in funding for the largest single academic project to establish the world's first 5G end-to-end network. The UK5G body and the 5GTT phase 1 projects are also contributing to the wider development of the UK R&D ecosystem.

Whilst there is no comprehensive baseline evidence, research conducted for this study suggests that there has been a slowdown of UK industrial R&D in the fields of wireless and networking systems in recent years. However, this has been partially compensated for by the work of university research groups and institutes.

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[40] The 5GTT Programme will contribute indirectly to 5G standards through various projects. Results from projects will be shared with the UK5G Innovation Network Advisory Board, some of whom work with standards bodies. The 5G Innovation Centre at the University of Surrey is working with the six Phase 1 projects in a working group which looks at how they can more formally feed into standard setting bodies.

[41] Ofcom (2018), Review of spectrum used for fixed wireless services. Our decisions to enable future uses of fixed wireless links.

[42] https://www.ofcom.org.uk/consultations-and-statements/category-1/physical-infrastructure-market-review Accessed 29 January 2019.

[43] https://www.gov.uk/government/publications/local-full-fibre-networks-challenge-fund. Accessed on 24 October 2018.

4.2.1.3 Remaining development needs and requirements

The literature review and interviews did not point to significant development needs which are specific to the UK as 5G is seen as a global technology and individual components for infrastructure, devices and the application layer will need to be developed in accordance with 3GPP standards. However, some issues which came up both in the context of the published literature and the stakeholder consultations were:

- the importance of creating an application ecosystem;
- testing of millimetre wave band devices against evolving standards; and
- the development of better cloud-based solutions.

4.2.2 Regulatory environment

The current state of development of the regulatory framework within which 5G is developed and deployed is also a relevant factor for the baseline evaluation given the impact that the UK's regulatory regime – alongside the 5GTT Programme – can have on the development and deployment of 5G.

At present, the regulatory environment continues to evolve and, within that context, both the literature and stakeholder interviews identified a number of regulatory enablers and barriers to the further development of 5G.

4.2.2.1 Enabling regulatory factors

The main UK regulatory factors identified in literature/interviews as important for enabling 5G development are:

- Ensuring there is an effective planning regime in place – this will be crucial to enable the widescale roll-out of small cells. Stakeholders interviewed thought that the recently amended Electronic Communications Code (ECC) was a positive step but, to enable network expansion, further reforms to planning regulations would be needed. In addition, the literature refers to the reform of planning and site access in recent years to ease the deployment of communication infrastructures in England, especially in rural areas.
- The way spectrum allocation is handled in the future – this is seen as either a significant enabler or inhibiting factor. In relation to trial activity, views on Ofcom's spectrum policy expressed during interviews suggest that updates to non-operational licences have helped the speed and effectiveness of the allocation process. Overall, Ofcom is seen to have taken a very proactive and helpful stance in allowing access to sub-6GHz and in mm wavebands. For more permanent deployments, there have been calls for Ofcom to make 5G spectrum available to a wider range of market players through more flexible licensing arrangements.
- Spectrum sharing and spectrum brokering – this was highlighted by several interviewees as a key enabler to facilitate new business models outside the current MNO models.

- Ensuring regulation that keeps pace with the rate of innovation – for instance, on intellectual property protection. The challenge for policy-makers will be to ensure appropriate 5G regulation without stunting innovation[44].

4.2.2.2 Inhibiting regulatory factors

Several inhibiting factors were identified and may hinder the 5G deployment process in the UK, including:

- The difficulty in getting access to suitable locations for infrastructure installation and to backhaul. However, stakeholders interviewed were largely optimistic that the proposed reform to the ECC could help to reduce future barriers relating to infrastructure, but thought it was too early to judge whether these changes will have a substantial positive impact.
- Spectrum regulation. Some stakeholders expressed concern about the current approach to auctioning spectrum, including the associated costs. This may delay 5G roll-out since existing mobile network operators have less remaining capital to invest in new infrastructure. These high auctions costs may result in large operators focusing their 5G investments in the most profitable urban or high-density areas to maximise the return on their investments, and/or could inhibit market entry.
- A possible mobile divide. A further concern voiced by stakeholders was that of a possible mobile divide, as the current model is seen to incentivise roll-out largely in urban or suburban areas and provides no incentives for rural areas. Making spectrum available for shared use by fixed wireless operators might be able to resolve this challenge.

4.2.3 Risks and enablers for 5G roll-out

Baseline research also gathered evidence on the main risks and enablers that, according to the literature review and interviews undertaken, would have a substantial effect on 5G roll-out. The research focused on risks and enablers related specifically to the 5GTT Programme, rather than 5G roll-out more generally.

4.2.3.1 Enablers

Concerning 5G roll-out enablers, the most frequently raised issues throughout the literature and/or via interviews were as follows:

- Networks asset sharing, especially for reducing investment costs and influencing the investment case.
- Standards are also expected to be an enabling factor for 5G roll-out, as discussed earlier. 5G deployment appears likely from 2020 onwards, when standards providing the set of 5G capabilities will be finalised.
- Ensuring an acceptable return on investment – this is a factor enabling large-scale investments. It could be achieved for instance through a supportive regulatory policy framework[45].

[44] IHS (2017). The 5G economy: How 5G technology will contribute to the global economy. Available at: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf. Accessed on: 11 September 2018.

[45] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf

- The rapid roll-out of, or access to, dark fibre – this could be a key enabler for backhaul to support 5G deployment, to meet capacity demands from both existing and new cell sites. In this context, the Ofcom key proposals were for unrestricted access to ducts and poles, and not dark fibre. That being said, Ofcom proposed that BT should provide this dark fibre access at a price that reflects its costs.
- An ecosystem of start-ups – by demonstrating new applications which may not be possible in other countries yet, this ecosystem of start-ups could be an enabler in pushing forward the 5G agenda in the UK in terms of public support and private investment.

4.2.3.2 Risks

Concerning 5G roll-out risks, the most frequently raised issues throughout the literature and/or via interviews were as follows:

- The size of investments required to provide the necessary 'backhaul' and small cells installations for 5G roll-outs. As noted earlier, 5G networks will require high 'backhaul' capacity, including for the deployment of new small cells to meet localised demand (for which there is a lack of infrastructure currently).
- Specific risks related to a neutral hosting model and the concept of network sharing. Cost savings from network sharing might be less extensive than the fixed cost saving achieved by having one vertically integrated player. However, competition should not be compromised through resource sharing.
- Consumer take-up: many users may find 4G sufficient to meet their needs, which could result in an initial lack of demand for some 5G applications and services.

4.2.4 Industry's development and roll-out plans

The baseline evaluation considered the deployment trajectories in the UK and investment estimates related to these deployment trajectories. This is relevant for considering what may or may not have occurred in the absence of the 5GTT Programme (i.e. the counterfactual scenario) using these deployment trajectories to inform that assessment.

From discussions with industry players, the study team identified three potential deployment scenarios that may be associated with 5G networks and services development which are summarised below.

In terms of 5G deployment within the indoor environment, in cases where full fibre to the premise is provided, the study team expects that Wi-Fi technology would remain significant, even as 5G solutions develop. In cases where no fibre and poor fixed line broadband exists, 5G technology could provide some benefits – either via fixed wireless access, or via use of modified 5G mobile solutions for home access. If 5G is seen as a network system (rather than a radio access technology), as it may do, it may be that 5G core networks will embrace many different radio technologies at the access level. In such cases, 'true' convergence may develop – with converged services across both fixed and wireless networks. Finally, 5G small cells have the potential to improve coverage in commercial premises (such as offices, shopping centres and railway stations).

In terms of 5G deployment outdoor in dense urban areas, 5G technology is expected to experience high market take-up levels and high traffic capacity demands. Essentially, in such cases, 5G technology is likely to be deployed to provide capacity augmentation on 3G and 4G existing sites, thus conserving investment levels. A key

issue will be the development of 5G services which offer incremental value over 3G and 4G based services; service 'slicing' with leverage of 5G technology to varied vertical sectors may be critical. In any case, the investment cases for 5G deployments remain unclear.

Finally, in terms of 5G deployment outdoor in non-urban areas, demand becomes sparse and the investment case for cellular technologies becomes more challenging as lower revenue levels can be expected per unit area. Investment cases thus demand lower capex density levels, but sparse deployment of radio sites weakens the case for cost-efficient deployment of high capacity services – one of the key differentiators envisaged for 5G. If new innovative forms of network and spectrum sharing are developed and supported by Ofcom, it may be that costs can be reduced and competition is opened up for new players across the country, and this may drive increased deployment of 5G solutions across the country as a whole, as opposed to urban centres only.

4.2.5 Expected future take-up

Another relevant factor for the baseline evaluation of the 5GTT Programme is the expected level of consumer and business demand/take-up for 5G. This is relevant when assessing the benefits of the 5GTT Programme for end users.

In the UK, GSMA data shows that the percentage of 5G connections (excluding licensed cellular IoT) is foreseen to be on a continuous growing path starting with Q4 2019 through Q4 2025. UK growth of 5G connections is forecast to pick up slightly slower than in selected international countries (US, South Korea, Germany) but by 2025 is forecast to reach 43% of all connections.

While 5G connections will be growing in the UK, other technologies are expected to witness an opposite trend. The proportion of 4G connections is projected to gradually decrease from 2021 to 2025. The share of 3G connections is expected to decrease from late 2019, with no 3G connections left in 2025 in the UK.

It is difficult to predict 5G network coverage by population in the UK with certainty. For instance, the GSMA forecast points to an increasing trend, with ~83% of the population having 5G network coverage by Q4 2025. However, forecasts are, by their nature, assumptions-based and, in this context, there is uncertainty around future 5G network coverage given the lack of consensus on the number of small cells required for 5G, the level of infrastructure sharing, and the outcomes of future spectrum auctions. Furthermore, the uncertainty about the demand for use cases and business models make it difficult to predict MNOs' level of future investment. The analysis undertaken by Frontier Economics[1] to support the DCMS's Future Telecoms Infrastructure Review indicates that whilst rolling out 5G on a mid-2020s timetable on existing sites is feasible assuming that MNOs will collectively invest around £1 billion per year, rolling out a more extensive 5G network that meets the needs of all potential use cases, may take considerably longer.

According to the GSMA, however, outside the UK, the US, Finland and South Korea are expected to have a higher population coverage initially, potentially a function of varying degrees of urbanisation and available backhaul infrastructure.

It is also relevant to consider the launch dates of the current 4G network across countries, as this might influence the remaining lifetime of existing networks and business case for introducing 5G. Further details in this regard are in Annex 3.

4.2.6 International state-of-play

Finally, the baseline evaluation sought additional context for the development and deployment of 5G in the UK because of the Programme by considering the international state-of-play with respect to 5G. This has focused on two main aspects – the development of 5G technology, and industry roll-out plans.

4.2.6.1 Technology development

Apart from the UK, some countries have already made a start trialling or launching 5G services, including South Korea, the US, China, Japan, Spain and Germany, for which further detailed examples are presented in Annex 3.

Finally, stakeholders interviewed for this study were mostly of the opinion that the US and Asia appear to have a more significant programme for 5G than European countries.

4.2.6.2 Industry's development and roll-out plans

Industry data from GSMA suggests that 5G networks are forecast to cover around a third of the global population by 2025, with adoption reaching 1.1 billion connections, and 5G mobile broadband connections will exceed 12% of total mobile connections in about the same time-frame.

It is likely that before 2020, mobile operators will invest $700 billion in mobile networks and infrastructure worldwide, and further uplifts in investment are likely to happen after 2020, as operators roll-out 5G networks. [46]

South Korea can be considered a frontrunner in 5G-network deployment. South Korean operators are widely expected to launch commercial 5G services in 2019.[47]

The US and China are expected to dominate 5G related R&D and capex investments, with estimates of about $1.2 trillion and $1.1 trillion respectively until 2035. It is estimated that US investments will account for about 28% of global 5G investment and Chinese investment for around 24% during this period. Overall, the 5G value chain will drive an output of $3.5 trillion, and 22 million jobs will be created, most of which will be in China. The US and China are therefore expected to be among the first countries deploying commercial 5G: China's plan is to deploy 10,000 5G stations by 2020.[48]

The European Union (EU) launched on September 2016 its 5G for Europe Action Plan, which would drive developments in France, Germany, Spain and Sweden. The Plan aims at stimulating investments in 5G infrastructure and services roll-out in the Digital Single Market before 2020. Moreover, the European Commission (EC) is

[46] GSMA (2017a). The mobile economy. Available at: https://www.gsmaintelligence.com/research/?file=9e927fd6896724e7b26f33f61db5b9d5&download. Accessed on 12 September 2018.

[47] FCCG (2017). UK strategy and plan for 5G & Digitisation - driving economic growth and productivity. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf. Accessed on 11 September 2018.

[48] IHS (2017). The 5G economy: How 5G technology will contribute to the global economy. Available at: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf. Accessed on: 11 September 2018.

[48] GSMA (2017). The 5G era: Age of boundless connectivity and intelligent automation. Available at: https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download. Accessed on: 11 September 2018.

planning to work with industry, Member States and other stakeholders to set roll-out objectives for monitoring progress of key fibre and cells deployment. Furthermore, the EC is working to identify actionable initiatives to increase the consistency of administrative practices and time frames to facilitate cells deployment, in line with provisions from the European ECC. The EC is also working to make spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference. The aim of the EC is to have all urban areas and main transport paths covered by 5G networks by 2025. Further detailed examples of the roll-out plans of individual EU Member States can be found in Annex 3.

In terms of competitive advantage, the UK might have a leadership position in 5G-enabled services and applications in the future according to stakeholders interviewed for this study. Operator rollout plans for 5G in the UK in 2019 support this argument. Three and EE have both committed to rolling-out commercial 5G services in the UK in 2019. Three is also investing on a £2bn+ upgrade to prepare their network[49]. Vodafone announced they are ready to launch 5G in mid-2019. They have ramped-up investments in RedStream, an optical core network that supports both fixed and mobile traffic and underpins the 5G plan.

Further UK strengths cited by interviewees included software expertise and a software start-up culture, the early award of spectrum, a strong skills base, a competitive market and the small geographical scale of the UK. Developing this ecosystem focused on designing the services and applications at the 5G digital services layer will be a good way of boosting the UK's competitive advantage. The Phase 1 testbed and trials projects in the UK have placed a lot of importance on verticals and demonstrating the delivery of use cases. That should help build the case for industry interest and investment further.

4.3 Evaluation implications and recommendations

This report makes a number of recommendations regarding the proposed approach to the process, impact and economic evaluations of the 5GTT Programme. Additionally, the baseline evaluation work conducted for this scoping study highlights a number of potential implications for the evaluation of the 5GTT Programme. These implications and associated recommendations are summarised below.

4.3.1 Process evaluation

Feedback from Programme beneficiaries highlighted certain aspects of the implementation of 5GTT that the study team recommends form areas for further exploration in the process evaluation.

Baseline survey findings show that, although the Programme's processes and eligibility requirements were generally clear and appropriate to beneficiaries, feedback from the assessment processes (i.e. feedback on the IUK and DCMS scoring, and the subsequent interview) was not always 'helpful and well structured'. In addition, there were mixed views among beneficiaries as to how 'appropriate and well structured' project monitoring and reporting requirements are.

[49] https://www.ispreview.co.uk/index.php/2018/11/three-uk-commit-2bn-to-commercial-5g-broadband-rollout-in-2019.html . Accessed on 30 January 2019.

Paying particular attention to these areas as part of the process evaluation may identify potential improvements in the implementation process for additional future 5GTT projects.

4.3.2 Impact and economic evaluations

One finding emerging from the baseline work of relevance to the impact evaluation is the critical role played by fibre networks, as well as radio spectrum, as enablers for 5G roll-out. It is widely considered that the development of local fibre and 5G connectivity must go 'hand in hand'. Consequently, there are benefits form ensuring that the ongoing evaluation of the Local Full Fibre Networks (LFFN) programme is joined-up with the evaluation of 5GTT.

Linked to this is a broader point emerging from and emphasised by the baseline findings – the role/importance of various 'contextual' factors in influencing the success of the Programme identifying and alleviating potential barriers to 5G roll-out and service development. These contextual factors extend beyond the availability of fibre networks and include spectrum availability and regulatory barriers (including planning). In addition, skills emerged as another potentially significant barrier/enabler to 5G roll-out. These factors emphasise the need for the impact and economic evaluations of 5GTT to identify and take account of these contextual factors as they are largely outside the direct control/influence of the Programme.

Another baseline finding which has potential implications for the impact and economic evaluations relates to the time horizon over which some of the impacts of the 5GTT Programme are likely to be realised and observable. Although the Programme is likely to accelerate the roll-out of 5G, the main impacts/benefits are likely to be only fully-realised beyond the proposed 2025 deadline for a 'final' evaluation. Consequently, there may be merits in delaying the final evaluation of 5GTT beyond 2025, although this should be balanced with the risk that Programme beneficiaries (as a key source of evidence linking impacts to the Programme) move on and/or find it more challenging to recall the role of the Programme in the longer-term. On balance, it is recommended that the proposed timescales for the evaluation (with a final evaluation in 2025) be retained, but that the evaluation gives explicit recognition to the likely partial nature of the impacts that can be quantified and monetised.

The baseline work and, specifically, evidence surrounding the wider global context for 5G means that most of the outcomes that the 5GTT Programme seeks to deliver are likely to happen largely anyway, with the main impacts of the Programme related to timings of roll-out and the development of applications rather than the fundamental technologies. This emphasises the importance attached to the impact and economic evaluations measuring the additionality of the Programme, including seeking to quantify/monetise any deadweight.

The baseline work highlighted challenges in designing and deploying a robust impact and economic evaluation approach given the dependency on self-reported results which involve a degree of bias. It emphasised the importance of the impact and economic evaluation drawing-on multiple evidence sources where these are available – and consulting with a wide range of stakeholders (and a wider range than fell within the scope of this baseline work) – before triangulating and synthesising all evidence sources to counter the overreliance on any one source and the potential impact of bias in self-reported Programme benefits.

Finally, on a practical level, the baseline helped to identify improvements that could be made to the evaluation research tools. For example, interview topic guide questions on R&D went largely unanswered given the commercial sensitivity

surrounding organisations' R&D spend/focus. Further, the evaluation should remain mindful of the overall length of research tools and prioritising key questions (linked to priority impacts identified from the logic model for 5GTT) to ensure evidence is gathered from a wide range of stakeholders/sources for a core set of impacts and outcomes.

ANNEXES

Annex 1 Proposed evaluation work programme

Evaluation element	Stage 1	Stage 2	Stage 3	Stage 4
Process evaluation	Initial process evaluation, to be conducted towards/shortly after completion of the phase 1 projects – implying a start around early Q2 2019. This would focus on the provision of feedback on early lessons – particularly in relation to the 'front end' stages of the process – and identifying potential modifications to improve delivery and effectiveness.	Interim evaluation, to start 12 months or so after stage 1 in particular to: • Provide a more comprehensive assessment of the programme processes. • Assess the implications of any modifications made following process changes introduced in response to the Stage 1 assessment.	To provide a 'wrap up' assessment/overview, including 'lessons learned' to feed into the Final Interim Evaluation Report. The overall timetable for the 5G testbeds & trials programme suggests that this stage should start around Q1/Q2 2022.	N/A
Impact evaluation	Stage 1 Early Assessment –/Q2 2019 – focused upon: • Project additionality and the extent to which projects are delivering their expected outputs and results. • Emerging policy lessons	Stage 2 Follow-Up – 6 months after stage 1 • Whether the programme requires adjustment in light of contextual developments and emerging project related evidence. • Assessment of the achievement of expected interim outcomes and potential implications. • Consideration of contextual change and key drivers. • Assessment of project related outputs and impacts. Include evaluation plan review points for elements of the impact	Stage 3 Interim Evaluation – Q1/Q2 2022 – as above plus the following: • Contribution analysis of the role of the programme in delivering the desired short and medium-term outcomes. • Progress towards long term outcomes. Include evaluation plan review points for elements of the impact evaluation focussing on future projects (UCC, RCC, innovation fund, sector testbed projects etc) to refine/amend the work programme in response to any changes to programme design or objectives.	Stage 4 Final Evaluation – 2025 or later – this part focuses on: • Extent of success in achieving desired long-term outcomes. • Providing evidence to inform the fuller economic evaluation. Include evaluation plan review points for elements of the impact evaluation focussing on future projects (UCC, RCC, innovation fund, sector testbed projects etc) to refine/amend the work

Evaluation element	Stage 1	Stage 2	Stage 3	Stage 4
		evaluation focussing on future projects (UCC, RCC, innovation fund, sector testbed projects etc) to refine/amend the work programme in response to any changes to programme design or objectives.		programme in response to any changes to programme design or objectives.
Economic evaluation	Stage 1 - Interim Evaluation – Q1/Q2 2022: • Work to estimate the costs incurred and establish scenarios of the potential associated benefits which are likely to be attributable to the programme, leading to the calculation of an indicative BCR • Assembly of evidence on how its cost effectiveness could potentially be/have been improved.	Stage 2 - Final Evaluation – Q1/Q2 2025 or later: • Estimating the total cost of the programme • Using evidence from the impact evaluation to inform an updated estimation of the monetary value of the benefits of the programme • An updated assessment of the BCR of the programme	N/A	N/A

Annex 2 Evaluation framework

This annex presents the evaluation framework for the impact and economic evaluation and key links to evaluation questions identified throughout the evaluation scoping exercise.

A2.1 Impact evaluation

A2.1.1 The programme level impact assessment framework

The proposed methodology requires the evaluation to provide a systematic – and as far as possible quantified – assessment of the extent to which the intended outcomes of the programme are realised over different timescales. The theory of change focuses on the role of the programme in contributing to a process of technological development which will enhance the competitive position of the UK in relation to a key emerging and enabling technology and secure a range of benefits from accelerating its deployment and extending its application in a range of 'vertical sectors' – with both associated competitiveness benefits to the private sector and productivity benefits to the public sector.

Examples of unintended programme outcomes have been included in our framework, however the evaluation is designed in a way to allow flexibility to continuously monitor for unintended outcomes and identify them should they materialise.

Table A2.1 summarises the proposed key assessment considerations/criteria in relation to the different stages of the evaluation based upon the overall programme logic model, along with the associated metrics which potentially can be utilised in the assessment process.

Table A2.1 Impact assessment framework - assessment considerations/criteria and metrics

Timescale	Assessment considerations / criteria	Metrics	Outcomes	Data sources
Early assessment and throughout	■ Extent to which milestones achieved/outputs delivered as planned ■ How far projects activities are additional ■ How far key barriers/baseline has 'moved'[50] ■ Perspectives of international companies on UK as a place to invest	■ Performance against milestones and end output targets ■ Extent to which participants believe same activities (would) have taken place without DCMS funding (qualitative) ■ Extent to which nature, scope and scale of activities (would) have changed in absence of DCMS funding (qualitative) ■ Extent to which key international companies in telecoms and auxiliary / vertical sectors consider UK a prime target for 5G related investment		■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey
Interim Evaluation - A Short Term Outcomes	■ Technology challenges overcome / increase in technology readiness levels (TRL) ■ Network development and deployment ■ Development of ecosystem and collaborative activities ■ Business model and use case development ■ Knowledge and skills development and knowledge diffusion ■ UK contribution to 3GPP standards ■ Stimulation of additional/earlier 5G related investment ■ Displacement of competing standards and technologies ■ Crowding out effects	■ Progress in relation to TRLs of 5G related projects -registration of patents, academic publications, other research outputs (quantitative) ■ Associated development of industry networks and development/exchange of good/best practice (largely qualitative) ■ Level of participation in 5G activities – i.e. SMEs, start-ups/spin-outs (quantitative) ■ Increased/more effective R&D in infrastructure, potential applications and business models (quantitative, increase in level of investment, and qualitative) by 'players' / ecosystem ■ Related knowledge and professional skills development – including number of associated academic qualifications (e.g., PhDs) secured ■ Development/timing of agreement of common 5G technical standards; Contribution to	■ Progress is made in technology readiness level & standards ■ Increased 5G network deployment preparations ■ Increased industry participation within Ecosystem [e.g. SMEs/start-ups] ■ Stimulation of R&D & commercial domestic & international investment beyond funded projects ■ Development of 5G professional knowledge, skills, expertise	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis

[50] Such as suitability of the testbed infrastructure; SMEs/other project partners dropping out of the projects funded; commercial and technical delivery risks materialised; spectrum allocation issues/delays for those projects which require licenses; demonstration/showcasing from funded projects not visible enough (lack of awareness of programme results within the ecosystem).

Timescale	Assessment considerations / criteria	Metrics	Outcomes	Data sources
		development of 3GPP standards by UK based 'players' (qualitative) ■ Increase in/acceleration of intentions to invest in development of 5G and its applications (quantitative e.g., value of planned R&D and qualitative) ■ Nature of actual roll-out consisting of a 'technology mix' (e.g. combining 5G, LTE-U, Zigbee, IEEE 802.11ax) or using only 3GPP type 5G ■ Has programme crowded out / replaced investments by industry in 5G testbeds & trials / How far has the programme resulted in operators holding back investment ■ Has the programme resulted in operators holding back investment in fibre infrastructure (FTTH/C/P)	■ Progress is made in technology readiness level & standards	
Interim Evaluation - B Medium Term Outcomes – as A plus other criteria	■ Demonstration/showcasing effects – including failure ■ Reduced costs and barriers to deployment ■ Development/establishment of commercial case for investment ■ UK a leading 5G country ■ creating commercialisation opportunities for programme participants ■ Policy learning effects – including lessons from failures	■ Showcasing of "what works" (qualitative) ■ Reduced costs and barriers to deployment (qualitative) -resolution of spectrum issues, etc. ■ Knowledge/reduced uncertainty/increased confidence around the potentials of the technology and its applications and creating. Successful demonstration of business cases and potentially viable applications (qualitative) ■ Enhanced perception of UK as a centre for development and application of 5G technology (largely qualitative); Linked inward investment by overseas players (number and value of investments) ■ Turnover effects, changes in net exports etc ■ Policy learning effects – including lessons from failures (qualitative)	■ Funded activities identify /show case what works ■ Reduced cost and barriers to deployment ■ Increased certainty over demand/ revenue opportunities [■ The UK is a leading 5G country	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis ■ Counterfactual / econometric analysis
Final Evaluation – as above plus additional criteria	■ Attraction of inward investment ■ Accelerated and/or enhanced deployment ■ Realisation of 5G benefits	■ Related inward R&D and production related investment in UK (number and value of investments)	■ Attract inward investment in telecoms, digital and more widely in the UK	■ MI and Secondary Data Analysis

Timescale	Assessment considerations / criteria	Metrics	Outcomes	Data sources
		■ Role of programme investments in: development and acceleration of 5G and its associated benefits to consumers, economy and public services (qualitative) ■ Role of programme investments in: development and acceleration of 5G and its associated benefits to consumers, economy and public services (qualitative)	■ Accelerated and /or enhanced deployment of 5G	■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis ■ Counterfactual / econometric analysis

A2.1.2 The evaluation framework for specific interventions

A broadly similar approach to the one described in section A2.1.1 needs to be applied in relation to specific interventions. An associated framework of assessment considerations and criteria are identified within the tables below.

Table A2.2 Summary of 5GUK Test Network Assessment Framework

Timescale	Assessment considerations / criteria	Metrics	Data sources
Early assessment and throughout	■ Extent to which milestones achieved/outputs delivered as planned ■ Extent of wider interest/engagement by other parts of ecosystem	■ Performance against milestones and end output targets ■ Extent of wider interest/engagement by other parts of ecosystem (qualitative)	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Interviews with project participants from universities ■ Lessons learned from workshops ■ Literature review ■ Update to baseline survey
Interim evaluation	■ Technological development aspects ■ Partnership development results ■ Development of UK wide connectivity for hubs and spokes using JANET JISC network ■ Extent of 'third party' and other use of networks ■ Knowledge and skills development and knowledge diffusion ■ Results in terms of development of business models and applications – including within 'vertical sectors' ■ Associated effects in terms of actual and planned R&D investment ■ Lessons learned in relation to programme development aspects ■ Development of spatial clusters of related activities ■ Other contributions to wider programme objectives ■ Spill over effects	■ Technological development -TRLs, development of common standards and processes, interoperability of systems, etc via testing and use activities (quantitative for specific testbeds & trial projects), related publication and patenting activity, Open source software, citations, etc. Generation of spin-offs from partner organisations, licensing activity, etc. (quantitative) ■ Actual testing of prototype equipment hastening bug fixing ■ Commercialisation of equipment from vendors such as Ericson, Huawei ■ Levels of interaction/cooperation/coordination between partners – establishment of principle of interoperability (qualitative) ■ Development of UK wide connectivity for hubs and spokes using JANET JISC network (qualitative) ■ Levels of usage of network by different parts of the ecosystem as well as associated revenue generation (quantitative) ■ UK capacity and capabilities in relation to 5G (including workforce knowledge & skills, related educational outcomes, sharing knowledge with Phase 1 and other projects), (largely qualitative through PhDs, etc. achieved) ■ Development of business models and applications, including within vertical sectors (qualitative) ■ Commitments to increased/accelerated investment in R&D in 5G and associated applications (in principle quantitative)	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis ■ Counterfactual / econometric analysis

Timescale	Assessment considerations / criteria	Metrics	Data sources
		■ Lessons learned in relation to 5G T&T and follow on programme development (qualitative) ■ Spatial clustering effects and associated agglomeration benefits (maybe largely qualitative) ■ Other contributions to wider programme objectives (qualitative) ■ Licensing and Patent citations by firms in other technology areas (quantitative)	
Potential final evaluation	■ Long term sustainability ■ Contribution to wider programme objectives	■ Sustainability – development and level of use of networks post-funding (quantitative) ■ Contribution to wider programme objectives (qualitative)	■ Stakeholder and other consultation ■ Project Surveys and Case Studies

Table A2.3 Summary UK5G Assessment Framework

Timescale	Assessment considerations / criteria	Metrics	Data sources
Early assessment and throughout	■ Extent and reach/pattern of membership/participation/level of participation ■ Awareness of network within ecosystem	■ Extent, diversity and pattern of change in membership ■ Extent of attendance, and diversity and seniority of attendees at events (quantitative and qualitative) ■ Awareness and perceptions of value of role of the network within the ecosystem (qualitative)	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Update to baseline survey
Interim evaluation	■ Perceptions of value of network within ecosystem ■ Contributions to: – increasing awareness of 5G potentials and opportunities - enhancing interests in/commitment to taking actions for related development – partnership development - exploitation, including within 'vertical sectors' – knowledge diffusion - technical and standards development ■ increasing the international profile of the UK ■ increasing the volume and effectiveness of R&D investment	■ Increase in awareness of the potentials and opportunities to be created by 5G, avoiding "filtering" based upon interests of major "players" (qualitative) ■ Spin-out, Enhanced interest in taking forward actions to develop/exploit opportunities involving horizontal and vertical sectors (qualitative) ■ Enhanced interest in taking forward actions to develop/exploit opportunities involving horizontal and vertical sectors, academic actor, academic actors (qualitative) ■ Collaborative relationships formed through network (qualitative)	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis ■ Counterfactual / econometric analysis

Timescale	Assessment considerations / criteria	Metrics	Data sources
		■ Enhanced rate of diffusion of 5G related knowledge and expertise, including more rapid “pull through” of related academic research into industry based R&D (qualitative) ■ Development/timing of agreement of common 5G technical standards; Contribution to development of 3GPP standards by UK based ‘players (qualitative) ■ Increased international profile of UK “brand” in relation to 5G (qualitative) ■ Increased, accelerated and more effective R&D investment in 5G technology, applications and business models (partially at least qualitative)	
Potential final evaluation	■ Long term sustainability ■ contribution to wider programme objectives	■ Sustainability of network post-DCMS funding (qualitative) ■ Role of UK5G and associated benefits to consumers, economy and public services (largely qualitative)	■ Stakeholder and other consultation ■ Project Surveys and Case Studies

A2.1.2.2 Phase 1 and later projects assessment framework

The framework here will clearly need to adapt with the changes in the types of project which receive funding and their differing objectives so that the proposals tabulated below are to some extent indicative.

Table A2.4 Summary Phase 1 and Later Projects Assessment Framework

Timescale	Assessment considerations / criteria	Metrics	Data sources
Early assessment and throughout	■ Extent to which milestones achieved/outputs delivered as planned ■ Direct commercial and employment impacts (additional R&D investment, net additional employment etc)	■ Delivery of Planned Outputs Against Milestones and End Output Targets (including progress in relation to TRLs, etc.) ■ Direct R&D employment, wage premia, etc. (qualitative and quantitative) -Indirect wage premia generated in linked activities -Spin-offs generated	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Counterfactual / econometric analysis

Timescale	Assessment considerations / criteria	Metrics	Data sources
Interim evaluation	■ Contributions in terms of: – network development and deployment – progress in technology readiness and research outputs – development of ecosystem and collaborative activities – business model and use case development – knowledge and skills development and knowledge diffusion – stimulation of wider 5G related investment – wider programme objectives, including reduction in costs and barriers to deployment – spill over effects to other sectors – Policy learning effects	■ Usage of networks created for trials post-project and by third parties not reflected in above outputs (qualitative) ■ Progress not reflected in achievement of milestones and targets above publications, patents, citations, value of IPR generated, licensing income, etc. (qualitative and quantitative) ■ Spin-outs and collaborations formed through projects (qualitative and quantitative) ■ Development and demonstration of business models and applications, including within 'vertical sectors ■ Research outputs: patents, publications, conference papers, publications, patents citations, etc. numbers on related Masters and PhD programmes, IP and licensing income generated (quantitative) ■ Increased, accelerated and more effective R&D investment in 5G technology, applications and business models (quantitative and qualitative) ■ Wider programme objectives, including reduction in costs and barriers to deployment (qualitative) ■ Patent citations and licensing by firms in other sectors (quantitative) ■ Policy learning effects (qualitative)	■ MI and Secondary Data Analysis ■ Stakeholder and other consultation ■ Project Surveys and Case Studies ■ Literature review ■ Update to baseline survey ■ Bibliometric and patent analysis ■ Counterfactual / econometric analysis
Potential final evaluation	■ Long term sustainability ■ Contribution to wider programme objectives	■ Long term sustainability (qualitative) ■ Contribution to wider programme objectives (qualitative)	■ Stakeholder and other consultation ■ Project Surveys and Case Studies

A2.2 Economic evaluation

Table A2.5 provides an overview of the costs and benefits to be considered derived from the Logic Model, along with the basis on which these can potentially be measured. The contribution analysis approach will need to be utilised to assess how far the observed costs and benefits can be attributed to the expenditure on the programme.

Table A2.5 Economic evaluation framework and metrics – all costs and benefits to be expressed in present values

Timescale	Costs and Benefits to be Considered	Metrics/Basis of Measurement	Data sources
Interim evaluation	*Costs (up until 2022)* ■ DCMS funding and administrative costs ■ Contributions from public sector participants (e.g., Universities) ■ Private sector funding component ■ Other funding contributions ■ Other private sector R&D expenditure, expenditure on network development, etc as attributable to the programme	*Up until 2022* ■ Value of DCMS contribution (£) ■ Administrative and related costs based upon standard cost model (SCM) (£) ■ Value of contribution of other public sector participants and associated administrative costs based on SCM (£) ■ Value of private sector participant contributions and implementation costs based on SCM (£) ■ Value of other funding contributions (£) ■ Primary research with project participants and the wider ecosystem and analysis of secondary data	■ Extension of the literature review and update of baseline survey ■ Review and collation of the MI data and estimation of likely final expenditure. ■ Qualitative interviews with DCMS 10 programme staff ■ Inclusion of questions within project participant interviews and case studies forming part of the interim impact evaluation. ■ Construction of scenarios ■ WTP survey ■ Estimation of indicative BCRs of the scenarios, leading to an initial potential VFM assessment
	Benefits (potential) ■ Consumer benefit ■ Private and public sector productivity type/producer benefits	■ Estimated additional spending on 5G services in future years compared to alternatives, using estimated take up of services and willingness to pay for technological enhancements (price differential between 4G and 5G) ■ Projected increase in productivity in future years due to products / infrastructure developed in the programme. Value of IP/licensing deals/enhancement of project participant valuations	
Final evaluation	*Costs (up until 2025)* ■ DCMS funding and administrative costs ■ Contributions from public sector participants ■ Private sector contributions ■ Other contributions ■ Other private sector investment in R&D, network and service development, etc attributable to programme	*Up until 2025* ■ Value of DCMS contribution, etc (£) ■ Value of contribution of other public sector participants, etc (£) ■ Value of private sector participants contributions, etc (£) ■ Value of other funding contributions (£) ■ Secondary data and research with project participants and the wider ecosystem, etc	■ Update of literature review and baseline survey ■ Review and collation of the MI data and confirmation of likely final expenditure. ■ Qualitative interviews project beneficiaries ■ Construction of scenarios ■ Update of WTP survey Estimation of indicative BCRs of the scenarios, leading to an
	Benefits ■ Consumer benefits ■ Acquisition of qualifications	*Benefits* ■ Additional consumer spending on 5G services attributable to programme compared to projected	

Timescale	Costs and Benefits to be Considered	Metrics/Basis of Measurement	Data sources
	■ Updated estimates of observed and projected private and public sector productivity type/producer benefits ■ Knowledge spill overs	spend on 5G and alternatives available in its absence, probably based on econometric modelling approach ■ Increased output/earnings/tax receipts from individuals completing Masters' and PhDs due to programme funding net of opportunity and non-programme related costs involved ■ Revised scenarios of observed and projected productivity impacts in 'vertical sectors' and public sector attributable to programme. Value of IP/licensing deals, etc generated, enhancement in valuations of participating SMEs. From mix of quantitative and qualitative research. ■ Value of licensing income from 5G related patents outside telecoms sector, value of firms spun out into vertical sectors, etc.	initial potential VFM assessment

Annex 3 Detailed baseline evidence and findings

This annex presents the detailed evidence underpinning the baseline findings presented in Section 4.

A3.1 Technological development

The development of 5G equipment and devices hinge on the establishment of 5G standards[51], together with chipset and product development cycles. Standards 'frozen' to date allow only for the deployment of the 5G air interface alongside an existing 4G network. Following the agreement on the 3GPP Release 15[52] in July 2018 (the initial standalone 5G specification), equipment manufacturers are now expected to proceed with the development and production of standards-compliant network and terminal equipment.

The commercial availability of network elements for deployment is expected to follow subsequent 3GPP releases, but remains uncertain. Industry product availability typically follows 12-18 months after standards are frozen.

Access to fibre transport networks on an affordable basis for backhaul will be of paramount importance for 5G networks, reflecting the need for higher capacity. Fibre could also play a critical role in supporting the introduction of small cell networks and centralised Radio Access Network (RAN) architectures (DCMS, 2017).[53] At the time of this report, the UK had far less backhaul fibre available than many other countries, but Ofcom is taking steps to ease access for backhaul connectivity[54] and to the physical infrastructure of ducts and poles owned by BT[55] and DCMS funding programmes such as LFFN are progressing which involve a number of 'models' to help industry to extend fibre to the premise connections[56]. Furthermore, the FTIR proposes the changes that are needed to give most of the population access to 5G, connect 15 million premises to full fibre broadband by 2025, and provide full fibre broadband coverage across all of the UK by 2033.

A3.1.1 Standardisation and UK contributions to these standards

A3.1.1.1 Literature review findings

At a global level, 3GPP is the technical standards body developing 5G technical standards to meet International Telecommunications Union (ITU) requirements. The

[51] Interviews

[52] 3GPP 5G standardisation consists of two phases. Phase 1 (Release 15) to be completed by September 2018 tackles commercial needs, boosted performance for enhanced mobile broadband and some low latency applications. Phase 2 (Release 16) to be completed by March 2020 will cover all identified use cases and commercial requirements, together with future updates to mobile data.

[53] DCMS (2017). 5G. the next generation mobile communication standard that is set to transform business and society. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652263/DCMS_5G_Prospectus.pdf. Accessed on: 11 September 2018.

[54] Ofcom (2018), Review of spectrum used for fixed wireless services. Our decisions to enable future uses of fixed wireless links.

[55] https://www.ofcom.org.uk/consultations-and-statements/category-1/physical-infrastructure-market-review Accessed 29 January 2019.

[56] https://www.gov.uk/government/publications/local-full-fibre-networks-challenge-fund. Accessed on 24 October 2018.

ITU itself established high level requirements in its "IMT 2020" (International Mobile Telecommunications) specification.

The 3GPP standardisation process has two phases (Frontier Economics, 2018)[57,58]:

- Phase 1 (Release 15), completed in July 2018, addresses initial commercial needs, including increased performance for enhanced mobile broadband and low latency applications.
- Phase 2 (Release 16) expected by March 2020 will cover further identified use cases and commercial requirements, together with future updates to mobile data[59].

The standards will cover the following basic (bearer level) service areas:

- enhanced mobile broadband;
- machine to machine communications; and
- ultra-reliable and low latency communication.

Key technical elements of 5G standards will include:

- 5G New Radio (NR) used for the air interface – it is expected that this will increase spectral efficiency and coverage in comparison to 4G, though the extent of improvements in these areas relative to 4G technology remains as yet commercially unproven.
- Network Function Virtualisation (NFV) – this will enable the use of network functionality with commodity hardware instead of specialised equipment. It should be noted that NFV is proceeding anyway in the market and the value of such standards is questionable.
- Network slicing – this will allow the use of separate logical networks, meaning that use cases with dissimilar quality of service requirements can be deployed.

In addition, 5G is expected to be deployed in new radio frequency bands. This, in itself, offers the potential for additional capacity over previous cellular systems, and support for new use cases.

UK-based contributions to technical standards show leadership in the following areas (FCCG, 2017)[60]:

- Radio Access Technology 3GPP;
- Core Network Architecture and Protocols;
- vertical Industry solutions; and
- security and privacy.

[57] Frontier Economics (2018). UK MOBILE MARKET DYNAMICS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728816/Frontier_report_on_Mobile_Market_Dynamics.pdf. Accessed on: 11 September 2018.

[58] http://www.3GPP.org/release-15. Accessed on 24 October 2018.

[59] The University of Surrey 5G Innovation Centre standards and dissemination workstream across Phase 1 projects of the 5GTT may touch on this.

[60] FCCG (2017). UK strategy and plan for 5G & Digitisation - driving economic growth and productivity. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf. Accessed on 11 September 2018.

Work in technical standards bodies is often international in nature, with many of the major contributors being multinational corporations. It can be difficult to discern in some cases where national contributions lie. One approach for this could lie in rankings on R&D and patent contributions from national sources.

A3.1.1.2 Stakeholder consultation findings

Interviewees agreed that, in line with its scope and objectives, the 5GTT Programme is likely to have little to no impact on standards development[61], which tends to be driven by private firms. However, one stakeholder highlighted the contribution that UK-based participants have made to standards by producing new solutions for service orchestration. Another stakeholder noted that there are many UK-based experts involved in the standardisation process.

A3.1.2 R&D and patenting activity

A3.1.2.1 Literature review findings

The UK has been involved in significant research and development (R&D) activities related to 5G development across fundamental aspects of the communication stack and the user presentation, e.g. quality of experience, virtualisation, and system integration.

However, as with any R&D programme, the valuation of contributions can be indeterminate.

Systems integration is a distinct area from product development, though many large vendors offer professional services business units.

The 5GTT Programme has added to the stock of 5G knowledge and has provided £16 million in funding for the largest single academic project involving the University of Surrey, the University of Bristol, and King's College London to establish the world's first 5G end-to-end network. The UK5G body and the phase 1 projects are also contributing to the wider development of the UK R&D ecosystem.

Across 2013-2018, 135 5G-related R&D projects received Government funding according to the Digital Catapult's 5G mapping study.[62] The table below provides an overview of the key terms used to describe EPSRC and EU-funded public research grants relevant for 5G development.

Table A3.1 Top 5 classification terms for EPSRC & EU research grants awarded to UK organisations (2013-2018)

All projects	EPSRC	EU
SDN	Baseband / Signal Processing	NFV
NFV	Radio Frontend / RF	SDN
Heterogeneous Networks	Antenna	Network Slicing
Baseband / Signal Processing	Massive / MU-MIMO	QoS / QoE

[61] The 5GTT Programme will contribute indirectly to 5G standards through various projects. Results from projects will be shared with the UK5G Innovation Network Advisory Board, some of whom work with standards bodies. The 5G Innovation Centre at the University of Surrey is working with the six Phase 1 projects in a working group which looks at how they can more formally feed into standard setting bodies.

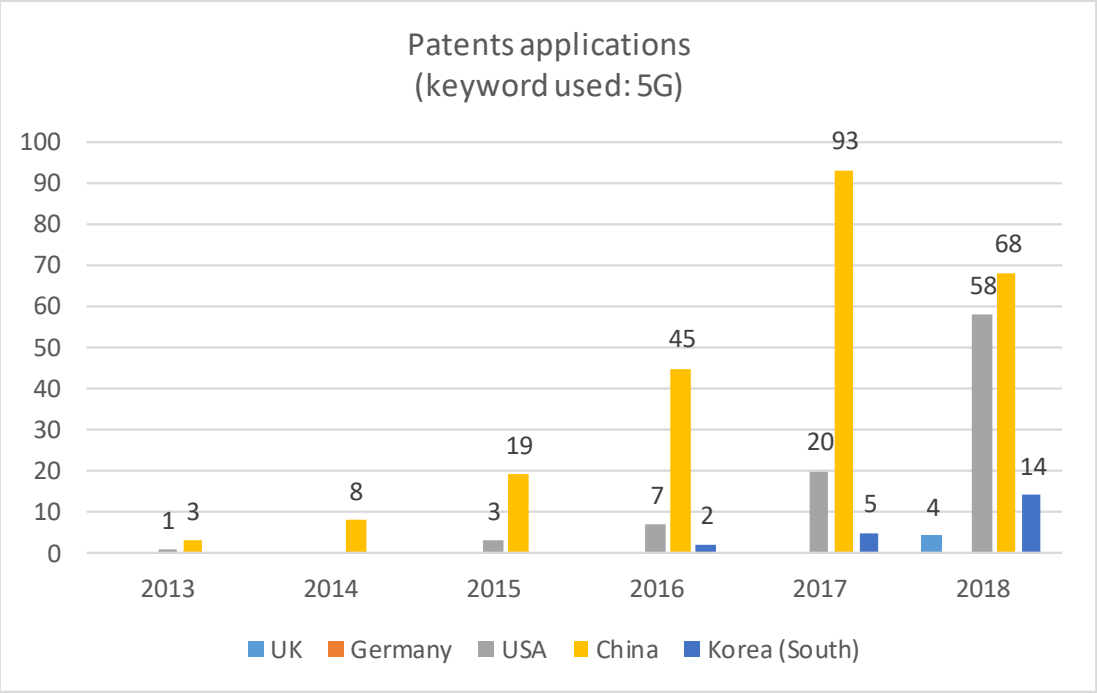
[62] Digital Catapult (2018), 5G Nation: The UK 5G Ecosystem 2018.

All projects	EPSRC	EU
MEC (Mobile Edge Computing)	SDN	System Integration / Validation / Simulation

Source: Digital Catapult

Using the keyword '5G' for a patent search, China, South Korea and the US dominate patenting activity, whilst patent applications from the UK and EU countries are rare.[63]

Figure A3.1 Patent applications including '5G' as key word, 2013-2018



Source: Espacenet, September 2018[64]

Whilst there is no comprehensive baseline evidence, research conducted for this study suggests that there has been a slowdown of UK industrial R&D in the fields of wireless and networking systems in recent years. However, this has been partially compensated for by the work of university research groups and institutes. For instance, the University of Edinburgh has developed several industrial collaborations with key stakeholders (a £5 million investment from Xilinx for semiconductor design, a partnership with Huawei for development of AI robotic systems supported by next generation wireless networks).

Ongoing relevant R&D activities involving the UK private sector include those below:

- According to the Digital Catapult's 5G mapping study, 28 UK-based companies are involved in R&D type activities directly linked to 5G technology or applications that will be enabled by 5G roll-out. This includes R&D in topics such as massive MU-MIMO, network slicing, RAN, NFV, mmWave, Media/AR/VR, optical networks, MAC/RRM, security and AI standardisation.

[63] The keyword search was undertaken using the European Patent Office's Espacenet, filtering for patent applications submitted between 2013 – 2018 by authors based in China, South Korea, United States, Germany, France and the United Kingdom. No analysis of patent citations, a proxy for relevance of individual patents, was undertaken.

[64] There were no patent applications including "5G" as key word from the UK between the period 2013-2017

- Other examples of industry-driven development activities include the creation of the 5G Innovation Centre at the University of Surrey, the "Bristol is Open" smart city platform that is using advanced networking technology from the University of Bristol, and the Ericsson 5G Lab at King's College London.

The UK also benefits from strengths in some R&D driven industries as below:

- Compound semiconductors - ten councils in the Cardiff Capital Region announced in 2017 that they are investing £38 million, together with the Welsh Government, in a cluster for compound semiconductors situated in Newport.
- 5G-enabled applications and the underlying technology – the Samsung R&D centre in Surrey has been involved in developing both types of applications.
- Some strengths in chip design are present within ARM based in Cambridge.

Some key R&D players have established themselves across the activities discussed above and form the 'core' of a UK network of 5G-related development activities. These include the University of Bristol, University of Surrey, King's College London, University College London, the Universities of Oxford, Lancaster and Edinburgh, and from the private sector Thales, Interdigital, BT, Samsung, NEC and Nokia.

A3.1.2.2 Stakeholder consultation findings

Stakeholders were reluctant to share information on their 5G-related R&D activities because of commercial sensitivities. Most of the stakeholders who expressed an opinion considered that there is an important level of such activity within the UK. It was noted that a constraint on further R&D exists due to uncertainty in relation to spectrum issues and investment cases.

A3.1.3 Remaining development needs and requirements

The literature review and interviews did not point to significant development needs which are specific to the UK as 5G is seen as a global technology and individual components for infrastructure, devices and the application layer will need to be developed in accordance with 3GPP standards. Aspects that have proved challenging are latency, capacity, reliability and consumer applications (including VR and AR).

A3.1.3.1 Literature review findings

Previous research by Arthur D. Little in 2017 suggests that the following aspects represent priorities for development in international terms[65]:

- The creation of an application ecosystem – the success of 5G depends to a large extent on the existence of an ecosystem of applications that use 5G connectivity; for this reason, telecom operators should seek to build partnerships with application and service providers.
- The preparation for small-cell 5G network – this is an area where there are differing opinions. It will require access to possibly many physical locations where such demand is likely to exist although these will likely be concentrated into certain geographical areas (hot spots) / venues (e.g. parts of city centres, public places which host large numbers of people, arenas / stadium locations). There is unlikely

[65] Arthur D Little (2017). 5G deployment models are crystallizing. Available at: https://www.key4biz.it/wp-content/uploads/2017/07/ADL_5G_Deployment_Models.pdf. Accessed on: 11 September 2018.

to be a general national roll-out of small cells as provisioning will only be economically viable where sufficient demand exists.

- The development of millimetre wave ("MMWaves") cells needed for the low latency and high bandwidth demands predicted as necessary to support future services. Ofcom released a Call for Inputs in July of this year, the output from which is yet to be seen, including Ofcom's thinking on the release of the 26 GHz spectrum. However, release of spectrum is unlikely before the early 2020s. There is already mmWave spectrum at 28 GHz available (e.g. Arqiva and Vodafone licences) and 5G fixed wireless access trials have been proposed in this band).
- The preparation of an increased number of macro cells – a power supply and fibre link will be required for the macro cells.
- The development of fixed-access fibre networks – Gigabit capacity is expected to be required and sector carriers will need to backhaul these traffic levels in aggregate. There are only a couple of technologies able to deliver this if the distances are of more than several hundred meters, one of them being fibre, which is not extensively available across the UK currently. The other technology that can deliver this is DOCSIS (co-axial cable)**.**
- The development of cloud-based core network solutions – these will allow telecom operators to configure services in a flexible and agile manner.
- The preparation of the computing and networking infrastructure – computing and data centre capability will be highly important to enable 5G services, which is why established and new operators will need to develop and upgrade their computing and networking infrastructure. In broader terms, the UK skills base is seen to require further improvements in the following areas which are considered critical for developing and exploiting 5G-enabled opportunities.[66]
- ICT research and development community – skills related to the development and comprehension of critical infrastructure and new technology 5G.
- Engineering talent able to develop future 5G technology.
- Development of digital applications and software.
- Cross industry and sector participation, to ensure development of new vertical 5G-enabled services.
- Security and safety – strong 5G knowledge that ensures a good comprehension and control of networks, as well as safety and security for users.
- Systems integration or digital value system.

A3.1.3.2 Stakeholder consultation findings

Some of the issues found in the literature were also mentioned during the stakeholder consultation. These include:

- the importance of creating an application ecosystem;
- testing of millimetre wave band devices against evolving standards; and

[66] FCCG (2017). UK strategy and plan for 5G & Digitisation - driving economic growth and productivity. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf. Accessed on 11 September 2018.

- the development of better cloud-based solutions.

A3.2 Regulatory environment

A3.2.1 Enabling regulatory factors

A3.2.1.1 Literature review findings

During the literature review, the following enabling regulatory factors that might facilitate the development of the 5G economy were identified:

- On a general level:
  - enabling firms to make long-term investments and R&D commitments;
  - stimulating public-private partnerships on development of 5G standards;
  - ensuring regulation that keeps pace with the rate of innovation, for instance on intellectual property protection. The challenge for policy-makers will be to ensure appropriate 5G regulation without stunting innovation[67]; and
  - drawing a globally-harmonised policy plan that would avoid fragmentation, and a localised plan that would need to take local priorities into account[68]. Operators and policy-makers need to be able to create the right balance between global harmonisation and regionalised plans.
- In the UK specifically:
  - over the past few years, regulations on planning and site access have been reformed to ease the deployment of communication infrastructures in England. Such reforms are expected to mainly facilitate deployment in rural areas. Similar reforms are under consideration in Northern Ireland and Wales as well.[69]

A3.2.1.2 Stakeholder consultation findings

The regulatory enablers mentioned by stakeholders, in order of perceived potential impact, include the following:

- An effective planning regime in place – this will be crucial to enable the widescale roll-out of small cells. Some stakeholders mentioned that the planning system in the UK is more restrictive than in other countries their companies operate.
- The way spectrum allocation is handled in the future – this is seen as either a large enabler or inhibiting factor. In relation to trial activity, views on Ofcom's spectrum policy expressed during interviews suggest that updates to non-operational licences have helped the speed and effectiveness of the allocation process. Overall, Ofcom is seen to have taken a very proactive and helpful stance in

[67] IHS (2017). The 5G economy: How 5G technology will contribute to the global economy. Available at: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf. Accessed on: 11 September 2018.

[68] GSMA (2017). The 5G era: Age of boundless connectivity and intelligent automation. Available at: https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download. Accessed on: 11 September 2018.

[69] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf. Accessed on: 11 September 2018.

allowing access to sub-6GHz and in mm wavebands. For more permanent deployments, there have been calls for Ofcom to make 5G spectrum available to a wider range of market players through more flexible licensing arrangements.

- Spectrum sharing and spectrum brokering – this was highlighted by several interviewees as a key enabler to facilitate new business models outside the current MNO models.

A3.2.2 Inhibiting regulatory factors

On the other hand, several inhibiting factors were identified and may hinder the 5G deployment process in the UK, as demonstrated through the literature review and stakeholder consultation.

A3.2.2.1 Literature review findings

The main inhibiting regulatory factors found in the literature are the following:

- The difficulty in getting access to suitable locations for infrastructure installation and to backhaul[70]. This is a persistent problem faced by operators. Such issues have already been recognised with the proposed reform to the Electronic Communications Code (ECC) and changes to the English planning regime. Persisting impediments are various and range from aesthetic concerns and other kinds of objections and complexities to prohibitive rental costs.
- Spectrum regulation – ensuring sufficient spectrum availability to the 5G industry is essential and further actions are needed to make more spectrum available to UK operators.
- The current Net Neutrality rules – 5G network operators will be able to provide dedicated virtual networks over a common network, by deploying network slicing. Nevertheless, currently all traffic on the internet needs to be treated equally due to the 'Net Neutrality Regulation', and operators are concerned that such rules might hinder 5G development and investments. Some operators therefore believe that current Net Neutrality rules create uncertainties concerning the 5G return on investment.

Current views are that the ECC does not impede 5G slicing models.

A3.2.2.2 Stakeholder consultation findings

The stakeholder consultation findings were largely similar to findings from the literature review. The main inhibiting regulatory factors include:

- The difficulty in getting access to suitable locations for infrastructure installation and to backhaul. However, stakeholders interviewed were largely optimistic that the proposed reform to the ECC could help to reduce future barriers relating to acquiring sites, but thought it was too early to judge whether these changes will have a substantial positive impact.
- Spectrum regulation. Interviews with stakeholders highlighted that some are concerned about the current approach to auctioning spectrum, including the

[70] FCCG (2017). UK strategy and plan for 5G & Digitisation - driving economic growth and productivity. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf

associated costs. The effect of this auctioning approach resulting in high costs may delay 5G roll-out since existing mobile network operators have less remaining capital to invest in new infrastructure. It also means spectrum is sold on a national basis. Since large operators have a priority to achieve good returns for their investment in spectrum, they are more likely to focus their investments in the most profitable urban or high-density areas and neglect to use their spectrum in large areas of the country that are rural. Furthermore, these high costs could be discouraging potential new market entrants, potentially inhibiting the development of new start-ups and innovative solutions using 5G.

- A possible mobile divide. A further concern voiced by stakeholders was that of a possible mobile divide, as the current model is seen to incentivise roll-out largely in urban or suburban areas, and provides no incentives for rural areas. Making spectrum available for shared use by fixed wireless operators might be able to resolve this challenge.

A3.3 Risks and enablers for 5G roll-out

The subsections below provide narrative on what stakeholders consider the key risks and enablers, based on evidence collected during the baselining exercise. The focus here is on the main risks and enablers that, according to the literature review and interviews undertaken, would have a substantial effect on 5G roll-out. Stakeholders were consulted in relation to risks to the 5G Testbed and Trials Programme specifically, and not 5G roll-out risks.

It should be considered, however, that risks and enablers might overlap and interact, and indeed an enabler might become a risk and vice versa.

A3.3.1 Enablers

A3.3.1.1 Literature review

Concerning 5G roll-out enablers, the most frequently raised issues throughout the literature review have been the following:

- Networks asset sharing, which may be either a risk or an enabling factor.
  - 5G will involve additional costs for MNOs and other wireless operators compared to previous technologies, especially due to small cells deployment. Therefore, allowing sharing of network assets at different levels of the network architecture, e.g. physical sites, electronics and backhaul, may enable providers to reduce investment costs.
  - It might be possible that sharing arrangements are not extended further as a result of 5G, as 5G may require physically larger antenna systems on a mobile mast, therefore making sharing less practical.
- Standards are also expected to be an enabling factor for 5G roll-out.
  - 5G deployment appears likely from 2020 onwards, when standards providing the set of 5G capabilities will be finalised.
  - 5G will require larger antennas and new product volume cycles.

- Ensuring an acceptable return on investment – this is a factor enabling large scale investments. It could be achieved for instance through a supportive regulatory policy framework[71].
- The rapid roll-out of, or access to, dark fibre – this could be a key enabler for backhaul to support 5G deployment, to meet capacity demands from both existing and new cell sites. In this context, the Ofcom key proposals were for unrestricted access to ducts and poles, and not dark fibre. That being said, Ofcom proposed that BT should provide this dark fibre access at a price that reflects its costs.

A3.3.1.2 Stakeholder consultation findings

The stakeholder consultation findings were broadly in line with the literature review findings. Additional enablers mentioned by interviewees include:

- An ecosystem of start-ups – by demonstrating new applications which may not be possible in other countries yet, this ecosystem of start-ups could be an enabler in pushing forward the 5G agenda in the UK in terms of public support and private investment. The UK has a lot of software start-ups working in areas such as network software communication management, service automation, artificial intelligence, machine learning and data analytics which will become increasingly important with 5G in the future.
- Collaboration within the ecosystem – the willingness of operators to collaborate on projects can play an important role in pushing 5G deployment. This depends on whether competition among operators will stifle collaboration or operators will consider that the benefits of collaboration outweigh the disadvantages. International collaborations potentially looking beyond Europe could also constitute an enabler.

A3.3.2 Risks

A3.3.2.1 Literature review findings

Throughout the literature review, several key risks were identified. These include:

- The size of investments required to provide the necessary 'backhaul' and small cells installations for 5G roll-outs.
  - 5G networks will require high 'backhaul' capacity to transmit data from cells sites throughout the network back to the operator's core network.
  - 5G operators will need to deploy new small cells to meet localised demand, and these small cells will need to have access to suitable backhaul solutions.
- The current lack of infrastructure for small cells deployment. This risk is related to the need to deploy small cells mentioned above.
  - This might make necessary investments for 5G deployment more important compared to other countries where there is already a dense network of small cells towers in place.[72]

[71] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf

[72] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf. Accessed on: 11 September 2018.

- For millimetre wave, the deployment of small cells will depend on the availability of things like lampposts and public buildings rather than traditional towers, so it will be important for local government and communities who own these assets to recognise the benefits of 5G.
- The necessary 'backhaul' and small cells installations demonstrate the high investment costs that are necessary in the short term, which is considered difficult for the market to deliver in conditions of uncertainty about consumer demand and price models.

- Specific risks related to a neutral hosting model and the concept of network sharing.
  - While network sharing between MNOs can result in lower fixed costs and improved coverage, it needs to be supported by clear contractual arrangements between parties. Therefore, parts of the network might be excluded from the sharing agreement where interests diverge.
  - Cost savings from network sharing might be less extensive than the fixed cost saving achieved by having one vertically integrated player.
  - Competition should not be compromised through resource sharing.
- Consumer take-up: many users may find 4G sufficient to meet their needs, as 4G still provides an acceptable quality of service in cells which are not congested (in cases where 5G services may be rendered over 4G networks). This could result in an initial lack of demand for some 5G applications and services; therefore, the demonstration of 5G-specific use cases that will drive consumer demand will be a key step towards 5G roll-out.

A3.3.2.2 Stakeholder consultation findings

Stakeholders were consulted regarding risks that could represent an impediment for the success of the 5G Testbed and Trials Programme. The risks mentioned were:

- Internal risks (the Programme can influence these risks to a certain extent):
  - The potential for projects not to produce sufficient substantial learning – there was a concern amongst some interviewees that there is currently a lack of specific project objectives, with a potential risk that projects funded by DCMS focus on similar showcases to activities overseas.
  - The limited involvement of large vendors in phase 1 DCMS projects was seen as a further related risk, as there was a perception that Nokia, Ericsson and Samsung are not involved to a sufficient degree, and the Huawei standardisation teams involved reside largely in China and Germany.
  - Key players responsible for rolling out 5G infrastructure having limited involvement in the DCMS-funded 5G trials. Other international markets have managed their testbeds and trials differently. For example, in Italy the operators have led the initiatives. That approach provides an opportunity for those markets to get slightly ahead of the UK in accessing early 5G pre-commercial equipment which has potentially accelerated the trial in that market ahead of the UK. There is a view that operators who are going to be building and running the infrastructure in the UK are going to need to be more involved in the programme in the future to make progress in deployment.
- External risks (the Programme has no or limited influence over these risks):

– Competition in the market might be stifling collaboration within the ecosystem and result in duplication of efforts. Neutral hosting models might be a way to ensure competition whilst at the same time ensuring collaboration on infrastructure investments and roll-out. Because there is competition to obtain government funding to continue building new 5G testbeds, there is a risk that too little attention will be placed on the existing testbeds, which would be a waste of valuable resources.

– A risk that large vendors do not see small publicly-funded projects within the 5GTT as a key opportunity for them, and therefore commit their equipment and technology to large network operators rather than smaller trials. This was the experience of at least one interviewee. Furthermore, small projects may struggle to convince their partner network operators to provide them with access to spectrum to run their trial. Given that these issues have already emerged with small projects, they may become a larger issue when the DCMS testbeds are scaled up at the same time and in the same places as the network operators are deploying commercial networks.

A3.4 Industry's development and roll-out plans

The subsections below provide details on the deployment trajectories in the UK and investment estimates related to these deployment trajectories. An overview of models and trajectories for 5G roll-out of international competitors is also presented,

A3.4.1 Deployment trajectories in the UK

A3.4.1.1 Literature review findings

The literature review revealed that 5G is likely to be delivered through a combination of large and small cells.

Overall, the literature review suggests that a combination of three deployment scenarios is most likely, depending on the environment being connected.[73]

- indoors: indoor small cells in commercial buildings.;
- outdoors in dense urban areas: existing macrocell base stations with outdoor small cells provided where demand justifies the addition of capacity; and
- outdoors in economically challenging areas: in challenging outdoor areas it is unlikely that there will be new 5G specific build if there is not already an existing base station footprint. However, there is the possibility that 5G provides opportunities for new solutions to meet connectivity challenges in other areas. 5G could be used to provide fixed wireless access in rural areas where fibre to the premises is not possible.

MNOs are likely to be the first to deploy 5G networks and services, but there appears to be potential for new types of providers to emerge, such as sector-specific private networks or new types of intermediaries. Over time, MNOs are likely to use 5G-enabled innovations such as 'network slicing' to offer new services to industry sectors. Connectivity solutions linked to a specific business case might be delivered at very localised areas or by private networks. Verticals may indeed choose to deploy their

[73] GSMA (2017). The 5G era: Age of boundless connectivity and intelligent automation. Available at: https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download. Accessed on: 11 September 2018.

own private networks rather than setting arrangements with MNOs; companies might also act as intermediaries and provide infrastructure to wireless network providers in a particular location, such as a factory. However, since the business case for 5G roll-out is still uncertain, it is difficult to draw conclusions concerning involved actors as well as providing a timeframe.[74]

Indeed, there are various paths operators may follow to develop their 5G deployments. Different approaches may lead to changes in the relationships between operators, or in a reconfiguration of the core networks.[75]

Some figures on the likely impact of 5G in the literature include:

- A study conducted for the European Union showed that a EUR 7bn (approximately GBP 6.2bn) investment in 2020 in the UK to roll out the 5G network can create over EUR 16bn (GBP 14.2bn) of benefits in GDP terms and over EUR 172bn (GBP 153bn) in employment terms in 2025. The result was obtained through an input-output analysis, examining inter-industry relationships of sales and purchases of 38 industrial sectors (European Commission, 2016b).
- IHS estimates suggest that, on a global basis, 5G will enable USD 12.3 trillion (GBP 9.6 trillion) of economic output, representing about 4.6% of all global real output in 2035. This result was obtained by modelling industry investments and impact on productivity from expected use cases (IHS, 2017).
- A study published by the Australian Government suggests that 5G is likely to improve MFP growth across the economy by an additional AUD 1,300 to AUD 2,000 (GBP 720 to GBP 1,100) in GDP per person after the first decade of roll-out. This estimation does not fully account for the consumer and non-market benefits and it is therefore expected to be conservative. Indeed, 5G roll-out may lead to cost and time saving thanks to 'smart cities' or improved services, such as health (Australian Government, 2018).

Concerning the trajectory for future 5G roll-out, the literature suggests that there are four phases:

- Phase 1 - Research and Development to develop the 5G technology;
- Phase 2 - Trials and Test Beds, aimed at further developing the technology and testing solutions while working with verticals and use cases (healthcare, transport, etc.);
- Phase 3 - Early commercial trials to scale and create early deployment infrastructure; and
- Phase 4 - Full commercialisation.

Currently, the focus is on phase 1, as the technology building blocks still have to be fully defined. However, the UK is entering phase 2 by defining the end use cases, and many testbeds and trials are underway, either supported by DCMS or driven by industry.

Following commercial deployment, it is expected that 5G roll-out will take place among the most populated areas first. MNOs are expected to deploy 5G first on existing sites to alleviate network congestion where needed and efficiently meet the growing

[74] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf. Accessed on: 11 September 2018.

[75] Arthur D Little (2017). 5G deployment models are crystallizing. Available at: https://www.key4biz.it/wp-content/uploads/2017/07/ADL_5G_Deployment_Models.pdf. Accessed on: 11 September 2018.

demand for data, according to stakeholder interviews. The proportion of population covered annually is expected to decrease over time as the unit costs of delivery rise for less populated areas. Therefore, within the first year of 5G roll-out, city centres of urban areas are expected to access 5G infrastructure; suburban areas are expected to access 5G coverage between 2022 and 2023; rural areas are likely to access 5G networks between 2024 and 2030.[76]

However, the pace of 5G roll-out will depend on a variety of factors which may influence deployment trajectory, for instance the chosen business and overall market models. Some stakeholders also highlighted that the evolving policy environment will to some extent dictate how MNO deployment plans will develop.

Indeed, 5G roll-out might not happen under the current market model, and alternative trajectories have been outlined throughout the literature:[77]

- A Single Wholesale Network (SWN).
  - A SWN would remove the costs associated with duplication of network infrastructure, which can occur when various operators deploy their own networks. Under this scenario, the cost of extending coverage should be lower. However, competition tends to incentivise cost reduction and roll-out through innovation.
  - A neutral host model would change the competitive dynamics experienced by equipment manufacturers as well as MNOs.
- The Market Expansion Model.
  - This model proposes the introduction of a higher number of network operators in the market. First, the model sees the introduction of neutral hosts for provision of connectivity in specific areas; second, it would facilitate bespoke entry into the market by a wider range of players alongside the existing MNOs. Such a path is expected to stimulate the development of more innovative solutions and specific use cases. The Market Expansion Model is expected not only to deliver increased competitiveness, but also to optimise 5G coverage through the neutral hosts model. Currently, MNOs do not provide the same level of coverage everywhere, and with 5G roll-out it is expected that in urban areas – where operators will densify their networks – hosting infrastructure will be at a premium. With supportive Government policy, neutral hosts could cover areas where commercial MNOs have no incentive to roll-out their networks or where issues in securing coverage are likely to arise. Furthermore, with more players entering the market, 5G use cases and innovations may not be limited by MNOs' investment decisions.
- Market Consolidation Model.
  - This model involves a reduction in the number of operators through mergers. This model would likely be industry-driven, with a hypothetical merger proposed as a starting premise. There have been two cases of proposed consolidation in the UK: T-Mobile and Orange, which led to EE, which was cleared, and a proposed merger between O2 and Hutchison 3G, which was blocked. The merger between T-Mobile and Orange was cleared on the

[76] Oughton and Frias (2017). The cost, coverage and roll-out implications of 5G infrastructure in Britain.

[77] Frontier Economics (2018). UK MOBILE MARKET DYNAMICS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728816/Frontier_report_on_Mobile_Market_Dynamics.pdf. Accessed on: 11 September 2018.

condition of the divestment of spectrum and that the new entity had sufficient spectrum to get a head-start on competitors in the deployment of 4G.

A3.4.1.2 Stakeholder consultation findings

Stakeholders emphasised during interviews that clarifying various definitions of 5G is important when discussing potential deployment trajectories and forecasts. For instance, 5G deployments by MNOs are likely to start with an evolution of 4G technology before being followed by a major step-up in the form of 5G new radio, which is a completely new air interface.

Some stakeholders interviewed stressed that a network of small cells will be indispensable to provide sufficient capacity in high-traffic areas such as city centres, local high streets, factories, and sports and entertainment venues.

During interviews, stakeholders were asked how they thought 5G roll-out might affect the structure of the mobile telecom and fixed lines sectors. Some interviewees thought that due to the competitive nature of the mobile sector in the UK, the large investments required to deploy 5G could potentially alter the current structures. One group of stakeholders thought that the roll-out of 5G could lead to consolidation between the fixed line and mobile network operators to improve the way a connectivity service is delivered to the end user if mergers or acquisitions are approved. This convergence would be beneficial due to complementary assets (the network architecture of 5G requires fibre transport) and the potential cost savings associated with rolling out this new infrastructure in collaboration.

The roll-out of 5G could potentially lead fixed-line operators to concentrate their future investment and roll-out of fibre primarily in urban areas. Interviewees largely thought that fixed wireless consumption of 5G connectivity will be predominantly a rural use case rather than an urban one. Mobile operators and fixed wireless operators could be key players in helping to replace fixed line connections in rural settings where it is particularly expensive to deploy fibre.

A3.4.2 Investment estimates

A3.4.2.1 Literature review findings

Regarding investments needed for 5G roll-out, an analysis performed by Frontier Economics and based on Vodafone estimations for 2017/2018 for their operations in major European markets (including the UK), has showed that only 18% of capital expenditure was incurred for new mobile capabilities. Assuming that the fraction of capex spent on new mobile capabilities was similar across the UK industry, the envelope for expenditure on 5G RAN upgrades is expected to be around £625 million a year, about a quarter of total capital expenditures for mobile operators. Other analyses show that the capital expenditure per operator could be significantly higher, around 50% of the total annual capex, i.e. £1,250 million a year (Frontier Economics, 2018).

A significant amount of investment is expected to come from operators: indeed, a key driver for investment is believed to be network-based competition, as competition between different networks is a proven way to drive innovative services. Research on 3G suggests that, in countries with network-based competition, coverage was 36% higher compared to countries served by a single network. Moreover, being at the

forefront of 5G deployment might attract inward investments and create export opportunities for UK companies.[78]

As a matter of fact, data on capital investments from MNOs show a generally increasing trend. However, it should be noted that overall capital expenditures cover a wide range of investments, including replacing existing assets and adding new capacity, as well as introducing new capabilities.

Concerning public funding, the Government has committed £740 million through the National Productivity Investment Fund (NPIF) to support the next generation of digital infrastructure.

A3.4.2.2 Stakeholder consultation findings

Based on interviews with stakeholders, key barriers to investment in 5G currently include uncertainties about initial consumer demand for enhanced mobile broadband, since many consumers already receive a good quality of network service and they are typically driven by price. There are also uncertainties about longer term use cases and therefore new revenue streams that 5G could open up, and the returns on investment that could be achieved. Currently, there is a lack of evidence about the efficiency gains 5G might bring in certain sectors; attracting business users and verticals to invest in 5G will in many cases require strong evidence that their requirements for a high reliability and quality of service will be met.

According to interviewees, potential investors are also facing supply-side constraints such as insufficient access to equipment and a lack of 5G-capable devices on the market. Access to spectrum was cited frequently by interviewees as a key barrier, since speculative investment before companies know what spectrum they can use is too high risk.

Key drivers for investment in the UK could include a more flexible regulatory framework that develops in line with the technology, according to interviewees. For instance, opening spectrum up to connectivity trading could attract new investment from businesses.

A3.5 Expected future take up

The GSMA data we analysed covers the UK, as well as a few other countries that have been identified as advanced in terms of 26GHz band availability[79], as well as countries advanced in 5G trials.[80] We focussed on data starting with Q4 2019 the earliest for which 5G forecasts are available. Forecasts were available in general until Q4 2025. The data cut-off was mid- August 2018.

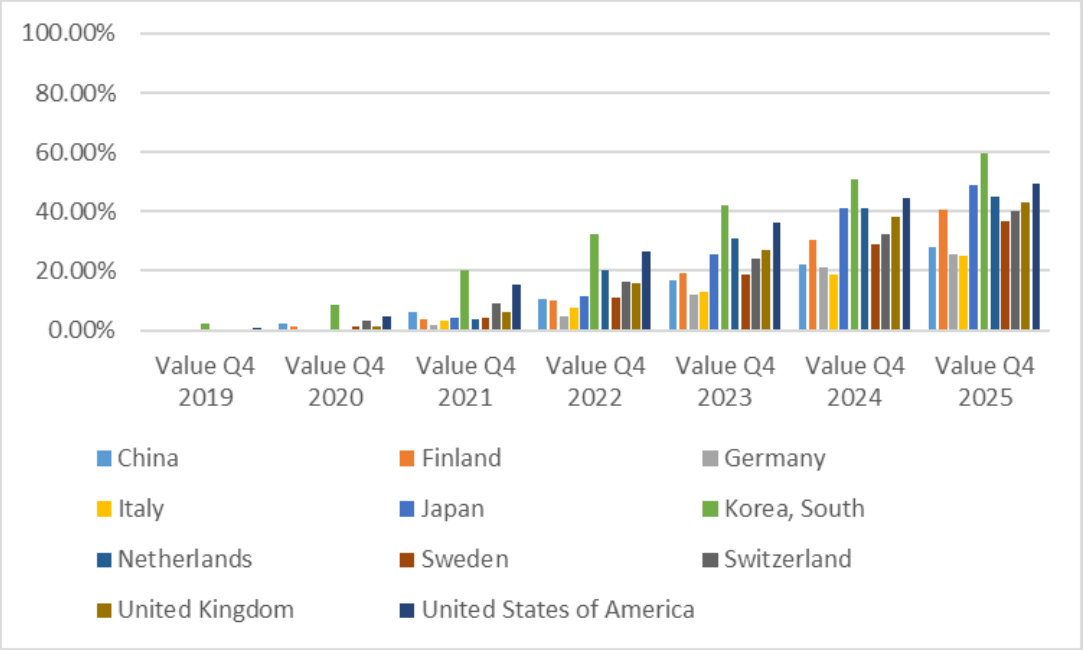
As the chart below shows, in the UK, the percentage of 5G connections (excluding licensed cellular IoT) is foreseen to be on a continuous growing path starting with Q4 2019. UK growth of 5G connections is forecast to pick up slightly slower than in the United States, South Korea, Germany in 2020 but by 2025 is forecast to reach 43% of all connections.

[78] Frontier Economics (2018). UK MOBILE MARKET DYNAMICS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/728816/Frontier_report_on_Mobile_Market_Dynamics.pdf. Accessed on: 11 September 2018.

[79] Finland, Germany, Italy, Netherlands, Sweden and Switzerland.

[80] Japan, South Korea and China as well as the United States.

Figure A3.2 Forecast of percentage of 5G connections across some of the most 5G advanced countries



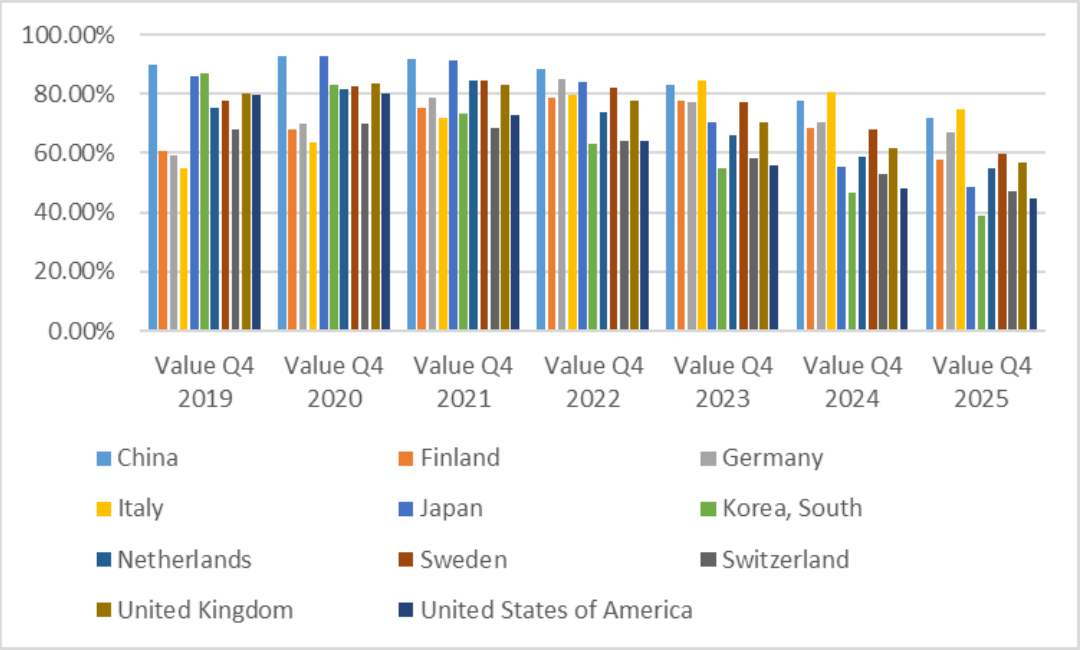
Source: GSMA, © GSMA Intelligence (2018)

While 5G connections will be growing in the UK, other technologies will witness an opposite trend. The proportion of 4G connections is projected to gradually decrease from 2021 to 2025. The share of 3G connections is expected to decrease from late 2019, with no 3G connections left in 2025 in the UK.[81]

[81] Please note that the GSMA forecasts are continuously reviewed and adjusted where appropriate on an operator by operator basis taking into account factors such as:

- Announced launch dates and roll-out plans
- Regulator obligations
- Latest developments in technology and specifications
- Operator trials
- Spectrum allocation
- Market opportunities

Figure A3.3 Forecast of percentage of 4G connections



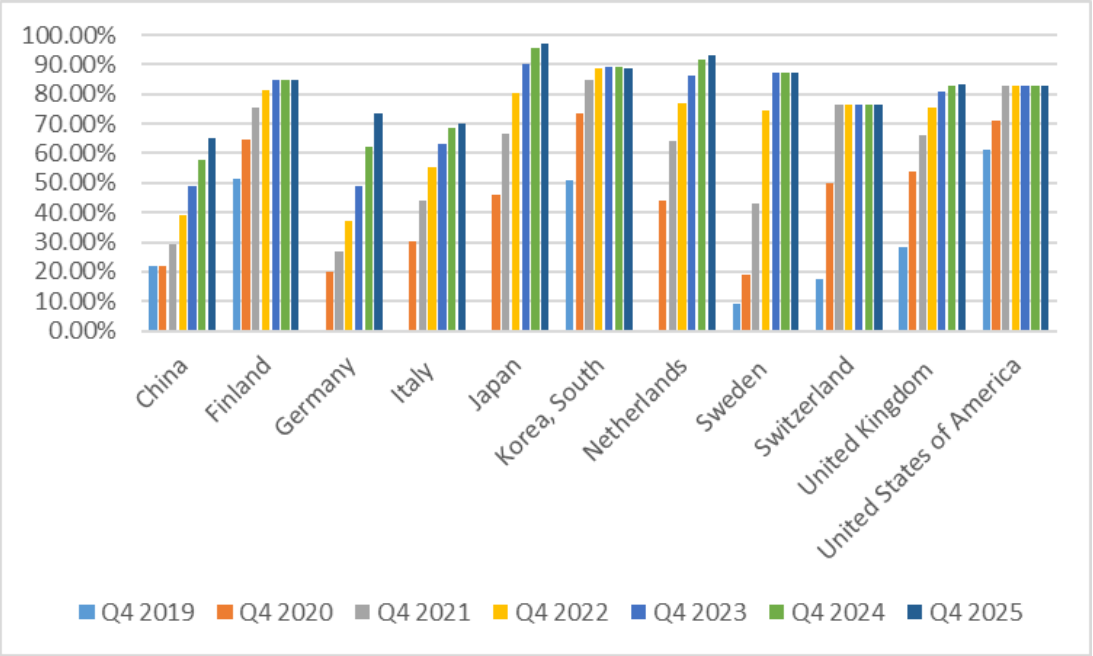
Source: GSMA, © GSMA Intelligence (2018)

It is difficult to predict 5G network coverage by population in the UK with certainty. For instance, the GSMA forecast points to an increasing trend, with ~83% of the population having 5G network coverage by Q4 2025. However, forecasts are, by their nature, assumptions-based and, in this context, there is uncertainty around future 5G network coverage given the lack of consensus on the number of small cells required for 5G, the level of infrastructure sharing, and the outcomes of future spectrum auctions. Furthermore, the uncertainty about the demand for use cases and business models make it difficult to predict MNOs' level of future investment. The analysis undertaken by Frontier Economics[1] to support the DCMS's Future Telecoms Infrastructure Review indicates that whilst rolling out 5G on a mid-2020s timetable on existing sites is feasible assuming that MNOs will collectively invest around £1 billion per year, rolling out a more extensive 5G network that meets the needs of all potential use cases, may take considerably longer.

According to the GSMA, however, the United States, Finland and South Korea are expected to have a higher population coverage initially, potentially a function of varying degrees of urbanisation and available backhaul infrastructure.

In 2019, the United States and Finland are the countries expected to have the highest 5G network coverage by population. By Q4 2025 the situation is expected to change with Japan and the Netherlands forecast to have the highest 5G network coverage by population, both more than 90%.

Figure A3.4 Forecast of 5G network coverage by population



Source: GSMA, © GSMA Intelligence (2018)

It is also of relevance to consider the launch dates of the current 4G network across countries, as this might influence the remaining lifetime of existing networks and business case for introducing 5G.

In the UK, the 4G network was launched in 2012 by EE (BT), followed by the launches of Vodafone, O2 and 3 in 2013. The latest launch of a dedicated network was by Vodafone in 2017, showing that there is extensive room for the 4G network to be further exploited in the UK.

Some countries, such as Japan, South Korea, Germany and the United States, had launched their 4G networks up to 7 years earlier (see table below).

Table A3.2 4G network launch date

Name of country	4G launch date
Japan	2009
South Korea	2006
Finland	2010
Italy	2012
Switzerland	2012
Netherlands	2012
Germany	2010
United States	2010
China	2013
Sweden	2009

A3.6 International take-up

A3.6.1 Technology development

At global level there is an interest in 5G and different countries have embarked on different approaches related to 5G deployment.

A3.6.1.1 Literature review findings

Apart from the UK, some countries have already made a start trialling or launching 5G services. A few examples include (Ofcom, 2018)[82]:

- South Korea – there is strong competition among a couple of operators who are competing to be the first to launch a 5G network. Mobile operator Korea Telecom in collaboration with other players showcased a 5G network during the Winter Olympics in PyeongChang. SK Telecom has purchased spectrum in the 3.5 GHz and 28 GHz frequencies to support its 5G deployment plans.
- United States – AT&T is carrying out 5G trials in a few US cities and has plans to launch 5G services in 2018. Another US operator, Verizon, plans to launch commercial 5G FWA broadband in up to five US cities in 2018, while T-Mobile has plans to deploy 5G-branded mobile services in 2019 (with the 600MHz band). However, the US market also presents some barriers, including the issue of local and municipal government zoning authority over cell towers and base stations. This means that, in practice, delays with planning permits can occur when deploying the necessary physical infrastructure.
- China – the telecoms provider ZTE forecasts that a 5G network will be available commercially in 2020, while China Telecom is working on 5G testing base stations, envisaging a 5G commercial launch in 2020. China Unicom have announced its first 5G testbeds in Beijing in August 2018. The Chinese Ministry of Industry and Information Technology stated that 5G could account for 3.2% of China's entire GDP in 2025 and create 8 million jobs[83].
- Japan – NTT, one of Japan's leading operators, is planning to offer commercial rate 5G services during the 2020 Summer Olympics. The company, together with other companies, worked on a trial where artificial intelligence, a drone with an HD 4K camera and smartphones were used. Other trials involving railway routes, autonomous vehicles, and other use cases have been undertaken by NTT, SoftBank and KDDI between 2016-2018, and all three operators aim to roll-out 5G at a commercial scale in 2020.
- Spain – Telefonica is trialling 5G technology, use cases and business models in Segovia and Talavera de la Reina, initially as an enhancement to 4G networks that will transform into standalone 5G networks and towards 2020 as fully operational 5G testbeds.
- Germany – a few operators have united their efforts to build a 30 kilometre test track for research and development of 5G infrastructure and applications, and Deutsche Telekom established a dedicated trial site in Berlin in early 2018.

[82] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf. Accessed on: 11 September 2018.

[83] http://www.chinadaily.com.cn/a/201706/29/WS59bbfa6fa310ded8ac190d4e_2.html, Accessed on 1 September 2018

A3.6.1.2 Stakeholder consultation findings

Interviewees agreed that the countries the study team identified in the literature review were the most advanced in terms of 5G trials and services. Moreover, they were mostly of the opinion that the US and Asian countries (China, Japan and South Korea) appear to have a more significant programme for 5G than European countries.

A3.6.2 Industry's development and roll-out plans

A3.6.2.1 Literature review findings

The literature review has shown alternative models and trajectories for 5G roll-out for competitor regions that have been reviewed.

Industry data from GSMA suggests that 5G networks are forecast to cover around a third of the global population by 2025, with adoption reaching 1.1 billion connections, and 5G mobile broadband connections will exceed 12% of total mobile connections in about the same time-frame. GSMA data suggests around 100 million 5G connections worldwide by 2021, around 0.3 million in 2022, around 0.5 million in 2023, around 0.8 million in 2024 and 1.1 billion in 2025.[84]

It is likely that before 2020, mobile operators will invest $700 billion in mobile networks and infrastructure worldwide, and further uplifts in investment are likely to happen after 2020, as operators roll-out 5G networks. [85]

South Korea can be considered a frontrunner in 5G-network deployment. South Korean operators are widely expected to launch commercial 5G services in 2019.[86]

The US and China are expected to dominate 5G related R&D and capex investments, with estimates of about $1.2 trillion and $1.1 trillion respectively until 2035. It is estimated that US investments will account for about 28% of global 5G investment and Chinese investment for around 24% during this period. Overall, the 5G value chain will drive an output of $3.5 trillion, and 22 million jobs will be created, most of which will be in China. The US and China are therefore expected to be among the first countries deploying commercial 5G: China's plan is to deploy 10,000 5G stations by 2020.[87]

The European Union (EU) launched on September 2016 its 5G for Europe Action Plan, which would drive developments in France, Germany, Spain and Sweden. The Plan aims at stimulating investments in 5G infrastructure and services roll-out in the Digital Single Market before 2020. Moreover, the European Commission (EC) is

[84] GSMA (2017a). The mobile economy. Available at: https://www.gsmaintelligence.com/research/?file=9e927fd6896724e7b26f33f61db5b9d5&download. Accessed on 12 September 2018.

[85] GSMA (2017a). The mobile economy. Available at: https://www.gsmaintelligence.com/research/?file=9e927fd6896724e7b26f33f61db5b9d5&download. Accessed on 12 September 2018.

[86] FCCG (2017). UK strategy and plan for 5G & Digitisation - driving economic growth and productivity. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/582640/FCCG_Interim_Report.pdf. Accessed on 11 September 2018.

[87] IHS (2017). The 5G economy: How 5G technology will contribute to the global economy. Available at: https://cdn.ihs.com/www/pdf/IHS-Technology-5G-Economic-Impact-Study.pdf. Accessed on: 11 September 2018.

[87] GSMA (2017). The 5G era: Age of boundless connectivity and intelligent automation. Available at: https://www.gsmaintelligence.com/research/?file=0efdd9e7b6eb1c4ad9aa5d4c0c971e62&download. Accessed on: 11 September 2018.

planning to work with industry, Member States and other stakeholders to set roll-out objectives for monitoring progress of key fibre and cells deployment. Furthermore, the EC is working to identify actionable initiatives to increase the consistency of administrative practices and time frames to facilitate cells deployment, in line with provisions from the European ECC. The EC is also working to make spectrum bands available for 5G ahead of the 2019 World Radio Communication Conference. The aim of the EC is to have all urban areas and main transport paths covered by 5G networks by 2025.

In Italy, Telecom Italia is working together with the city of Turin on a 'Turin 5G' project, which aims at rolling-out next generation communication networks while hosting services such as public security, information services, and transportation[88].

In Spain, the Government published its 5G Plan in 2017 and it proposed four action lines: spectrum planning, R&D and pilot experiences, regulatory aspects, national and international coordination[89].

In Sweden, the Government has considered 5G together with other types of broadband in its 'Completely Connected Sweden by 2025' strategy. The Government, to be ready for 5G launch in 2020, has proposed five action lines: public funding for broadband expansion, analysis of effective use of public funds, mission for the future need for frequencies, and analysis of the surrounding world, analysis of the level of functional internet access[90].

The German Government is also exploring potential new approaches other than exclusive national licenses awarded by auction, such as regional licenses or shared use of spectrum.[91] Spectrum auctions are expected to take place in 2019.

In terms of competitive advantage, the UK might have with a leadership position in 5G-enabled services and applications in the future, stakeholders were more positive. Perceived advantages identified by interviewees included strong software expertise and a software start-up culture. Developing this ecosystem focused on designing the services and applications at the 5G digital services layer will be a good way of boosting the UK's competitive advantage. The Phase 1 testbed and trials projects in the UK have placed a lot of importance on verticals and demonstrating the delivery of use cases. That should help build the case for industry interest and investment further. Operator rollout plans for 5G in the UK in 2019 demonstrate industry's appetite to invest in 5G. Three and EE have both committed to rolling-out commercial 5G services in the UK in 2019. Three is also investing on a £2bn+ upgrade to prepare their network. Vodafone announced they are ready to launch 5G in mid-2019. They have ramped-up investments in RedStream, an optical core network that supports both fixed and mobile traffic and underpins the 5G plan.

[88] Arthur D Little (2017). 5G deployment models are crystallizing. Available at: https://www.key4biz.it/wp-content/uploads/2017/07/ADL_5G_Deployment_Models.pdf. Accessed on: 11 September 2018.

[89] Ofcom (2018). Enabling 5G in the UK. Available at: https://www.ofcom.org.uk/__data/assets/pdf_file/0022/111883/enabling-5g-uk.pdf. Accessed on: 11 September 2018.

[90] NERA Economic Consulting (2018). Telecommunications Infrastructure International Comparison A Report for the Department for Digital, Culture, Media and Sports. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727891/FTIR_Annex_B-_NERA_Telecommunications_Infrastructure_International_Comparison.pdf. Accessed on 12 September 2018.

[91] See 5G strategy paper by German Ministry for Transport and Digital Infrastructure: https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/098-dobrindt-5g-strategie.pdf

A3.6.2.2 Stakeholder consultation findings

Stakeholders were asked what competitive advantages the UK might have that would allow it to take a leadership position in 5G deployment in the coming years. Most interviewees thought that whilst the UK is not a significant laggard in deployment, overall it is not a leader either. Specific strengths identified by stakeholders included:

- An early award of spectrum in the UK has helped companies make initial commercial plans more quickly, and some think Ofcom is respected internationally as a thought leader on spectrum.
- A strong skills base in software development, artificial intelligence and data science and analytics in the UK could play a valuable role in 5G network service optimisation through automation and the core network that will sit around 5G. The UK has already produced completely new solutions for service orchestration which have been taken up by standards.
- The competitive market in the UK should drive relatively compelling pricing, which should help drive demand for 5G technology and deployment.
- The small geographical scale of the UK means the investment required to deploy 5G across the entire country is small enough to make it possible for a few operators to do a large scale and relatively comprehensive roll-out. It is more challenging for any one operator to create a full national network in some other markets such as the US.
- There is still considerable relevant expertise in companies working within the military sector in terms of millimetre wave communications and some of the sub-6 GHz spectrum which could help the UK make a larger contribution to the 5G technology space.

Regarding global investments, interviewees from mobile operators believe that 5G requires new business models to drive the necessary level of investment and identified use cases.

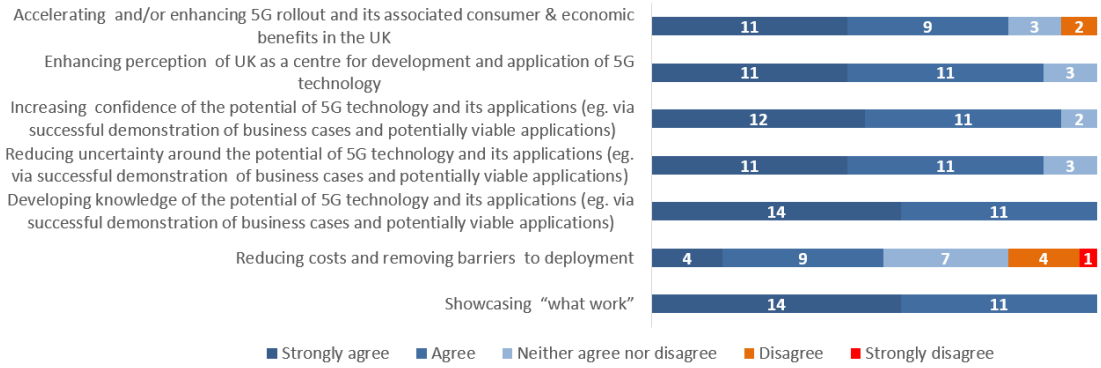
A3.7 Survey findings

The subsections below provide details on key findings from the survey of Programme participants.

A3.7.1 Outcomes and impacts

Programme beneficiaries largely expect the Programme to produce similar outcomes and impacts to those suggested by the Logic Model provided in Section 2. Enhancing perceptions of the UK as a centre for the development of the technology, increasing confidence in its potentials and reducing the uncertainties involved, are seen as important contributions, although it is unsurprising that beneficiaries take a positive view of the likely Programme benefits.

Figure A3.5 The DCMS 5GTT programme contributes to...[92]

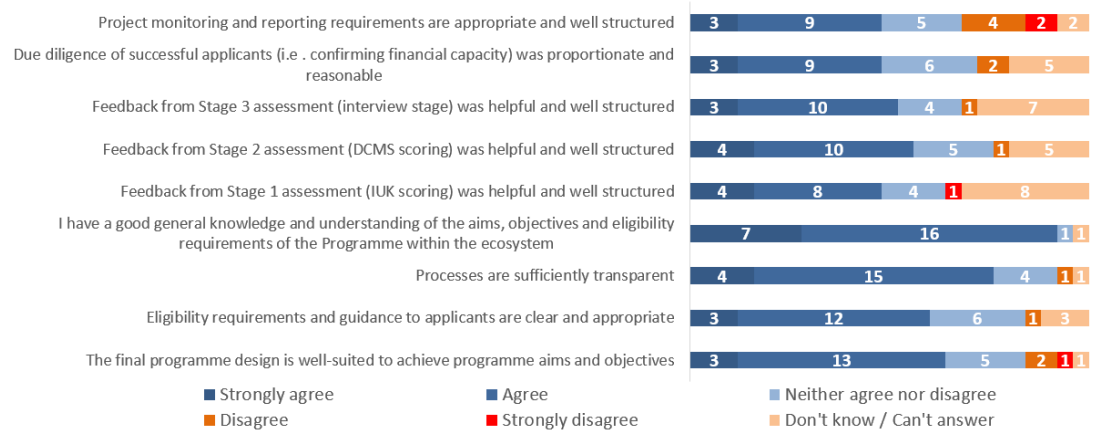


Source: Survey of 5GTT beneficiaries, n=25.

A3.7.2 Eligibility and implementation

Beneficiaries generally agreed that the Programme's processes and eligibility requirements were sufficiently clear and appropriate. However, they had more mixed views on the project monitoring and reporting requirements, whilst a significant number did not know whether feedback from the three assessment stages was helpful and well structured. Further detail on beneficiaries' views on implementation aspects is provided in the figure below.

Figure A3.6 5GTT views on programme implementation



Source: Survey of 5GTT beneficiaries, n=25.

A3.7.3 5G roll-out enablers and risks

Most respondents agreed that 3GPP standards release and general availability of 5G network and device products is a necessary precondition for large-scale 5G roll-out in the UK. Moreover, most respondents agreed that a barrier to effective 5G R&D / innovation in the UK includes effective coordination for influencing standards. This, however, should be kept in perspective. Technical standards provide a design input to product development; it is entirely possible to develop products having contributed nothing to standards.

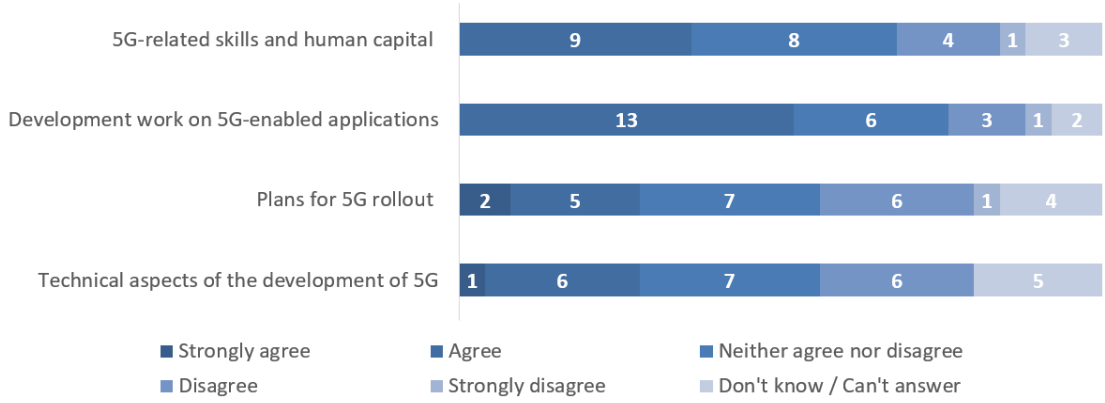
[92] Please note that "showcasing what work" refers to successful 5G technology and applications

Several respondents agreed to some extent that technology readiness and standardisation present risks to the success of the 5GTT Programme, and that UK-based operators and the supply chain using standards and IPR developed outside of the UK adds further risk.

A3.7.4 UK 5G advantages

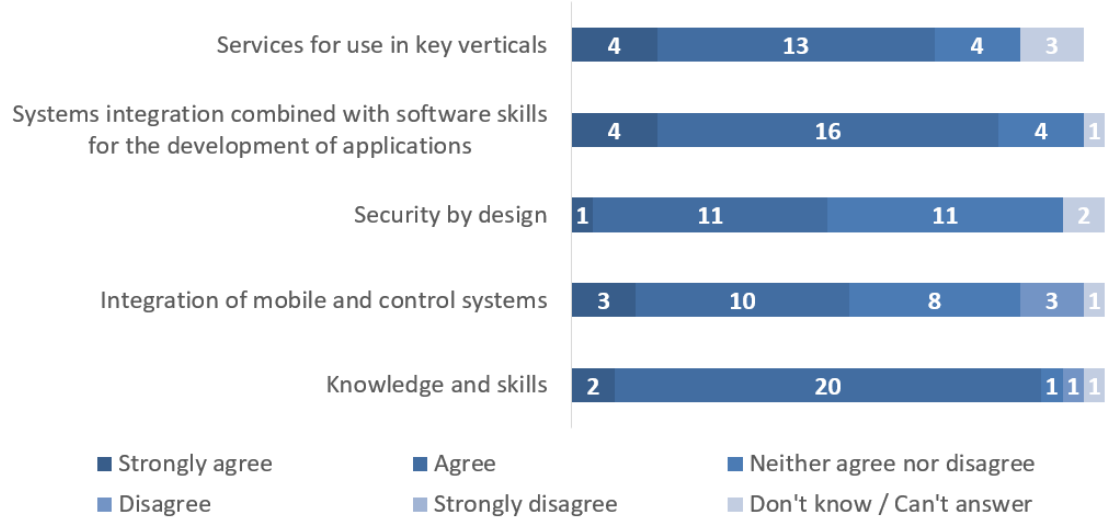
The survey of 5GTT beneficiaries paints a more optimistic picture of UK's contributions to 5G R&D development, although there is a risk that responses are influenced by positivity bias (described in further detail in Section 3). Responses largely support the view that UK strengths lie in the development of 5G-enabled applications, and related skills and human capital (see figures below).

Figure A3.7 The UK is perceived to be at the forefront in terms of…



Source: Survey of 5GTT beneficiaries, n=25.

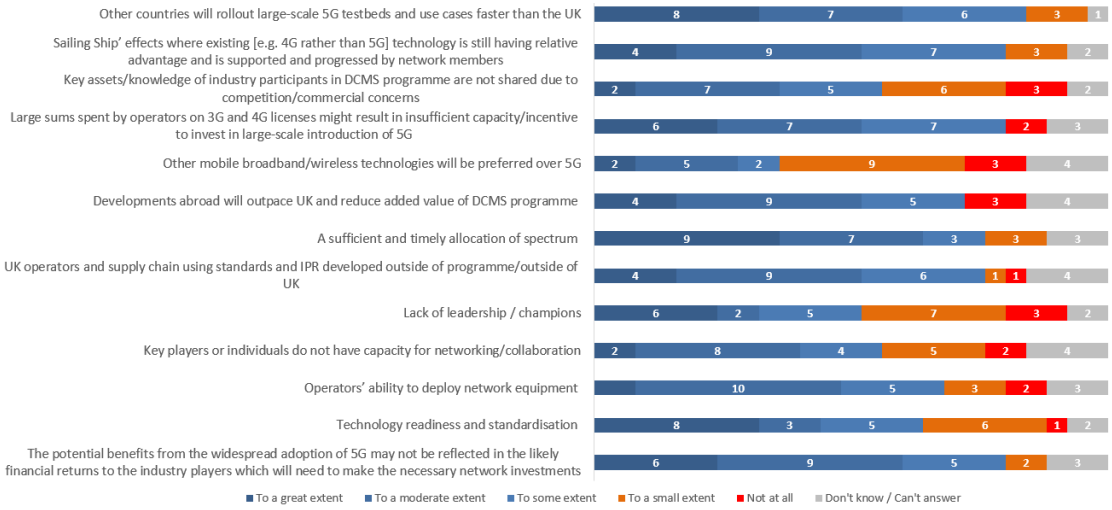
Figure A3.8 Existing UK advantages in 5G include…



Source: Survey of 5GTT beneficiaries, n=25.

A3.7.5 5GTT risks

Figure A3.9 To what extent do you think the following are key risks to the success of DCMS' testbeds & trials programme?



Source: Survey of 5GTT beneficiaries, n=25.

Respondents to the survey of 5GTT beneficiaries largely confirmed the risks discussed above, and suggested that the key risks to the success of the 5GTT programme are a sufficient and timely allocation of spectrum, speed of international development, 'sailing ship' effects of current 4G networks (whereby innovation in 4G networks is accelerated by the introduction and roll-out of 5G) and the inability of MNOs to internalise returns and benefits of 5G across key vertical sectors (see figure above).

The survey revealed that most respondents agreed or strongly agreed that a lack of credible 5G use cases is restricting investment and deployment of 5G. Similarly, most respondents agreed or strongly agreed that a lack of 5G-enabled and proven business models is restricting investment and deployment of 5G. Moreover, most respondents agreed or strongly agreed that the UK is perceived to be an attractive location for 5G-related foreign direct investments with regards to R&D related investment. In contrast, the same number of respondents agreed and disagreed that the UK is an attractive location for 5G-related foreign direct investments with regards to production related investment.

When asked to identify risks, most respondents agreed from 'some' to 'a great' extent that the potential benefits from the widespread adoption of 5G may not be reflected in the likely financial returns to the industry players which will need to make the necessary network investments. The same number of respondents agreed from 'some' to 'a great extent' that large sums spent by operators on 3G and 4G licenses might result in insufficient capacity/incentive to invest in large-scale introduction of 5G. In both cases most respondents stated that these two risks are likely to materialise.

Finally, most respondents stated that they were not aware of any R&D or production related inward investment focussing on 5G in the UK over the next 24 months.

Annex 4 Possible opportunities to apply CIE methods

Although they cannot be relied upon to provide a methodological basis for the evaluation, the evaluators will need to be alert to potential opportunities to apply CIE type methods during the impact evaluation wherever practicable, even where because of sample sizes or other issues the context is less than ideal and levels of statistical confidence may fall somewhat below normally expected benchmarks.

The counterfactual is usually estimated via a set of comparison units. These are units that are very similar to the intervention units, both in terms of their characteristics and preferably with a similar level of interest in the intervention, but who do not take up the intervention.

The estimation of the impact of the intervention is summarised as:

Outcomes for the 'units' in receipt of the intervention

minus

Outcomes for the 'units' in the absence of the intervention (the counterfactual).

There are several methodological approaches which can be used to estimate the counterfactual. These approaches use different methodologies to form a group of 'units' who are similar to the treatment group.

At the level of the *overall technology area*, consideration could be given to the use of a synthetic control approach. In summary this would involve constructing a 'clone' which replicates the pre-programme performance of the 5G technology area in terms of research outputs such as publications and patents and perhaps other metrics through combining elements of broadly comparable technology areas using a statistical method developed at Stanford University. The extent to which the performance of the 5G technology area outperforms that of the clone following the introduction of the programme then provides a measure of its impact.

Whilst this approach is increasingly used in other evaluations which confront problems of small sample sizes, it is not clear that it is feasible in this case, not least because of the problems in identifying potentially analogous technology areas which are not also being shaped by substantial public sector intervention, as well as issues of data availability. Similar problems would likely arise in seeking to construct the clone based upon the pattern of 5G development in competing countries.

At the level of *individual projects or groups of projects*, other CIE methods may become feasible depending on the future development of the programme. Possibilities include:

- A 'difference in differences' approach in which the pre-intervention relative performance of beneficiaries is treated as a counterfactual for their relative post-intervention performance. The modelling can also potentially incorporate relevant control variables.
- An 'early vs late' pipeline type approach, if the number of beneficiaries makes this feasible.
- An Intensity of engagement / dose-response approach in which the performance of beneficiaries in various terms is related to the extent of their involvement in the programme. For example, if a sufficiently large number of SMEs make use of the trial networks it might be possible to model the impacts of the level of use on their rate of growth and/or progress in bringing 5G related products to market.

As the 5GUK Test Network in particular involves investment in specific locations, it would be possible in principle to explore possible effects in developing clusters of related activities or technology intensive activities more generally through a spatial decay modelling approach which explores how the growth of such activities declines with distance from the facility. The issues which are likely to arise with its application derive from whether it will be possible to identify sufficient such activities to make this approach feasible and the challenge of establishing causality – the establishment of the network may partly reflect the presence in the area of potential users rather than the converse as the approach assumes (technically there is a potential endogeneity problem).

There may also be some value in modelling using the GSMA data on the rate of adoption of 5G devices relative to that of competitor countries.

Further information on the relevant techniques and the issues involved in their application are provided below.

A4.1 Using unsuccessful applicants as a comparator group

Unsuccessful bidders for the testbed programme could be used to form a comparator group. However, it is only applicable to elements of the programme that involved a competitive approach to funding. The following approaches could be used:

A4.1.1 Regression Discontinuity Analysis

This approach uses units which applied for the programme but were unsuccessful as the comparator group. To select a group that is similar to the treatment group, units that were only just unsuccessful (based on a scoring criteria) are compared to units that were only just successful (comparing units on either side of a scoring cut off point).

However, this approach requires large sample sizes, so that an adequate number of participants and non-participants that are close to the cut-off point can be compared). Due to the small number of participants in the programme to date, this approach is not a realistic option but might become feasible given future rounds of competitive funding attract sufficient demand.

A4.1.2 Difference in Differences

Where city regions are included as testbeds, it may be possible to use a Difference in Difference approach to measure impact. This approach involves comparing a selection of appropriate outcome measures for a city region which was an unsuccessful bidder to a city region which is a test bed site. The change in outcomes in the two city regions are compared (the change in outcomes in the participating city minus the change in outcomes in the comparator city) to measure the impact of the programme or project.

This approach is simple to construct and the results are easy to interpret. However, with such a small number of applicants, it is difficult to know if the unsuccessful city is comparable to the successful cities in any other way other than that both city regions applied. There may also be difficulties in attributing changes in outcomes to the 5G testbed programme, as other factors could affect the outcomes (and it may not be possible to collect data for these other factors).

A4.2 Using a 'synthetic clone' as a comparator group

A 'synthetic clone' comparator group is only applicable to elements of the programme that involved a competitive approach to funding.

A 'synthetic clone' approach forms a comparator group using businesses from other comparable sectors. These businesses are then weighted so that the comparator group matches the participants of the programme along a selected set of variables (e.g. size in terms of turnover or employment before the intervention, age and/or type of product/sector). The difference in the change in outcomes between the participants and the synthetic clone group estimates the impact of the programme. The outcomes which could be included in a synthetic clone impact evaluation are patents, research outputs, citations and investment.

However, a difficulty with this approach is that it might be challenging to obtain data at a sufficient level of granularity to form a synthetic clone group, and to collect outcome information for the group. Additionally, there may be difficulties in attributing changes in outcomes to the 5G testbed programme, as other factors could affect the outcomes (and it may not be possible to collect data for these other factors).

A4.3 Using late adopters or a dose response to measure impact

Using late adopters as a comparator group or a dose response approach is only applicable to elements of the programme that involved a competitive approach to funding.

This approach looks into the level of adoption for 5G services as a result of the funding received. The level of funding each business receives is included in the econometric modelling. The difficulty with this approach is to disentangle the effects caused by the intervention from other confounding factors at the firm or regional level. Adoption is also capped by other factors like the wider capabilities within and across firms, costs and benefits from early adoption, technological availability and others. These confounding factors would need to be included in the model to measure the "net effect" of adoption.

A4.4 Using a spatial decay model to assess the impact of the programme

A spatial decay model can only be applied where there is a clear boundary between beneficiary and non-beneficiary areas - for example because of eligibility criteria (e.g. an Enterprise Zone).[93]

A Spatial decay model can be used to examine how telecoms related R&D activity develops with varying distance from the 5GUK Test Network host institutions post programme introduction. The approach uses a regression discontinuity analysis, but all outcome variables are linked to geographic locators (for near vs. far location from 5GUK Test Network).

A difficulty with this approach is that there may not be enough activity to make comparisons between the treatment and comparator groups meaningful, and it is

[93] For an example see: Faggio, G., Schluter, T. & vom Berge, P. (2016). The impact of public employment on private sector activity: Evidence from Berlin (Report No. 16/11). London, UK: Department of Economics, City, University of London.

difficult to measure the geolocated output metrics for participating and non-participating businesses. There are also difficulties relating to the mobility of businesses during the programme (a business can change locations) and there is a potential endogeneity problem (the 5GUK Test Networks may have become involved partly because of the presence/growth of such activity in the region).

There is also a potential a potential issue here about the 'direction' of causality. The establishment of the network may partly reflect the presence in the area of potential users rather than the converse as the approach assumes (technically there is a potential endogeneity problem).

Annex 5 Topic guide for 5G T&T baseline interviews

A5.1 5G in general (all UK stakeholders)

A5.1.1 Opportunities of 5G

- **Key question**: What are your **current expectations for 5G deployment in the UK** in terms of extent of deployment (e.g. urban, sub-urban, rural) and timescales?
- **Key question**: What **competitive advantage** does the UK have that would allow it to take a leadership position in 5G deployment?
- **Key question**: What **competitive advantage** does the UK have that would allow it to take a lead in 5G-enabled services and applications in the coming years?

A5.1.2 Issues, challenges and enablers in deploying 5G in the UK

- **Key question**: Thinking about the UK market/industry overall, what are the **key issues preventing more rapid 5G deployment** on a large scale?

Ask the following question If any regulatory issues were mentioned above:

- Is the current **UK regulatory framework fit to consider and help mitigate the challenges of 5G deployment**?
- Are any of the following risks **a key impediment for the success of the 5G Testbed and Trials Programme**?
  - *Projects funded through the 5G TT fail to produce learning*
  - *Competition in the market stifles collaboration*
  - *Risk of jumping to trials and R&D / standards challenges left unaddressed (i.e. the selection of trials as part of the 5G TT programme will have little / no impacts on standards development)*
  - *Lack of leadership / champions*
  - *Limited cooperation with the international community and limited contribution to standards*
- What is the **likelihood that the above risks / challenges will materialise**?
- What is the **potential impact of the risks in the event that they do materialise**?
- Which are **the main enablers for 5G use and deployment**?
- What is the **likelihood that the above enablers will materialise**?
- **Key question**: What do you think **the Government/ Ofcom should do to better facilitate 5G deployment and usage**?
- **Key question**: Do you believe that **the 5GTTwill help make a difference to the UK 5G ecosystem and deployment conditions**? If so, why?

A5.2 International perspective (only international industry stakeholders)

- **Key question**: Are you aware of the **work being undertaken in the UK in 5G**? If yes, are you aware of the 5G Testbed and Trials Programme in the UK and the aims of the Programme? Are you aware of the UK5G Innovation Network and its aims?
- **Key question**: Do you have **an interest in future FDI in the UK**? Has this interest been influenced by your participation in any of the actions funded by the UK government?
- **Key question**: Can you **estimate the current and predicted levels of 5G** reach and adoption within your organisation?'
- **Key question**: Do you currently plan any **investment related to 5G in UK / outside UK**?
- **Key question**: What are the **key drivers and potential barriers to the realisation of these planned investments**?

***If knowledgeable about the UK market refer to the UK market if not refer to the country stakeholders have expertise in**:*

- **Key question**: What are your current expectations for 5G deployment in the UK in terms of extent of deployment (e.g. urban, sub-urban, rural) and timescales?
- **Key question**: What competitive advantage does the UK have that would allow it to take a leadership position in 5G deployment?
- **Key question**: What competitive advantage does the UK have that would allow it to take a lead in 5G-enabled services and applications in the coming years?
- **Key question**: What are the key issues preventing more rapid 5G deployment on a large scale?
- **Key question**: What do you think the Government should do to better facilitate 5G deployment and usage?

A5.3 International perspective (only international non-industry stakeholders)

- **Key question**: Are you aware of the work being undertaken in the UK in 5G? If yes, are you aware of the 5G Testbed and Trials Programme in the UK and the aims of the Programme? Are you aware of the UK5G Innovation Network and its aims?

***If knowledgeable about the UK market refer to the UK market; if not refer to the country the stakeholders have expertise in**:*

- **Key question**: What are your current expectations for 5G deployment in the UK in terms of extent of deployment (e.g. urban, sub-urban, rural) and timescales?
- **Key question**: What competitive advantage does the UK have that would allow it to take a leadership position in 5G deployment?
- **Key question**: What competitive advantage does the UK have that would allow it to take a lead in 5G-enabled services and applications in the coming years?
- **Key question**: What are the key issues preventing more rapid 5G deployment on a large scale?

- **Key question**: What do you think the Government should do to better facilitate 5G deployment and usage?
- **Key question**: What are the key drivers and potential barriers to the realisation of 5G investments in deployment?

A5.4 Current R&D and other activity (all industry stakeholders)

- **Key question**: What is the **scale of your current 5G technology R&D spending (excluding any investment in developing applications in vertical sectors)** in the UK/outside of the UK?
- **Key question**: What are the **R&D spending patterns (type of research, areas of research)** of your company?
- **Key question**: What is your **R&D spending on 5G-enabled applications and services** in the UK/outside of the UK? What are the verticals that you are prioritising in the UK/outside of the UK?
- **Key question**: Are you aware of **the development of spatial clusters of R&D activity** within the sector?

A5.5 Industry's future development and roll out plans (only UK industry stakeholders)

- **Key question**: What is **the scale of 5G development within your company** (UK subsidiary)?
- **Key question**: Do you currently plan any **investment related to 5G in the UK/outside of the UK**?
- **Key question**: What are the **key drivers and potential barriers to the realisation of the above investment**?

A5.6 Potential business models (only UK industry stakeholders)

- Can you share with us the **new or existing types of business models** you are looking to adopt for 5G deployment?
- Which **factors will determine the commercial viability of these business models**?
- What could be **alternative business models**?

A5.7 Expected future consumer and business take up (all stakeholders)

- What is the likely **pattern of take up and revenue generation** of 5G in your country (forecasts, likely spatial pattern)?
- Do you consider the **latest forecasts for the take up of 5G to** be realistic (by end of 2023, close to 50% of all mobile subscriptions in North America are forecast to be for 5G, followed by North East Asia at 34%, and UK at 27%[1])?
- Which are the **key primary & second tier users** in your country?

A5.8 Vertical, horizontal, spatial impacts (all stakeholders)

- What are the **potential effects of 5G deployment on key sectors in your country** e.g. health, transport and logistics, manufacturing, entertainment, media and broadcasting, telecommunication?

- What are the **potential effects on particular types of business activity in your country** (finance, operations, communications etc)?

- What are the **likely effects on the structure of the mobile telecom sector in your country**? What about the likely effects on the fixed lines sector?

- What are the specific **potential benefits on urban and rural area in your country**?

- What are the **timescales to impacts of different types** – in particular what will have happened by 2021 and 2025 in your country?

Annex 6 Survey questionnaire

Baseline of current situation regarding 5G development

Introduction

The Department for Digital, Culture, Media & Sport (DCMS) has commissioned a scoping study to design an evaluation programme and baseline for the 5G Testbeds and Trials Programme.

The current assessment

This survey has been developed to gather views, experiences and key feedback from the programme's beneficiaries. The questions seek to understand the context within which the 5GTTis implemented, to design an appropriate programme of evaluation work to assess the outcomes and impacts, and to establish a baseline against which these can be measured.

How to participate?

We would greatly appreciate if you could complete the following survey, consisting of multiple-choice questions, and some open-ended text boxes, that can be completed online at your convenience (a word version for printing out is available upon request). Based on the results of a pilot, this survey should take approximately 15 minutes **to complete.**

In case you would like to download the survey to enable colleagues' discussion, please click here.

Please note that * signifies mandatory question.

Timing

The survey will run until close of business on 12 September.

GDPR

This survey is designed to be compliant with the requirements of the General Data Protection Regulation (2016/679) of the European Parliament and of the Council (GDPR) and any data protection laws substantially amending or superseding the GDPR. For the purpose of the present study, data collected will be anonymised and presented in an aggregated manner. To find out more about how your information will be used please consult our Information Sheet for this survey, which can be downloaded herehere. All data will be stored by ICF in compliance with the ICF Privacy Statement.

If you have any questions about the completion of the survey or the evaluation study more generally, please contact jan.franke@icf.com.

We thank you in advance for your valuable time and input!

1) To proceed with the survey, we need you to confirm that you consent to your data being used as outlined in the Information Sheet.*****

( ) Yes

( ) No

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2) Please state below to what extent you think the following statements apply:*****

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know / Can't answer
An absence of 5G infrastructure is restricting R&D/innovation /5G development	( )	( )	( )	( )	( )	( )
An absence of 5G coordination is restricting R&D/innovation /5G development	( )	( )	( )	( )	( )	( )
A lack of capability that could be used in future testbeds & trials and can be retained in the UK is restricting R&D/innovation /5G development	( )	( )	( )	( )	( )	( )
A lack of compatibility that could be used in future testbeds & trials and can be retained in the UK is restricting R&D/innovation /5G development	( )	( )	( )	( )	( )	( )
A lack of credible 5G use cases is restricting investment and deployment of 5G	( )	( )	( )	( )	( )	( )
A lack of 5G-enabled and proven business models is	( )	( )	( )	( )	( )	( )

restricting investment and deployment of 5G						
3GPP standards release is a necessary precondition for large-scale 5G roll-out in the UK	( )	( )	( )	( )	( )	( )
The UK lacks an environment in which industry can develop and explore new business models around key 5G technologies (such as NFV, SDN and network slicing)	( )	( )	( )	( )	( )	( )
Before DCMS intervention, the UK lacked a forum where 5G best practice and knowledge from across the UK could be shared and a clear brand to market the UK's 5G activities	( )	( )	( )	( )	( )	( )
Commercial and other benefits of 5G go beyond telecoms sector to verticals (smart cities, health, transport etc.)	( )	( )	( )	( )	( )	( )
Before DCMS intervention, a lack of available testbeds & trial infrastructure restricting progress in developing 5G technology	( )	( )	( )	( )	( )	( )

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3) Please state below to what extent you agree or disagree with the following statements:*****

The UK is perceived to be at the forefront in terms of...*

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know / Can't answer**
Technical aspects of the development of 5G	( )	( )	( )	( )	( )	( )
Plans for 5G roll-out	( )	( )	( )	( )	( )	( )
Development work on 5G-enabled applications	( )	( )	( )	( )	( )	( )
5G-related skills and human capital	( )	( )	( )	( )	( )	( )

Please elaborate:

_____

The UK is perceived to be an attractive location for 5G-related foreign direct investments with regards to...*

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know / Can't answer**
R&D related investment	( )	( )	( )	( )	( )	( )
Production related investment	( )	( )	( )	( )	( )	( )

Please elaborate:

_____

A barrier to effective 5G R&D / innovation in UK include…*

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know / Can't answer**
Effective coordination for influencing standards	( )	( )	( )	( )	( )	( )
Availability of test equipment	( )	( )	( )	( )	( )	( )
Availability of R&D facilities	( )	( )	( )	( )	( )	( )

Please elaborate:

_____

Existing UK advantages in 5G include... *

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know / Can't answer**
Knowledge and skills	( )	( )	( )	( )	( )	( )
Integration of mobile and control systems	( )	( )	( )	( )	( )	( )
Security by design	( )	( )	( )	( )	( )	( )
Systems integration combined with software skills for the development	( )	( )	( )	( )	( )	( )

of applications						
Services for use in key verticals	( )	( )	( )	( )	( )	( )

Please elaborate:

_____

4) To what extent do you think the following are key risks to the success of DCMS' testbeds & trials programme?*****

	To a great extent	**To a moderate extent**	**To some extent**	**To a small extent**	**Not at all**	**Don't know / Can't answer**
The potential benefits from the widespread adoption of 5G may not be reflected in the likely financial returns to the industry players which will need to make the necessary network investments	( )	( )	( )	( )	( )	( )
Technology readiness and standardisation	( )	( )	( )	( )	( )	( )
Operators' ability to deploy network equipment	( )	( )	( )	( )	( )	( )
Key players or individuals do not have capacity for networking/collaboration	( )	( )	( )	( )	( )	( )
Lack of leadership / champions	( )	( )	( )	( )	( )	( )
UK operators and supply chain using standards and IPR developed outside of programme/outside of UK	( )	( )	( )	( )	( )	( )

A sufficient and timely allocation of spectrum	( )	( )	( )	( )	( )	( )
Developments abroad will outpace UK and reduce added value of DCMS programme	( )	( )	( )	( )	( )	( )
Other mobile broadband/wireless technologies will be preferred over 5G	( )	( )	( )	( )	( )	( )
Large sums spent by operators on 3G and 4G licenses might result in insufficient capacity/incentive to invest in large-scale introduction of 5G	( )	( )	( )	( )	( )	( )
Key assets/knowledge of industry participants in DCMS programme are not shared due to competition/commercial concerns	( )	( )	( )	( )	( )	( )
'Sailing Ship' effects where existing [e.g. 4G rather than 5G] technology is still having relative advantage and is supported and progressed by network members	( )	( )	( )	( )	( )	( )
Other countries will roll-out large-scale 5G testbeds and use cases faster than the UK, hence retaining first mover advantage	( )	( )	( )	( )	( )	( )

■

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5) Do you think these key risks are likely to materialise?

The potential benefits from the widespread adoption of 5G may not be reflected in the likely financial returns to the industry players which will need to make the necessary network investments*

( ) Yes

( ) No

( ) I don't know

Technology readiness and standardisation*

( ) Yes

( ) No

( ) I don't know

Operators' ability to deploy network equipment*

( ) Yes

( ) No

( ) I don't know

Key players or individuals do not have capacity for networking/collaboration*

( ) Yes

( ) No

( ) I don't know

Lack of leadership / champions*

( ) Yes

( ) No

( ) I don't know

UK operators and supply chain using standards and IPR developed outside of programme/outside of UK*

( ) Yes

( ) No

( ) I don't know

A sufficient and timely allocation of spectrum*

( ) Yes

( ) No

( ) I don't know

Developments abroad will outpace UK and reduce added value of DCMS programme*

( ) Yes

( ) No

( ) I don't know

Other mobile broadband/wireless technologies will be preferred over 5G*

( ) Yes

( ) No

( ) I don't know

Large sums spent by operators on 3G and 4G licenses might result in insufficient capacity/incentive to invest in large-scale introduction of 5G*

( ) Yes

( ) No

( ) I don't know

Key assets/knowledge of industry participants in DCMS programme are not shared due to competition/commercial concerns*

( ) Yes

( ) No

( ) I don't know

'Sailing Ship' effects where existing [e.g. 4G rather than 5G] technology is still having relative advantage and is supported and progressed by network members*

( ) Yes

( ) No

( ) I don't know

Other countries will roll-out large-scale 5G testbeds and use cases faster than the UK, hence retaining first mover advantage*

( ) Yes

( ) No

( ) I don't know

■

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6) Are you participating / Have you participated in any of the following networks:*****

	Yes I am a member	**Yes I was but I am no longer a member**	**No I am not a member**	**No and this is the first time I heard of this network**
UK5G	( )	( )	( )	( )

5G Innovation Centre	( )	( )	( )	( )
Cambridge Wireless	( )	( )	( )	( )
EU 5G public private partnership	( )	( )	( )	( )
5G automotive association	( )	( )	( )	( )
Other	( )	( )	( )	( )

■

7) If "Other", please specify:

_____

■

8) What kind of role did you have?*****

( ) I participate on a regular basis in network activities

( ) I participate from time to time in network activities

( ) I am a member but have not participated in any network activities

■

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9) Which type of research & development activities does your organisation focus on outside of any funding received through the 5G testbeds & trials programme?*****

	To a great extent	**To a moderate extent**	**To some extent**	**To a small extent**	**Not at all**	**Don't know / Can't answer**
5G network and infrastructure development	( )	( )	( )	( )	( )	( )
5G enabled software applications	( )	( )	( )	( )	( )	( )

5G enabled business models (e.g. in transport, healthcare, entertainment/media)	( )	( )	( )	( )	( )	( )

■

10) Which area do you think will require the largest investments in the future?*****

( ) Further research & development to ensure commercial maturity of 5G technology

( ) Physical deployment of 5G infrastructure

( ) Development of use cases and applications in key verticals such as transport, healthcare and entertainment/media

( ) Other, please specify: _____*

■

11) Has participation in the DCMS funded project accelerated, or otherwise influenced, any existing intention of your organisation to invest in development of 5G and 5G enabled applications?*****

( ) Yes

( ) No

■

12) What is the total value of your organisation's planned investment in 5G related research and development in the UK/outside of the UK (in £)?

_____

■

13) Has your organisation been undertaking any of the following activity in the last 24 months?*****

	Yes	**No**	**I don't know**
Recruiting new staff with specific technical knowledge or skills related to 5G	( )	( )	( )
Recruiting new staff with specific knowledge of potential 5G use cases in transport,	( )	( )	( )

healthcare, media/entertainment			
Sponsored training of existing staff on technical foundations of 5G	( )	( )	( )
Sponsored training of existing staff on potential 5G use cases in transport, healthcare, media/entertainment	( )	( )	( )
Sponsored/hosted PhD projects	( )	( )	( )

■

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14) Please state below to what extent you think the following statements apply:*****

The DCMS 5G testbeds & trials programme contributes to...

	Strongly agree	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**	**Don't know / Can't answer**
Showcasing "what work"	( )	( )	( )	( )	( )	( )
Reducing costs and removing barriers to deployment	( )	( )	( )	( )	( )	( )
Developing knowledge of the potential of 5G technology and its applications (eg. via successful demonstration of business cases and potentially	( )	( )	( )	( )	( )	( )

viable applications)						
Reducing uncertainty around the potential of 5G technology and its applications (eg. via successful demonstration of business cases and potentially viable applications)	( )	( )	( )	( )	( )	( )
Increasing confidence of the potential of 5G technology and its applications (eg. via successful demonstration of business cases and potentially viable applications)	( )	( )	( )	( )	( )	( )
Enhancing perception of UK as a centre for development and application of 5G technology	( )	( )	( )	( )	( )	( )
Accelerating and/or enhancing 5G roll-out and its associated consumer & economic benefits in the UK	( )	( )	( )	( )	( )	( )

Please elaborate:

_____

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15) What lessons can be drawn from the testbeds & trials programme for future government interventions?

_____

16) Which elements of the programme should be improved/changed in future interventions?

_____

17) Are you aware of any R&D or production related inward investment focussing on 5G into the UK over the next 24 months?*****

( ) Yes

( ) No

18) Please estimate the total £ amount over the next 24 months for the inward investment you are aware of:

_____

This section of the questionnaire is asking questions about your participation in DCMS' 5G testbeds & trials programme so far.

19) Did you need any support for....

*Finding partners?******

( ) Yes

( ) No

*Negotiating a collaboration agreement?******

( ) Yes

( ) No

If yes, who provided you support?*****

( ) DCMS

( ) Innovate UK

( ) Other, please specify: _____*

■

20) Please indicate below the extent to which you agree or disagree with the following statement:*****

I would have needed more support but did not receive any in....

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know / Can't answer
Finding partners	( )	( )	( )	( )	( )	( )
Preparing application	( )	( )	( )	( )	( )	( )
Negotiating collaboration agreement	( )	( )	( )	( )	( )	( )
Negotiating grant agreement with DCMS	( )	( )	( )	( )	( )	( )
Negotiating Programme Participation Agreement	( )	( )	( )	( )	( )	( )

■

Process evaluation baseline 2

21) Do you think you have been sufficiently engaged in the project design?*****

( ) Very much

( ) Somewhat

( ) Undecided

( ) Not really

( ) Not at all

( ) Don't know / Can't answer

■

22) If not, why not follow up?

_____

23) Please indicate below the extent to which you agree or disagree with the following statements:*****

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree	Don't know / Can't answer
The final programme design is well-suited to achieve programme aims and objectives	( )	( )	( )	( )	( )	( )
Eligibility requirements and guidance to applicants are clear and appropriate	( )	( )	( )	( )	( )	( )
Processes are sufficiently transparent	( )	( )	( )	( )	( )	( )
I have a good general knowledge and understanding of the aims, objectives and eligibility requirements of the Programme within the ecosystem	( )	( )	( )	( )	( )	( )
Feedback from Stage 1 assessment (IUK scoring) was helpful and well structured	( )	( )	( )	( )	( )	( )
Feedback from Stage 2 assessment (DCMS scoring) was helpful and well structured	( )	( )	( )	( )	( )	( )

Feedback from Stage 3 assessment (interview stage) was helpful and well structured	( )	( )	( )	( )	( )	( )
Due diligence of successful applicants (i.e. confirming financial capacity) was proportionate and reasonable	( )	( )	( )	( )	( )	( )
Project monitoring and reporting requirements are appropriate and well structured	( )	( )	( )	( )	( )	( )

■

Lessons Learned

Lessons Learned

24) What lessons can be drawn from the testbeds & trials programme for future government interventions?

_____

25) Which elements of the programme should be improved/changed in future interventions?

_____

26) Are there any barriers to participation that should be addressed/removed?

_____

27) What would you do differently if you participate again in the future?

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28) Do you consent to be contacted in the future by ICF to validate your responses or take part in further research?

( ) Yes

( ) No

29) Do you consent to be contacted by DCMS, or a third party conducting research on behalf of DCMS for future survey updates?

( ) Yes

( ) No

Thank You!

Thank you for taking our survey. Your response is very important to us.

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